PhD in Clinical & Experimental Medicine

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Implementation, integration and analysis of innovative training tools to improve disaster response and humanitarian assistance

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Coordinatore

Prof.ssa Marisa Gariglio

Tutor

Prof. Francesco Della Corte

Dottorando

Dott. Luca Ragazzoni

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1. Introduction

1.1. Disaster Medicine

Disaster medicine is "the science for analysis and development of the methodology requested to handle situations where available resources are insufficient in relation to the immediate need of medical care",[1] and is a comprehensive tool for mass casualty events management, more than a specific medical branch. It is "the study and collaborative application of various health disciplines, e.g. pediatrics, epidemiology, communicable diseases, nutrition, public health, emergency surgery, social medicine, community care, international health – to the prevention, immediate response, and rehabilitation of health problems arising from disasters, in cooperation with other disciplines involved in comprehensive disaster management".[2]

Disaster medicine was born from the union of different disciplines, but first of all from military medicine with the principles of strategy, tactics and logistics.

Military medicine developed the principles of triage, stabilization in the field, and evacuation to medical facilities. War surgery developed simplified and standardized treatment procedures. A medical officer is not only trained in leadership but also acts as a commander or coordinator in medical operations. He is also familiar to operate with other units in a hostile environment.

Disaster medicine takes also elements from emergency medicine. The principal attribute is a readiness for the full spectrum of somatic and psychic disorders both on the scene as in the hospital. Disaster medicine requires knowledge of emergency medicine as well as its technical skills and integrates elements of many other medical disciplines including preventive and occupational medicine, toxicology, psychiatry, social and forensic medicine.

Disaster medicine has also its own aspects. It is an emergency medicine in the field, a global medicine, a mass medicine, a medicine with extra-medical aspects and a doctrinal medicine.[3]

It is oriented to handle situations with a high number of casualties, lack of medical resources and the need for multidisciplinary teams,[4,5] both from a clinical and a resource-management point of view.

In order to be really effective, disaster medicine is a discipline that must not be applied only at the moment of a disaster, but has to be involved in all the phases of a disaster: mitigation, preparedness, response, recovery. This comprehensive view, applied to the whole response system, leads to a better performance and quality of service. In order to improve this discipline, and to base it on solid scientific concepts, "Club of Mainz" was founded in 1976 by Rudolf Frey.[6] This club was then turned into the World Association for Disaster and Emergency Medicine (WADEM).

Beside this comprehensive outlook, facing a disaster is one of the most challenging moments in a healthcare professional's life; in such conditions, involved personnel must have specific knowledge of organization, logistics and medical aspects far from daily routine, and mass casualty triage is inevitable.[5,7–9]

1.2. Disaster management performance

Researchers in disaster medicine have to deal with the difficulty of finding scientific methods that are suitable to apply on available data. Randomized controlled studies cannot be performed and retrospective studies sometimes have too much limitation.[10]

In the past, different aspects of performance during a disaster have not been considered and evaluated with quantitative methods.[11] For this reason there was a need to develop protocols that in a specific way indicates what is important to study and what should we be looking for.

World Association for Disaster and Emergency Medicine (WADEM) and Several other institutions and experts have developed protocols for the evaluation of disasters but they are too complicated and they can be subject to different interpretations.[10,11]

So researchers have begun to elaborate an alternative way of evaluating performance developing indicators that are easily measured quantitatively. These indicators, performance indicators, allow to record, measure and assess the results.[10] They can be applied on major incidents that directly or indirectly involve casualties and could constitute measurable parts of regional and national follow-up systems.[12]

It must be understood that it is not always possible to meet the standards of these indicators and that they must not be used to find a scapegoat but rather ways to create improvement.[11]

Anders Rüter studied the application of performance indicator in difference contexts[11]:

- Retrospectively. After studying a series of well-reputed reports from 13 different major incidents he found that the result of applying performance indicators to retrospective material will not serve as a base for quantitative research. However they are best used as prospective templates were evaluators or persons studying management are trained in how and when to use them.

- During a training. If the performance indicators shall be employed a method to test them is to start in training simulation. Using this method it is possible to be more specific than just describing shortcomings such as “problems in command and control”. All training in disaster medicine should include this technique where possible. One important factor is to ensure that indicators from different training programs are compatible. If not, this may lead to the concept as a whole being rejected.
- Implementation in real incidents. The aim is to improve patient management during major incidents and disasters after being tested in simulations.

1.3. Mass Casualty Triage

In these situations, where available resources are far from meeting the demands, rescuers’ perspective needs to change from doing “the greatest good for each individual” to “the greatest good for the greatest number”, in order to increase the global outcome of the involved population.[5]

In order to achieve this objective, resources must be addressed to patients with the most needs but still with a chance of a good outcome. The main instrument to sort patient and assign them a priority level is mass casualty triage. This consists in a rapid patient assessment in order to set the most appropriate level of care, considering the lack of available resources.[5,8,9] There are many triage methods, but the Simple Triage and Rapid Treatment (START – Fig.1) is the most common triage algorithm used in disaster and mass casualty incident management in USA, Canada, Saudi Arabia and partially in Australia and Israel.[13,14] It is also used in most of regional EMS operation centers in Italy.

This was developed in 1983 by the collaboration between the Newport Beach Fire Department and the Hoag Hospital of California and updated in 1994.[15,16]

The START algorithm assigns treatment priority based on the ability of the patient to walk, airway patency, breathing rate, presence of radial pulse or capillary refill longer than or less than two seconds, and ability to follow simple commands.[8, 17] The intent is to assess and identify conditions that can lead to death if not treated within 1 hour.

This algorithm has been adopted by many emergency medical service in United States and in Europe[15] and it also has been utilized during disasters such as the 1989 Northridge earthquake, the 1992 and 2001 attacks of the New York World Trade Center, and the 1995 Oklahoma City bombing.[8,18,19].

An important study, conducted by Mark E. Gebhart and Robert Pence, demonstrated that START triage, if properly used, decreases mortality during a mass casualty incident.[17]

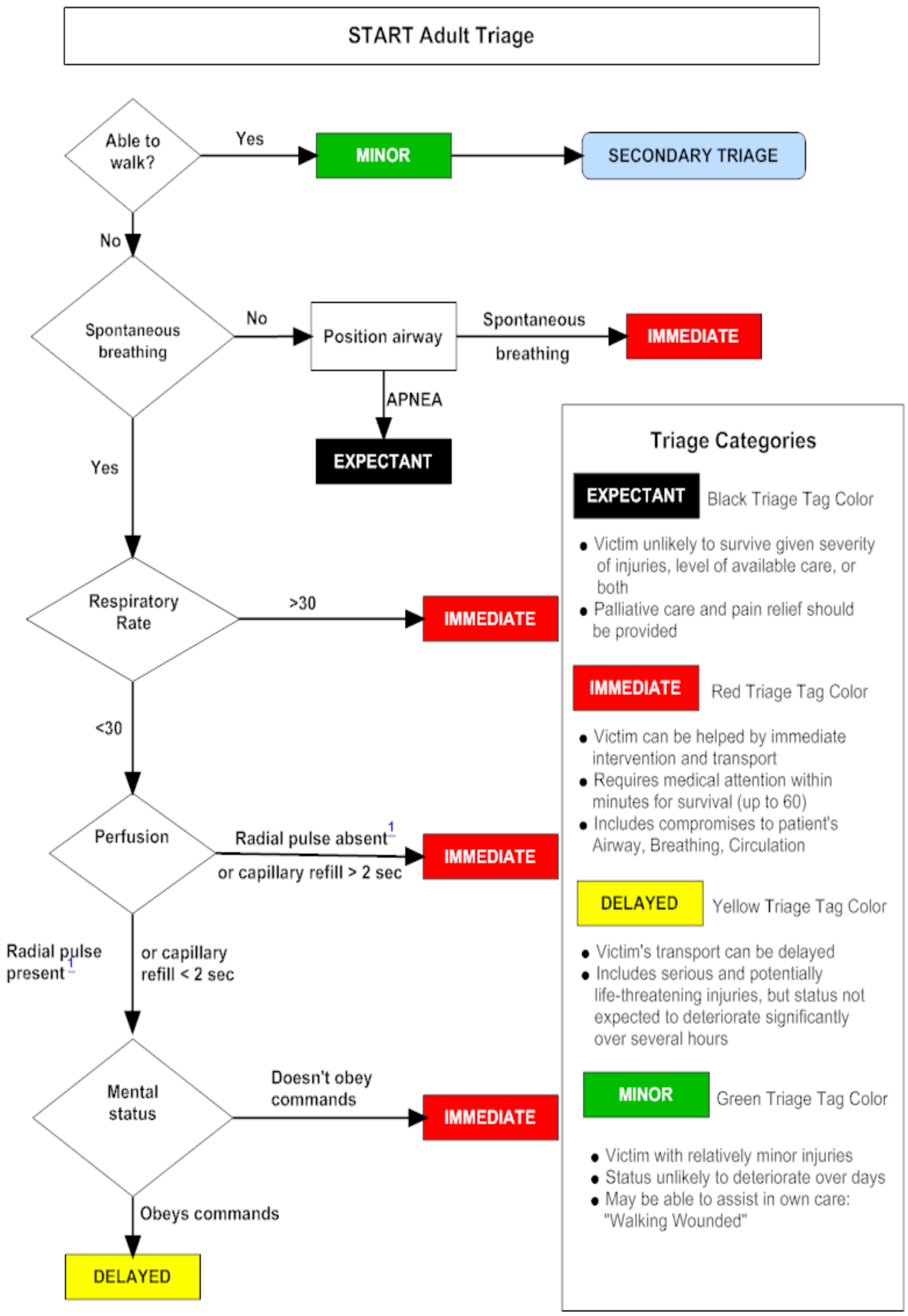

Figure 1 – START Triage protocol

1.4. Definition of simulation

Simulation is the imitation of the operation of a real-world process or system over time.[20]

The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors/functions of the selected physical or abstract system or process.

Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games. Simulation is also used with scientific modelling of natural systems or human systems to gain insight into their functioning. Simulation can be used to show the eventual real effects of alternative conditions and courses of action and is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist.[21]

David M. Gaba asserted, “No industry in which human lives depend on the skilled performance of responsible operators has waited for the unequivocal proof of the benefit of simulation before embracing it”.[22]

1.5. History of simulation

"When you consider the broadest definition of medical simulation being 'an imitation of some real thing, state of affairs, or process', the historical roots of simulation for the practice of skills, problem solving, and judgment are evident".[23]

Physical models of anatomy and disease were constructed long before the advent of modern plastic or computers.

Medical education evolved during the 1900s from a simple apprenticeship to incorporating the learning of scientific principles and, finally, to demanding objective measures of competence in the domains of knowledge, skills, and behaviors.[23]

When simulation skyrocketed in popularity during the 1930s due to the invention of the Link Trainer for flight and military applications, many different field experts attempted to adapt simulation to their own needs. Due to limitations in technology and overall medical knowledge to a specific degree at the time, medical simulation did not take off as acceptable training until much later. When the sheer cost effectiveness and training of which simulation was capable surfaced during extensive military use, hardware/software technology increased exponentially, and medical standards were established, medical simulation became entirely possible, affordable, standardized, and accepted.[24]

There was a greater than 10-fold increase in the annual prevalence of simulation-related publications this decade compared with the 1990s.[23]

Foundations of modern virtual reality (VR) began in the 1950s and 1960s.

The term VR was introduced to describe immersive environments. The CAVE at the University of Michigan broke new ground with the triage and management of patients in a virtual environment.

1.6. Aspects of Simulation

The simulation has a lot of aspects:

- It is widely customizable. Each session of simulation can be modeled in order to evaluate, increase or exercise a single or a group of skills. It's also possible to create different scenarios according to the level of the trainee and gradually increase it according to the experience acquired.

  Is demonstrated that simulation is useful in replicating complex and rare scenario or high-stress situation,[25,26] that technical performance of healthcare professionals facing uncommon situations was improved[27] and that there is a positive outcome of patient involved in uncommon situation due to a skill improvement of nearly 50% after training.[28]
- It is safe. Richard Satava said, "The greatest power of virtual reality is the ability to try and fail without consequence to animal or patient. It is only through failure—and learning the cause of failure—that the true pathway to success lies".[29]

  It is safe for the trainee who is not exposed to dangerous materials or other risks and it's free from legal point in case of error of a certain procedure.

It is safe also for the patient because it has been generally demonstrated that simulation actually improves the technical performance resulting in better outcomes for patients.[25,30]

- Is standardizable. This point is very important because it allows to provide a homogeneous level of learning: it’s possible in fact to dispense the same scenario with no variation in conditions, environment or complications to more trainees.

  Lately it has also been tried an attempt to develop also a system that check the real competency achieved. That means that the trainees must continue their training until their performances match the expected criteria.[31]

  Current simulation model have demonstrated to be useful even for performance assessment inasmuch it is possible to define specific metrics for each assets; each student is evaluated applying a standardized rating that allow ti give an objective evaluation of the procedure and to keep trace of the improvement in execution of each task.[31]

1.7. Characteristics of simulation

The simulation covers many areas: it can be used for education (cognitive skill), training (psychomotor skill), performance assessment, evaluation of organizational practices or investigation of human factors (such as fatigue).

Most of the simulations are usually used in individuals but can also be applied on groups of people and teams to test or teach teamwork. This is very useful especially in multi-disciplinary team. In fact not only physicians are involved in simulations, especially when training is performed at a crew or team level. Simulations are thus being used for nurses, aids, technicians, and clerical personnel.

The simulation can be applied to all age groups and at all levels of experience. Today in fact is also applied to the continuing education of personnel already trained and not just for the training of new staff.

For years the development has focused only on the technical aspects such as surgery, obstetrics and cardio-pulmonary resuscitation. Today, however, a new field that is taking place in the health care field is the simulation of the psychological aspects and patient communication to enhance also the non-technical skills.

Most of simulations have been addressed to adult patients and clinical activities relevant to adult medicine. Yet, simulation is applicable to nearly every type and age of patient.

Thinking of a simulation, one of the biggest errors we can get into is that a high technological level is always required. It is actually possible to make verbal simulations, with actors simulating standardized patients; it does not require any specific technological device, but can effectively simulate real and complex clinical situations.

Going to a slightly higher level of technology it is possible to organize simulations with very simple materials: for example, pieces of fruit or dolls can be used to reproduce the skin and muscles. However it is true that some special skills such as complex manual dexterity or the management of life threatening clinical situations needs more advanced technology that recreates a clinical setting high fidelity. At present, these types of simulators are dummies, computer screens, or virtual reality environments.

A simulation can be performed at any location, for example a library or a school for the multimedia screen-only ones, a laboratory for virtual and physical task or even inside a hospital in order to replicate all the fundamental aspects.

In each simulation it is appropriate to provide specific feedback phase to maximize learning. Often, in the computer simulations, the system itself provides detailed feedback while, in other cases, it is the instructor who has to deal with this important task.

This feedback can be provided during the simulation, putting it in pause from time to time or, especially in the training of expert personnel, at the end of the scenario so that participants can apply their skills without interruptions.

Last but not least a key issue is the cost. This is very variable, depending on the target population, the purpose of the simulation, the technology used and, of course, the efficiency of the organizing institutions.

1.8. Simulation in disaster preparedness

Simulation training has become an effective method for preparing people for disasters. Simulations can replicate emergency situations and track how learners respond, thanks to a lifelike experience. Disaster preparedness simulations can involve training on how to handle very different scenarios, such as terrorism attacks, natural disasters, pandemic outbreaks, or other life-threatening emergencies. But these are not the only possibilities: mass casualties can change from time to time, adapting to the new medical or political situations, taking inspiration from real life. Projecting a simulation is up to the needs of the tester, and there is an infinite variety of possibilities.

The success of the medical aid responding to a disaster depends primarily on a multi-disciplinary process of continuous education and training. The need to promote the preparation in this area has been recognized many times in the past, especially in connection with the emerging natural, terrorist and technology hazards.[32,33]

First of all, create preparedness means planning, then educate and finally train. Instructionally, the benefits of emergency training through simulations are that learner performance can be tracked through the system. This allows the developer to make adjustments as necessary or alert the educator on topics that may require additional attention. Other advantages is that the learner can be guided or trained on how to respond appropriately before continuing to the next emergency segment. This is an aspect that may not be available in the live-environment. Some emergency training simulators also allow for immediate feedback, while other simulations may provide a summary and instruct the learner to engage in the learning topic again.

In a real emergency situation, responders have no time to waste. Simulation-training in this environment provides an opportunity for learners to gather as much information as they can and practice their knowledge in a safe environment. They can make mistakes without risk of endangering lives and be given the opportunity to correct their errors to prepare for the real-life emergency.

Several studies confirmed that time to triage and command-and-control markers improved following exposure to a disaster simulation improves the ability of medical students to manage a simulated disaster,[34-35] furthermore student (and resident) enjoy this kind of education.

The benefit of performing exercises in Disaster Medicine has been emphasized in every text inherent in the "disaster planning" .[36]

1.9. Type of simulation in disaster medicine education

In disaster medicine there is a variant of this categorization: the two major categories are the “Discussion-Based Exercises” and “Operation-Based Exercises”.[37] The first one is mainly used to form both the personnel and staff with existing plans and capabilities. Participants are followed and guided by facilitators to keep them on track in achieving the objectives of the exercise. For example Seminar, Workshop, Tabletop and Games.[37] The second one is used with the aim to evaluate and validate the criteria for emergency preparedness, plans and procedures. They include drills, functional exercises and full-scale exercises. There is a real response and mobilization of personnel and equipment on a designated period of time.[37]

1.10. Virtual Reality

Virtual reality is a term used to describe a simulated reality.

Although, in theory, virtual reality could be formed through a totally immersive system in which all the human senses can be used (more specifically immersive virtual reality or RVI), currently the term is usually applied to any type of virtual simulation created through the use of computers connected to a monitor.

The term virtual reality was coined, it seems, in 1989 by Jaron Lanier, one of the pioneers in this field, who founded the company VPL Research (Virtual Programming languages, programming languages, virtual).[38]

The first product created for clinical virtual reality was the Sensorama (Fig. 2) constructed by Morton Heilig and the commercial product was released in 1961. The apparatus projected images, vibration, sound, smell, and wind to deliver 5 different immersive experiences. At the same time, Doug Engelbart envisioned the connection of computers to digital displays. Although his visionary ideas were initially dismissed, several events over the next decade propelled development in this direction. Two Philco employees designed the first head-mounted display in 1961. The first stereoscopic display was made by Ivan Sutherland in 1965. Initially, these head-mounted displays received input from cameras or film rather than computer-generated images.[23]

Today, the virtual simulation in medicine has made enormous progress, developing methods more immersive customizable and adaptable to the educational needs and the modern platforms have facilitated training in medical intervention in response to disasters[39] and application of triage abilities.[40,41] Not only can learners acquire, improve, and maintain skills over time within an emergency construct replicated through VR, their level of expertise can be differentiated as well. This makes the platform highly desirable for assessment purposes. Several study several studies have also shown that VR effectiveness in equivalent to live simulation.[42,43]

Figure 2 – Sensorama advertising

1.11. Stress

Stress is a physiological or pathological response to stimuli of different nature. This term was coined in 1930 by Hans Selye, an endocrinologist that studied the exposition to diverse nocuous agents like cold, surgical injury, excessive muscular exercise, spinal shock and intoxication with sub-lethal doses of diverse drugs in rats. He saw a syndrome in which the symptoms are independent to the nature of the damaging agent and he labeled it General Adaptation Syndrome (GAS)[44].

It also divided the GAS in three stages: the “Alarm Reaction”, the “Stage of Resistance” and the “Stage of Exhaustion”. All the typical manifestation are present only in the first stage while disappear, or even reverse, on the stage of resistance but reappear in the stage of exhaustion[45].

A long-term damage to the adrenal glands and the immune system is linked to the exhaustion phase leading to depression, cardiovascular problems and other mental iusses.[46]

There are some differences between the stages: the first (alarm phase) is closely correlated to the acute stress exposure while the other two phases to the chronic stress exposure.

Stress is the result of a perception of the demands and resources present in a particular situation.[47]

A person faced with a potential stressor, evaluates both the requirements imposed and the available resources.[48,49] If resources are sufficient to satisfy the requests it is established a positive psychological state (eustress) and the situation is interpreted as a challenge. If requests exceed the resources, a negative psychological state (distress) is established and the situation is interpreted as a threat.

The thoughts and behaviors used to manage both the internal and external demands of situations that are appraised as stressful are important mediating factor in the appraisal of a situation as a challenge or a threat.[50] This is called coping.

There are a lot of classification of coping, but the main categories of coping styles are three: problem-focused (appear to be more effective in situations in which individuals can manipulate the stressors), emotion-focused (seem to be effective when dealing with brief and uncontrollable stressors) and avoidance (is about trying to avoid or distract oneself from the situation).[50]

Avoidance coping styles, although associated with decreased subjective stress levels, have been associated with increased cortisol responses. As such, they may be detrimental to performance under stressful circumstances.[50]

In addition to the psychological aspects, stress also strongly influences the physiological factors.

In fact there is an activation of the sympathetic nervous system that causes a rapid increase in heart and respiratory rate and an activation of the hypothalamic-pituitary-adrenal axis resulting in a release of cortisol.

Indeed, elevated anxiety and cortisol levels have been associated with impairments in memory, attention, and decision-making abilities in research conducted with military recruits and with university students.[51,52]

1.12. Physiology of stress

Stress is identified with a psycho-induced secretion of catabolic hormones by the adrenal glands in response to stimuli hypothalamic-pituitary and autonomic nervous system.

1.12.1. Hypothalamus-pituitary-adrenals axis

The hypothalamus secretes releasing factors to the pituitary gland to produce antidiuretic hormone (ADH) and Adrenocorticotropic hormone (ACTH): ADH (or vasopressin) corrects hypovolemia by water retention (causing an increase in blood volume) and vasoconstriction while the ACTH stimulates the adrenal glands at the cortical level, causing the release of cortisol and aldosterone. (Fig. 3)

Cortisol stimulates gluconeogenesis and inhibits the action of insulin (insulin resistance), the Aldosterone acts on the kidney by stimulating the reabsorption of sodium, which by osmosis "drag" along the water, helping to restore the proper level Fluid challenge.

The reabsorption of sodium is associated with the excretion of potassium and hydrogen ions (antiporter), whose depletion causes urine acidification and alkalization of the blood.

The kidney detects the pressure drop across the macula densa of the juxtaglomerular apparatus and through the secretion of renin, activates the renin-angiotensin-aldosterone system with the final release of angiotensin II, a potent vasoconstrictor.

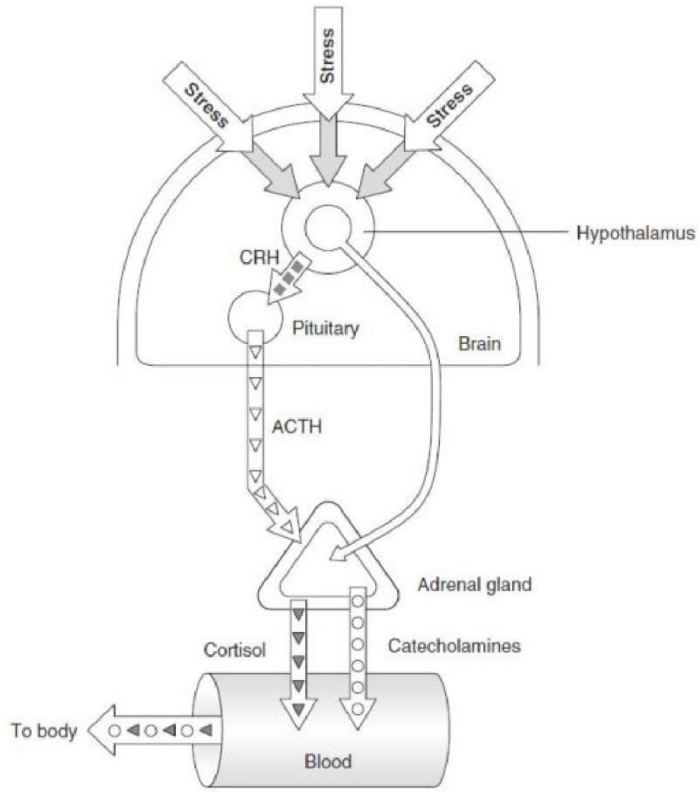

Figure 3 - Hypothalamic–pituitary–adrenal axis

1.12.2. Autonomic nervous system

There is also an activation of the ortho-sympathetic system that releases adrenaline and noradrenaline especially from the adrenal medulla.

These hormones act on receptors alpha and beta and cause:

- bronchodilation
- increased heart rate (resulting in increased cardiac output)
- mydriasis
- inhibition of the release and efficacy of insulin

- increased sensitivity to glucagon
- a constriction of cutaneous vessels (pallor) and visceral abdominal
- a vessel dilation muscle

1.13. Stress effects on task performance

By now many studies have shown that the majority of health professionals working constantly under stress[50] and this affects the quality and accuracy of performance.[53,54] However, there were also, on several studies, demonstrations contrasting despite an increase in the perception of stress reported by the staff, there were no decreases in the quality of performance in the simulations, even in some cases an increase of these.[53] Also, a study with Emergency Medicine residents showed that stressors like scenario design can influence perceived stress levels but that performance levels are more affected in less experienced personnel.[53]

1.13.1. Stress and attention

Under stressful conditions there is a decreasing of a person's attentional resources due to an overload of the cognitive system, that is literally bombarded with all sorts of perceptual information.[50]

Fortunately it comes in the "selective attention", a mental process that filters out external stimuli and information allowing the individual to focus only on stimuli considered relevant to correctly execute a given task avoid overloading them avoiding cognitive process.

From this point of view, stress is therefore useful when you are managing a task that requires an exclusive concentration in finding information but can lead to a diminished ability to filter out irrelevant information from the relevant ones.

One explanation for these conflicting results might reside in the relationship between a stressor and the task to be performed.

When there is a perception of anxiety, people's attention is directed to the information about the threat.

Selective attention will be focused on those aspects that induce the stress response. If the task performed is fully linked to the source of stress, then selective attention should be restricted to the same task but if the source of stress is secondary to the task being performed, then the focus will be on the source of stress resulting in the exclusion of information related to the task itself.

In summary, the restriction of selective attention can be detrimental to performance when the stress is due to factors not related to the task and can facilitate performance when the task is the source of the stress response.

1.13.2. Stress and memory

The effects on the memory depend on the phase of the memory that is stimulated during a stress situation.

There are in fact different components of memory, but only three are mainly involved: the working, the consolidation and the retrieval of information. An increase in stress seems to compromise the working memory, reducing the ability to gather information from multiple sources and to make decisions.[50]

A moderate level of stress on the other hand seems to have a good effect on memory consolidation, establishing better new and fragile memories but this does not occur if the stress level is very high.[50]

Finally, as for the other two types of memory, stress seems to affect also the recovery of memories. In this case it is still debating whether the stress is caused by a challenge or a competition.[50,51]

1.13.3. Stress and decision making

There are two main types of decision making: vigilant one and hypervigilant one.

The vigilant decision making consists of a systematic and organized information research, a detailed examination of all the available alternatives and the dedication of sufficient time for the assessment of alternatives and data review before making a decision.

In contrast, the hypervigilant decision making process is considered a disorganized and impulsive model. It is composed by a non-systematic and non-selective information research, by a consideration of a limited set of alternatives, by a rapid evaluation of the data and by a choice of solution without the revaluation. This, obviously, leads to a poor performance in task solving.

Stress is associated with the hypervigilant model but it is not clear if this is considered a worse thing. While it has been demonstrated[55] a loss of performance during the laboratory activities, the hypervigilant model may represent an adaptive response to the activities that must be made under time pressure on the decisions already known.

A study demonstrated that participants who used expert in hypervigilant decision-making have made better performance than those who used the vigilant one.

What makes the difference is the experience and familiarity for the task to be performed.[50,56]

1.13.4. Stress and teamwork

Due to the extremely complex and dynamic nature of the doctor's job they often have to work in teams. In situations of urgency-emergency, people need to work together in a coordinated way to make important decisions regarding the management and treatment of patients.[50,57]

Unfortunately very little is known about the effects of stress on the performance of teamwork. Most of the available research is based on retrospective studies of air accidents and observation of teamwork in acute events.

The results of these studies have shown a relation of stress with the prospect of the team perspective and centrality of authority.

Two groups of researchers have observed that an increase in stress leads to a loss of team union and to a performance diminution of the entire team. [50,57,58]

This diminished union team is due to the reduction of attention that occurs under stress.

Although these studies provide some data on the effects of stress on team performance, these results have not been confirmed or replicated by other studies.

Regarding the effects of stress on the centrality of the authority, the results are in conflict.

In fact, some researchers have observed a centralization of authority under stress. In this case the control and decision-making were concentrated in the higher hierarchical levels.[50,59] The team leader was much less receptive to input from other team members. In contrast, other researchers have observed that the members of the team (especially the leader) became more receptive to information provided by other members.

Several characteristics have been identified on team performance during high-stress events such as the ability to adapt to situations, effective communication, the presence of situational awareness and clear leadership. These features depend on the presence of implicit coordination that occurs when team members are able to anticipate the needs and the actions of other members, setting their behavior accordingly. All this depends on a shared mental model, a common mental understanding of the situation and tasks to be carried and allows team members to make predictions and decide the action to take.[50]

1.13.5. Stress and anxiety

The development of anxiety disorders involves multiple factors, including biological abnormalities, past and present psychological stressors, maladaptive cognitions, and environmentally conditioned behaviors. [60]

If stress is viewed in a cognitive perspective as a call for action instigated by appraisals of properties of situations and personal disposition, then anxiety can be viewed as self-preoccupation over the inability to respond adequately to the call. [61]

Stress induces high levels of anxiety with its many physiological and psychological concomitants. T.W.Kamarck, S.B. Manuck and J.R. Jennings have conducted several study about the effects of a non evaluative social interaction on cardiovascular responses to psychological challenge[62]. In one condition, a friend accompanied a college student who participated in two laboratory task. In the other condition, the subject came to the laboratory unaccompanied. Subject who were accompanied by a friend showed reduced heart rate reactivity to both task relative to the alone condition. The result suggest that interpersonal support reduces the likelihood of anxiety and exaggerated cardiovascular responsivity.[63]

1.14. Stress Measurement

1.14.1. Psychological Measurement

1.14.1.1. State Trait Anxiety Inventory (STAI)

The State Trait Anxiety Inventory (STAI) is a questionnaire given to adults that was created and developed by psychologists Charles Spielberger. It shows how strong a person’s feelings of anxiety are. It is offered and translated in twelve languages: English, Chinese, Danish, Dutch, Finnish, French, Italian, Norwegian, Portuguese, Spanish, Swedish, and Thai. It was developed to provide both short and reliable scales based on a person's answers to access state and trait anxiety.

Spielberger was not alone in creating the STAI, R.L. Gorsuch, and R.E. Lushene also contributed to its development. It underwent revision to its current form in 1983. It was developed as a method to assess the two types of anxiety, state and trait, in the fields of practice and research. The inventory was developed in a way so that it could be one set of questions that, when given the proper direction, could be applied towards the assessment of a specific type of anxiety. Some of the information used in the inventory was taken from other forms of measurement, and in the case of The Affect Adjective Check List (AACL) was even subject to the slight change of its current adjectives. After the inventory had been developed it underwent research to determine if it could be concluded as a valid source of assessment before it could be taken any further.

The State-Trait Anxiety Inventory is one of the first tests to assess both state and trait anxiety separately. Each type of anxiety has its own scale of 20 different questions that are scored. Scores range from 20 to 80, with higher scores correlating with greater anxiety. The creators of this test separated the different anxieties so both scales would be reliable. This means the S-anxiety scale would only measure S-anxiety and the T-anxiety scale would only measure T-anxiety, the ultimate goal in creating this test. They found that they could not achieve this if the questions were the same to examine both types of anxiety. Each scale asks twenty questions and they are rated on a 4-point scale. Low scores indicate a mild form of anxiety whereas median scores indicate a moderate form of anxiety and high scores indicate a severe form of anxiety. Both scales have anxiety absent and anxiety present questions. Anxiety absent questions represent the absence of anxiety in a statement like, “I feel secure.” Anxiety present questions represent the presence of anxiety in a statement like “I feel worried.” More examples from the STAI on anxiety absent and present questions are listed below. Each measure has a different rating scale.

The 4-point scale for S-anxiety is as follows:

1. not at all
2. somewhat
3. moderately so
4. very much so

The 4-point scale for T-anxiety is as follows:

1. almost never
2. sometimes
3. often
4. almost always

The various State-Trait tests evaluate a number of different emotions. The State-Trait Anxiety inventory measures anxiety by assessing someone’s state and trait anxiety. The STAI was one of the first tests to examine both state and trait anxiety at the same time. There are two different forms of the STAI, one that evaluates children, and one that evaluates adults. This scale is useful for many different socio-economic backgrounds and groups and anyone that has the equivalence of a sixth grade reading level, it therefore can be utilized for many people. Clinicians use this in diagnosing patients in a clinical setting. It is also used to diagnosis clinical anxiety in surgical and other medical patients besides just mental health patients. The STAI, itself, assesses anxiety but also can be used to make a discrimination when wondering whether a patient is experiencing anxiety or depression. This inventory is used in different research projects.[47,64–66]

1.14.2. Physiologic Measures

1.14.2.1. Heart and respiratory rate/Blood Pressure

The adrenaline is part of the reflex pathways of the sympathetic nervous system and is involved in the reaction "fight or flight" (fight or flight). At the systemic and local level the effects of adrenaline can be very different or even opposite depending on the type of receptor expressed by cells of a specific tissue: α_1, α_2, β_1, β_2, β_3. Each receptor subtype is encoded by a different gene. Adrenergic receptors are variably distributed in the central nervous system and peripheral tissues. Norepinephrine and epinephrine are roughly equipotent in activating α and β1 receptors. Epinephrine is much more potent in activating β2 receptors and norepinephrine is more potent in activating β3 receptors.

The release of catecholamines generally increases heart rate and cardiac output and causes peripheral vasoconstriction, leading to an increase in blood pressure. These events are modulated by reflex mechanisms, so that, as the blood pressure increases, reflex vagal parasympathetic stimulation may slow the heart rate and tend to reduce cardiac output. Although norepinephrine usually has these effects, the effect of epinephrine may vary depending on the smooth muscle tone of the vascular system at the time. In addition cardiovascular function is integrated by the central nervous system, so that, under appropriate circumstances, one vascular bed may be dilated while others remain unchanged. The central organization of the sympathetic nervous system is such that its basal regulatory effects are quite discrete in contrast to periods of stress, when stimulation may be rather generalized and accompanied by release of catecholamines into the circulation.

Others important effects are gastrointestinal relaxation, dilation of the bronchial tubes, diversion of blood flow to the muscles, liver, myocardium and brain and increase blood glucose.[67]

1.14.2.2. Body Temperature

A study conducted by LeMay LG, Vander AJ, Kluger MJ. has demonstrated as an increase in stress can lead to an increased release of IL-6 by T lymphocytes and macrophages.[68] This protein is able to cross the blood-brain barrier[69] and stimulate the hypothalamus to synthesize prostaglandin E2 (PGE2) thereby changing the body's temperature set point with a consequent increase of it. A second mechanism of temperature increase of IL-6 is linked to the catabolism of energy substrates in muscle and adipose tissue.

2. Study 1

2.1. Rationale of the study

The setting where disaster medicine is applied is characterized by a high number and variety of casualties, lack of medical resources, and the need to operate in multidisciplinary teams with different tasks.[1–3] In particular, specific knowledge of organization, logistics, and medical aspects, frequently far from one's normal activities, is required, and mass casualty triage (MCT) is inevitable.[3,4] The MCT concept was born in these situations, wherein changes in a rescuer's perspectives from doing 'the greatest good for each individual to the greatest good for the greatest number' are necessary to increase the global outcome of the involved population.[1] Therefore, MCT consists of a rapid patient assessment to set the most appropriate level of care and treatment in the light of the limited availability of resources.[1–4]

The Simple Triage and Rapid Treatment (START) is the most common triage algorithm used in disasters and mass casualty incidents (MCIs) management in USA, Canada, Saudi Arabia, and partially in Australia and Israel.[4,5] In Italy, most regional emergency medical service operation centers also use the START method. Lessons learned from recent international emergencies suggest that healthcare professionals do not feel sufficiently competent or knowledgeable in this area and, above all, they are unfamiliar with the most common triage protocols.[6–8] The medical scientific community has become very sensitive toward disaster education[9] and has been working to create an effective teaching and training program to improve MCT expertise among health personnel.[10–13] Simulation is the current cornerstone of modern disaster medicine education, with a strong potential for generating positive learning outcomes.[14–30] With increasing frequency, simulation-based medical education is also used for formative and summative evaluations.[14,15] Even though in recent years several educational programs in disaster medicine have been developed worldwide, only a relatively few of them have been assessed through a rigorous evaluation methodology in terms of the efficacy of technical skills acquired by participants including the ability to perform MCT.[16,25,29–31] In two different studies, we have recently shown the efficacy of live simulation in assessment of triage skills after a disaster medicine training session.[19,32] However, live simulations, 'whilst accepted to be the 'gold-standard' are challenging to organize, expensive and disruptive'.[33] In the light of the above, in recent years, virtual reality (VR) simulation has been shown to be a valid, clinically appropriate, and cost-effective training method able to achieve a good degree of realism.[24–30] However, little is known about the possibility of using this simulation methodology to test the MCT skills acquired after brief teaching sessions.[33]

2.2. Aim of the study

The aim of this study was to explore the ability of VR simulation, compared with live simulation, to test MCT skills, in terms of triage accuracy, intervention correctness, and speed to complete triage, of naive medical students using the START triage algorithm in a simulated MCI scenario and to detect the increase in this expertise after a brief learning session on MCT. It was hypothesized that VR simulation is equivalent to live simulation for assessment of MCT skills, such as triage accuracy, intervention correctness, and time to triage, in inexperienced health personnel and to identify the improvement in these abilities after a short lesson.

2.3. Methods

2.3.1. Study Design

A randomized cross-over study was designed. Written informed consent was obtained from each participant before the start of the study. As all data were deidentified and reported in aggregate, the study was deemed exempt from institutional review approval by the local ethics committee.

2.3.2. Study Setting and Population

Fifty-six medical students in their sixth year of study, attending the emergency medicine curricular course at the Universita` degli Studi del Piemonte Orientale ‘A. Avogadro’ in Novara, Italy, were enrolled.

2.3.3. Scenario description

The same scenario, centered on a car accident resulting in 10 casualties, was developed identically both on VR simulation and on the live simulation. The simulation scenario was expressly planned for testing MCT skills, in terms of triage accuracy, intervention correctness, and time to triage, of the participants. The students entered one at a time in the scenario and, before the entrance, a scenario description allowed students to completely understand their role in the simulation. The fire brigades had already provided ‘safety at the scene’ and the student played the role of the healthcare provider aiming to triage all the victims involved in the car accident. In the live scenario, the students had a backpack at their disposal, containing oropharyngeal airways for airway management, tourniquets and nonsterile gauzes for hemorrhage control, and triage tags in the four START triage different colors (red or immediate, yellow or delayed, green or minor, and black or deceased).[4] The same medical equipment was available in the VR scenario. A screenshot of the VR scenario environment is presented in Fig. 4.

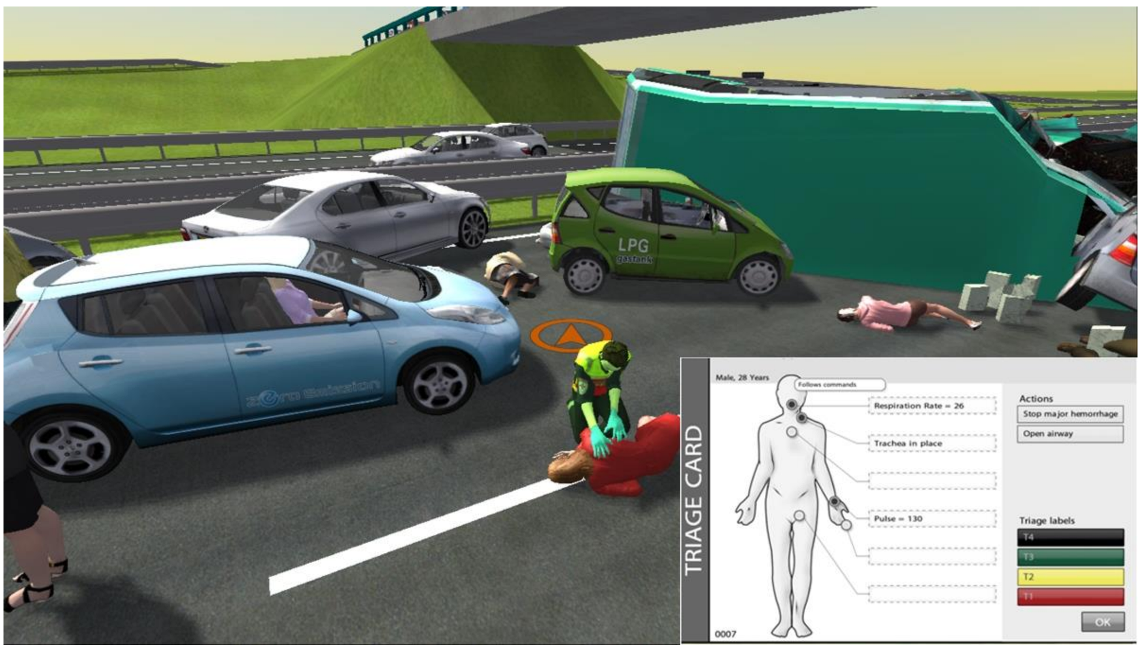

Figure 4 – A screenshot of the virtual reality scenario environment with an example of triage card visualized during the simulation.

The setting of the live simulation was reproduced in an open space in the Department of Translational Medicine courtyard at the Universita` degli Studi del Piemonte Orientale. Ten third-year medical students at the same medical school volunteered to participate as mock victims for the live simulation. They underwent intense makeup by a professional makeup artist of the Italian Red Cross and they wore the Dynamic Casualty Cards (DCCs) as described below and in our previous studies.[19,32]

2.3.4. Simulation technology

The set of 10 casualties was created using Victim- Base.[34] VictimBase is a web-based platform designated to create victims and to store them in an online library with the specific aim of facilitating the interchangeable use of these victims across a number of different simulation tools and environments including paper-based simulations, table-top exercises, computer-based simulations, live exercises, and triage exercises. For each victim, an initial clinical condition was designed, including general victim data, such as sex, age, and nature of injury, and physiological parameters, such as respiratory rate, capillary refill time, radial pulse, level of consciousness in terms of ability to follow simple commands, and ability to walk. On the basis of the initial clinical condition, VictimBase automatically calculated labels (red or immediate, yellow or delayed, green or minor, and black or deceased) according to the START triage algorithm (Fig. 1).[4] Life-saving interventions were also identified according to the initial clinical condition and among those maneuvers allowed by the START triage algorithm (open airway and hemorrhage control).[4] The XVR training software (E-Semble, Delft, the Netherlands) was used for developing the VR environment. XVR is currently used by different institutions and organizations in more than 16 countries and, being used for more than 10 years in the European Master in Disaster Medicine (EMDM) program,[35] it has been validated as an effective simulation tool for disaster management training. The XVR library contains dozens of threedimensional environments and hundreds of virtual objects such as rescue vehicles, rescue staff, buildings, injured and uninjured individuals, fires, damaged and undamaged vehicles, leaks, and countless other static and dynamic objects, and casualties imported from VictimBase. Using a joystick, XVR allows the participant to walk around in the simulated reality of an incident. By clicking on the virtual victims, the Triage Card (Fig. 4) appears on the screen and the VictimBase-related clinical conditions can be retrieved for triage. Time, triage accuracy, time key-points in victim's management, and applied treatments are recorded automatically by the software. The Disaster Simulation Suite (DSS) software (iNovaria, Novara, Italy) was used to design live simulation. DSS is a web-based multidimensional tool for designing and customizing a real-size drill and performing multiuser real-time data collection. DSS allows the user to select the type of event and the number of casualties planned in the scenario and to import victim profiles available on VictimBase. Once a victim set is defined, DSS generates the following: (i) a set of paper DCCs, containing evolving vital signs and designated to be inserted into transparent plastic envelopes and safely attached to a lanyard to be worn around the mock victim's neck; (ii) instructions for casualties 'moulage' (professional instructions to cosmetically create standard and high-fidelity rendered wounds on the actors); and (iii) storyboards for simulating realistic and evolving patients (guidelines to be matched with the data cards to simulate injuries and related symptoms). Moreover, DSS allowed authors to collect data on the fly through a wide range of devices, including smartphones and tablets, and lets them record time, triage accuracy, time key-points in victim's management, and applied treatments. DSS has already been shown to be an effective tool for assessing the level of education and training of healthcare providers during MCI live simulations.[32]

2.3.5. Study flow

The 56 sixth-year medical students were randomized into two groups, respectively, called group A and group B, each one composed of 28 participants. The study was carried out over a 3-day period. Each day was labeled day 1, day 2, and day 3. On day 1, group A was exposed to a live scenario and group B was exposed to a VR scenario. All students were naive to both simulation tools. Two-minute orientation seminars were carried out before both the VR and the live simulation scenario to allow familiarization with the VR software XVR and the set of DCCs, respectively. On day 2, all students attended a 2-h lecture about triage in MCIs focusing on START triage. On day 3, groups A and B were, respectively, exposed to a VR scenario and a live scenario. Group A was assessed in the morning and group B was assessed in the afternoon of day 1 and day 3 to avoid an encounter between the two groups and exchange of information on the simulations. Even though it was expressly required not to share information with colleagues, it cannot be excluded that this could have occurred in some case outside the university.

2.3.6. Measures

The goal of the simulation was to assess the scene and perform a primary triage survey and eventually life-saving treatments of all victims. Three outcomes were measured for each scenario: (i) triage accuracy, (ii) intervention correctness, and (iii) time to triage or also named speed. Triage accuracy was measured as accuracy comparing the ‘assigned’ with the ‘expected’ triage category. The ‘assigned’ triage category was defined as the triage category actually assigned by the students. The ‘expected’ triage category was considered the triage label generated automatically by VictimBase and based on the investigator-generated clinical condition. Intervention correctness was measured as accuracy of treatments assigned by students versus investigator-identified treatments focusing on individual decision-making rather than an ability to perform a task, which is assumed. For example, the decision to compress a hemorrhage to a limb injury was assessed, rather than the ability to apply the maneuver correctly. The time to triage was considered the total average time for completing the scene assessment and triage.

2.3.7. Data Analysis

Data were analyzed using GraphPad Prism version 5.0 (GraphPad Software, San Diego, California, USA), tested for normality by the Kolgomorov–Smirnov test. Results that were compatible with the normal distribution were expressed as mean±SD, whereas others were expressed as median and interquartile range. Treatment accuracy is presented as percentage of correctly applied treatments of the total number of expected treatments.

2.4. Results

Study findings related to the three outcomes measured, such as triage accuracy, treatment correctness, and time to triage, are presented in Table 1 and Fig. 5, Table 2, and Fig. 5, respectively.

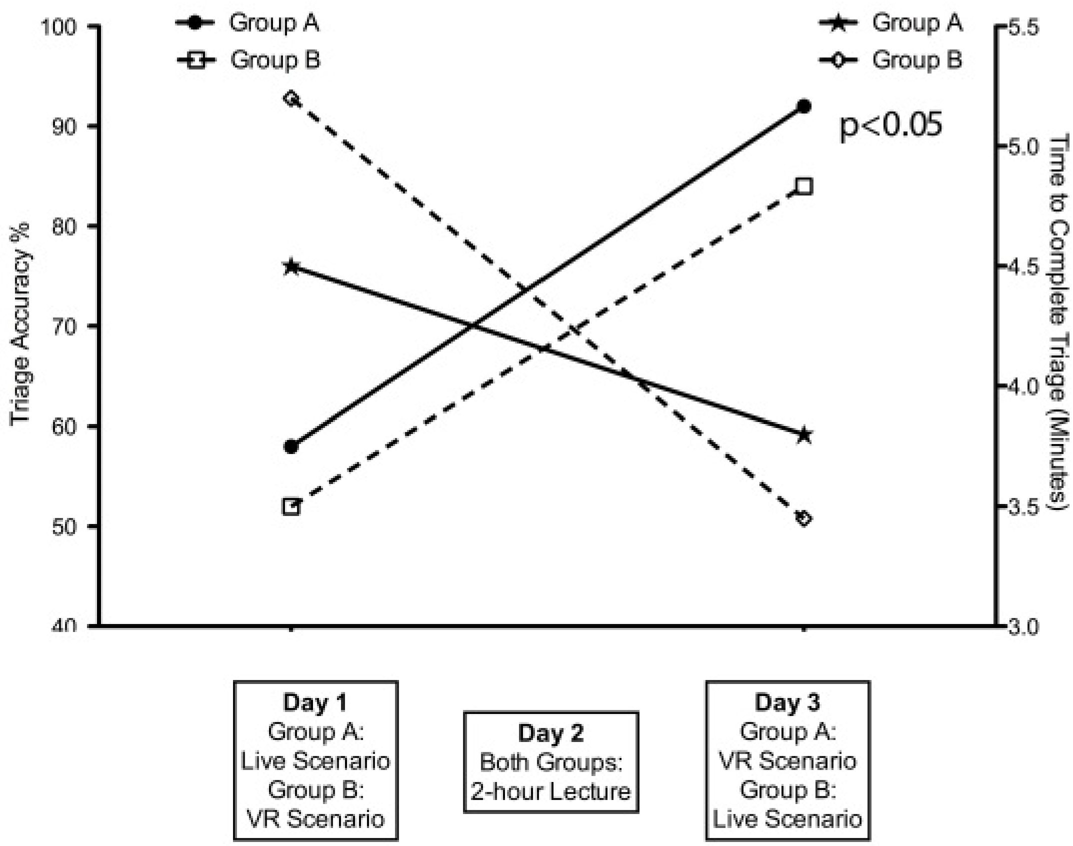

Figure 5 – Comparison of the improvement in triage accuracy and speed in both groups through the timeline.

Table 1 Accuracy of triage

	Day 1 Expected				Day 3 Expected			
	Red	Yellow	Green	Black	Red	Yellow	Green	Black
	Group A live scenario (%)				Group A VR scenario (%)			
Assigned								
Red	61.4	33.3	2.0	83.7	100	4.1	0.0	6.1
Yellow	12.5	52.0	22.2	0.0	0.0	86.5	1.0	0.0
Green	0.0	14.7	75.8	0.0	0.0	9.4	99.0	0.0
Black	26.1	0.0	0.0	16.3	0.0	0.0	0.0	93.9
	Group B VR scenario (%)				Group B live scenario (%)			
Assigned								
Red	55.3	33.8	4.7	77.4	89.2	12.8	1.0	9.6
Yellow	10.0	60.0	22.4	0.0	2.5	76.9	8.8	1.9
Green	0.0	6.2	72.9	2.6	0.0	10.3	90.2	0.0
Black	34.7	0.0	0.0	20.0	8.3	0.0	0.0	88.5

Table 1 – The results highlighted by shading represent the percentage of 'correct' triage; those above and below them identify the percentage of overtriage and undertriage per category, respectively. 'Expected': triage category automatically generated by VictimBase and on the basis of the investigator-generated clinical condition. 'Assigned': triage category actually assigned by the students. VR, virtual reality.

Table 2 Treatment correctness

	Day 1 (%)	Day 3 (%)	*P*
Group A			
Hemorrhagic compression	18	42	<0.01
Airway management	22	62	<0.01
Group B			
Hemorrhagic compression	20	45	<0.01
Airway management	16	60	<0.01

Table 2 – The treatment correctness (expressed as percentage) is the actually assigned by the students versus investigator-identified lifesaving treatments according to the Simple Triage and Rapid Treatment triage algorithm.

In detail, Table 1 outlines the actual accuracy data given in terms of the assigned category versus the expected triage category showing the percentage of 'correct' triage on the diagonal, and then overtriage and undertriage above and below the diagonal for each different START triage category. As shown in Fig. 3, on day 1, the overall group A live scenario triage accuracy was 58±16% and the average time to assess all patients was 4'28'' per participant. For group B, the overall VR scenario triage accuracy was 52±26% and the average time to complete the assessment was 5'18''. There was no statistical difference between the two groups. On day 3, the overall triage accuracy for group A in VR simulation was 92±13% and the average time was 3'53''. In live exercise, group B performed the triage with an overall accuracy of 84±15% in 3'25''. Again, there was no statistical difference between the two groups. However, there was an equivalent significant improvement between the preintervention and the postintervention triage scores (day 1 vs. day 3, $P<0.001$). The time to complete each scenario also equivalently decreased from day 1 to day 3 in both groups ($P<0.05$). Table 2 lists life-saving treatment results underlining a significant and equivalent improvement between the day 1 and day 3 treatment scores in both groups (day 1 vs. day 3, $P<0.01$).

2.5. Discussion

This study explored the ability of VR simulation, compared with the most widely used live simulation, to assess the performance of naive medical students in performing MCT in a simulated disaster scenario and to discover the skills acquired by participants after a brief teaching session. The results showed that VR simulation, compared with live simulation, had equivalent power to test the MCT skills of inexperienced medical students during an MCI scenario, such as ability to correctly categorize patients and perform life-saving interventions, to carry out these tasks in a timely manner, and to detect improvement in this expertise after the theoretical lesson. Several studies have assessed the efficacy of educational programs or seminars on MCT through the evaluation of the knowledge acquired,[10–13] but only a few have the ability of such teaching sessions to improve triage performance during a simulated MCI.[16,26,29–31] Even though simulation-based medical education has been shown to be an effective tool to assess medical expertise,[14,15] it has not yet been used widely for this purpose in disaster medicine education.[31] Recently, just a few studies have explored the feasibility and reliability of triage skills assessment in an MCI response exercise carried out in a live environment.[17,31] In two previous studies, we showed the effectiveness of live simulation to assess MCT skills of personnel involved in managing an MCI in both prehospital and inhospital settings and to identify the level of education and training of different health professionals.[19,32] On day 1, before the lecture, both simulation tools equivalently identified a low triage accuracy and a poor treatment correctness for both groups of medical students. The two simulation tools detected similar differences in the actual triage accuracy in terms of overtriage and undertriage percentage for each START triage category both on day 1 and on day 3. On day 1, the percentage of victims overtriaged was higher than the percentage of victims undertriaged. These results reflect those presented in our previous study,[32] in which overtriage was higher than undertriage among inexperienced health personnel. Accordingly, Nie et al.[36] have reported recently, after the Sichuan earthquake, that junior emergency medicine physicians, with no specific training in disaster medicine and MCT, were more likely to overtriage patients and 'this can potentially be explained by junior emergency medicine physicians being accustomed to aggressively pursuing life-threatening diagnoses of patients, thus leading to overtriage'. After a retrospective review of different mass casualties from terrorist bombings, the same deduction has been made by Frykberg,[1] underlining the importance of MCT training as an essential requirement of triage officers to enhance triage accuracy and minimize overtriage. Again, on day 1, even the time to conclude the triage was high for both groups of medical students using the two different simulation methodologies. These results clearly reflect the level of knowledge of naive medical students before a teaching session and show the identical power of the two simulations used for the purpose of testing. On day 3, results of triage accuracy and life-saving treatment both for group A in VR simulation and for group B in live simulation showed a significant improvement from the preintervention triage scores. The time to complete each scenario also decreased significantly from day 1 to day 3 in both groups. These findings undoubtedly showed that both simulations equally detect the same level of knowledge and expertise in medical students and they are able to similarly assess the improvement in MCT skills from an identical baseline. Moreover, they accurately reflect the conclusions of a recent study,[33] and provide further evidence on 'the feasibility of utilizing these immersive, low-cost virtual training environments for skills assessment as an adjunct to existing training and assessment tools in major incident preparation'.[33] Second, this study has shown that even a short lesson on the basic principles of MCT and a description on how to use a simple and broadly used disaster triage algorithm could improve the ability of medical students to categorize patients and manage limited resources in a simulated MCI scenario. These results could be easily generalized to any healthcare provider involved in different disaster educational programs. Moreover, they should stimulate the scientific community to create such simple and effective disaster training sessions and raise the importance of assessing their actual effectiveness of learning through the use of valid evaluation methodologies.

2.6. Limitations

The limitations of the study are essentially linked to the number of participants. It was a difficult limit to overcome because of the size of the class of sixth-year medical students attending the emergency medicine curricular course. Possible extension to other medical students of different years would result in a nonhomogeneity of the study groups in terms of medical background (acquired knowledge).

2.7. Conclusions

As part of the general principles applicable to disaster management, MCT requires training. The efficacy of such training through the testing of the skills acquired has rarely been evaluated in a rigorous manner. In this paper, it has been shown that VR simulation, compared with live simulation, had equivalent ability in assessing MCT skills, in terms of triage accuracy, intervention correctness, and speed, of naive medical students using the START triage algorithm, and to detect improvements in the medical expertise after a 2-h lecture.

3. Study 2

3.1. Rationale of the study

Since the time of the Napoleonic wars, health care providers have discussed, debated and invented multiple triage systems designed to rapidly triage victims in order to save the most lives.[1] A key medical procedure in a mass casualty incident (MCI) is the rapid and accurate sorting of victims with life, limb, or serious injuries from those without.[2] There are different triage methods proposed for use during a MCI, but few have been validated scientifically.[3] Validation of field triage methods for MCI is difficult because of issues of rarity, reproducibility, study groups, logistics, and different processes using different methods. Most of the evidence to date has been based on simulation and post-event evaluations, rather than prospective trials.[2] START (Simple Triage and Rapid Treatment) is now the most widely used method in the world, but there has been little scientific evaluation of this triage method.[4-6] This method divides patients into ambulatory and nonambulatory, and then, using a set of basic physiologic parameters, sorts remaining patients into immediate, delayed, minor, or expectant categories, with each victim receiving a color code of red, yellow, green, or black. After the attacks on September 11th, 2001, in New York City, ThinkSharp Inc. began developing a commercial, evidence-based and outcome-driven approach called the Sacco Triage Method (STM).[4,6] It is the only method evaluated for National Incident Management System compatibility in the United States (US).[4,6,7] STM uses a simple physiologic score that predicts survival and deterioration, where patients are triaged to maximize expected survivors in consideration of the timing and availability of transport and resources.8 In addition to the START and STM triage systems having been derived using markedly different methods, an important difference between the two triage methods is that the START system is opensource and in the public domain, while the STM system is proprietary and licensed for commercial use only.

3.2. Aim of the study

The aim of this study was to use virtual reality (VR) simulation of actual historical train crash MCI victims to compare advance care paramedic students' use of START and STM triage methods in terms of time to triage and assignment of severity order of MCI victims.

3.3. Methods

3.3.1. Study Design

This was a prospective observational cohort study using VR simulation technology based on actual MCI cases that resulted from a train accident in Chatsworth, Los Angeles, California (US) on September 12, 2008.9 The ethics committee for human research at Holland College, Charlottetown, Prince Edward Island, Canada approved the study.

3.3.2. Study Setting and Population

Twenty-six students in their final year of the Advance Care Paramedic program at Holland College were invited to participate in the study. Inclusion criteria included male and female students who were 18 years or older and in good academic standing within the Advanced Care Paramedic program. Potential participants were excluded if they opted not to voluntarily participate in the study or were unable to complete the study. All study participants consented to be included in the study. The study database contained no participant personal identifiers.

3.3.3. Study protocol

The XVR training software (E-Semble, Delft, the Netherlands) was used for developing the VR study scenario.10 XVR is currently used by different institutions and organizations in more than 16 countries.10 It has been validated as an effective simulation tool for disaster management training.10 XVR has also been demonstrated to be a reliable and effective tool for training and teaching different mass casualty triage methods.[11] The XVR library contains dozens of 3D environments with multiple open objects from casualties, vehicles, buildings, sounds, and equipment. Each casualty has physiologic parameters that can be accessed by the user. By using a joystick, XVR allows the user to walk around in the simulated reality of an incident. By clicking on the virtual victims, the Triage Card (Figure 6) appears on the screen.

Figure 6 – A screenshot of the virtual reality scenario environment with an example of Triage Card visualized during the simulation.

This card displays the victim's clinical condition with parameters, and allows the assignment of a triage color using the joystick. To create the study scenario, ten real patient scenarios with known outcomes were taken from the database of over 100 case descriptions from the 2008 train accident in Chatsworth, Los Angeles, and the triage cards of the virtual victims were created (Table 3). For each victim, real clinical conditions, including general victim data, such as sex, age, nature of injury, and physiologic parameters, were imported into the software. These parameters included respiratory rate, capillary refill time, radial pulse, level of consciousness in terms of ability to follow simple commands, and the ability to walk. The patients were distributed in a realistic fashion based on real life locations from the Chatsworth train crash.

Victim ID	Sex	Age	Airway	RR	HR	CRT	Amb	Outcome
43	M	19	Clear	16	110	<2	Y	Released from ER with superficial abrasions
282	F	17	Clear	18	90	>2	Y	Fractured wrist, reduced and casted, released
378	M	44	Clear	20	130	>2	Y	Resuscitated with IV fluids, wound repair by plastics
380	M	60	Clear	18	130	>2	N	Liver laceration, right hemothorax, right tib/fib fracture, pelvic fracture, died day 3 of sepsis
412	F	27	Clear	24	130	<2	Y	Deep lacerations, right eye globe rupture, lived with right vision loss
538	F	60	Clear	24	100	<2	N	Taken to OR for reduction of hip dislocation, left ankle fracture reduction
784	M	57	Clear	12	45	>2	N	Left initially by first responders, upon return found pulseless, pronounced dead in the field
803	M	23	Clear	22	110	<2	Y	Traumatic pancreatitis, discharged one week later
864	F	32	Clear	26	110	<2	N	Required mild sedation, released to family
911	F	32	Obstructed	12	140	>2	N	Released from pinned position, suffered respiratory arrest, pronounced dead in the field

Abbreviations: Amb = ambulatory; CRT = capillary refill time (seconds); HR = heart rate (beats/minute); RR = respiratory rate (breaths/minute); N = no; Y = yes.

Table 3 – Patient parameters with known outcomes from a train accident in Chartsworth, Los Angeles, California, on September 12, 2008.

3.3.4. Study flow

The study was carried out over a 1-day period. Following an explanation of the study, informed consent was provided by the 26 advance care paramedic students. No volunteers out of the 26 withdrew from the study. The volunteers were randomized into two groups; 50% were randomized to use the STM triage method and 50% were randomized to use the START triage method. The groups were provided a 30-minute lecture on their assigned triage method. Four computer stations, each loaded with the XVR training software, were set up in one large room. Study participants were given a 30-minute orientation session on how to interact with the XVR virtual reality environment. This consisted of a three-person scenario allowing the participant to become familiar with the computer simulation software, and to practice how to use the mechanics of the program. Included were how to: assign triage scores using the joystick, open car doors, and enter a bus in the 3D environment. The orientation scenario was the same for both groups. After fielding any questions from the study participants with regards to the mechanics and use of the program, the study was started. The volunteers were told prior to the start of the simulation that there were 10 casualties. The order of triage and the approach to the accident scene were left up to the study participants. All patient triage maneuvers were done in real time. Study participants were able to request assistance from an evaluator who was co-located in the workstation with them. If there was an issue with the program or the participant had questions about the mechanics of the simulation, an expert on XVR was available in the room. Each participant entered the VR environment and was directed to an artificially intelligent, computergenerated firefighter where the first casualty was located. Having already been informed that there were 10 causalities, and that the scene was safe, the participant user approached the scene and triaged each patient.

3.3.5. Measures

The primary outcome measures were the differences in time to triage and the differences in triage order. Using a data collection tool, the participant was timed using a stopwatch from the start of the scenario until the last patient was triaged. This time was recorded. The participant then communicated which order they wanted the patient evacuated from the scene.

3.3.6. Data Analysis

Statistical analysis used a two sample t test to compare the time to triage. Differences in victim rank order between the two groups were assessed statistically by a nonparametric permutation test based on the sum of squared deviations between average rank order across victims. A rank-ordered logistic regression model analysis was performed in Stata software (Statistical Software, College Station, TX: StataCorp LP, 2013) to explore whether specific victim characteristics were related to differences between the two groups. Generally statistical tests had a two-tailed alternative and were interpreted at a significance level of p = 0.05.

3.4. Results

Twenty-six students agreed to participate in the study (2 groups of 13 students each). All 26 were present for their respective triage method lecture, the orientation session, and the study scenario. The mean total triage times per individuals in groups STM and START were 709 seconds (11 min, 49 sec) and 609 seconds (10 min, 9 sec), respectively, corresponding to a mean difference of 100 seconds (95% CI: −11 sec, 211 sec). The difference was not statistically significant (p = 0.07). Statistical analysis by a nonparametric permutation test based on 9,999 simulations shows a significant (p =0.008) difference between victim orders in the two groups. The statistical significance is essentially driven by victim 538, who was given higher priority by the START method; the difference disappeared when this victim was removed from the ordering (Figure 7). This victim was located in the train and had a left ankle fracture. The difference between the two groups was not significantly linked to any physiologic victim characteristics (airway, respiratory rate, heart rate, ambulatory) when assessed by a rank-ordered logistic regression model.

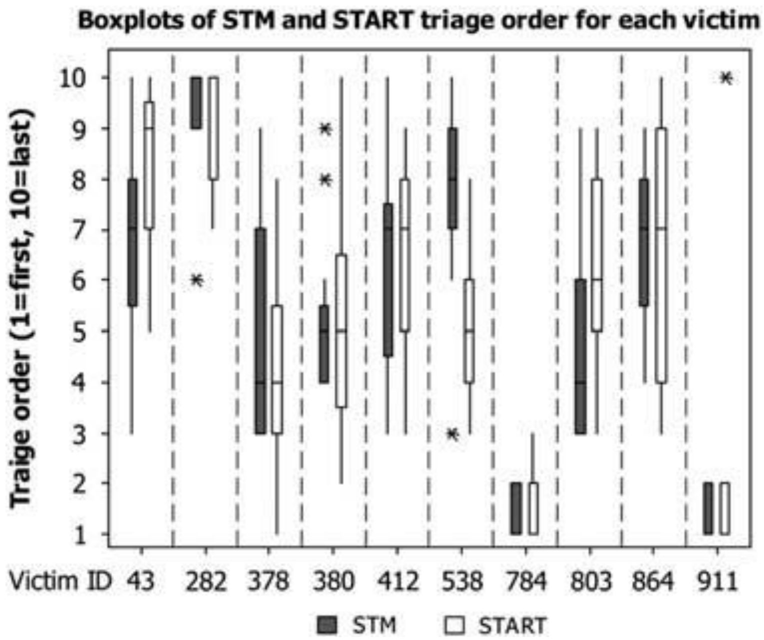

Figure 7 – Boxplot of the victim ordering in the two groups, STM and START. This figure also shows the distribution of order scores for each victim within each of the two groups. The statistical significance is essentially driven by Victim ID 538, and disappears when this victim is removed from the ordering. The difference between the two groups is not significantly linked to any physiological characteristics. The asterisks indicate outliers.

3.5.Discussion

Although STM has been marketed as a mathematical model that orders the treatment of patients based on their probability of survival, potential for deterioration, and available resources,[12,13] we wanted to look at time to triage and triage order to compare the two methods. This study showed no statistically significant difference in the time to triage between the STMand STARTmethods. The average time to triage was 100 seconds longer by the STM method. In this study, we believe that 100 seconds is not a clinically significant time difference between these two triage methods, based on this type of MCI. According to our results, there was a difference in the order of triage. This was statistically driven by victim number 538, who was located in the train with a left ankle fracture. The statistical difference disappeared when the victim was removed from the ordering. It is of interest to note that the triage order was not significantly linked to any of the provided physiologic characteristics. START triage takes into account the mechanical act of ambulation, whereas STM does not. This may have had an impact with regards to the ordering involving victim 538. Previous studies have looked at the operational viability of the STM method compared with the START method.[4,6,8] According to Navin and co authors, emergency responders' STM assessments were more accurate, and the STM time to complete the triage assessments and to clear the scene was less.4 According to their results, emergency responders did not implement START successfully. Navin et al. also stated that STM out-performed START in all objectives.4 The study arms examined were not completed during the same time of day, with START being done first and STM second. The study's physiologic parameters were also artificial, as they were read from patient profile cards. There was also the question of conflict of interest, in that at least one of the authors was involved with the company that sells the STM method. The present study looked at the time to triage and triage ranking order. No significant difference was found for time to triage, while a difference was found in triage ranking order. This difference was due to one patient scenario and not related to patient physiologic characteristics. STM relies on resource allocation as part of outcome measures and the order of triage, and therefore the order of transport to definitive care. If one considers the medical assistance chain as having three parts, with the first being triage capacity, the second being transport capacity, and the third being hospital treatment capacity, it can be argued that triage capacity is the more important of the three. With no difference demonstrated between both methods with regards to triage outcome measures used for this study, the relative cost of the STM may justify using START for emergency medical service systems with limited funding. Unlike other aspects of paramedic training in which exposure to real situations during clinical rotations is the primary method of teaching and a way of comparing processes, MCI training does not lend itself to such methods. This makes it difficult to study objective differences in triage methods. Simulation presents a practical way to study and evaluate different triage methods in a MCI setting, allowing for comparisons of simple outcome measures.

3.6.Limitations

There are design limitations that should be considered when interpreting the results of this study. The STM triage method uses physiologic parameters, as well as resources available, to look at the probability of survival. This study looked at the “front end” of the MCI event, focusing more on the time it takes to triage and the initial ranking order of evacuation. Although 100 seconds may not be of clinical significance for a difference in time to triage ten victims, a larger study with a greater number of casualties may demonstrate a difference in time that would be considered clinically significant in a MCI event. An important limiting factor for this study was the small number of study participants. We employed a convenience sample of paramedics without a prior sample size calculation based on a clinical difference in the primary outcome measure. A repeat of this study with more participants may have revealed differences that went undetected in this study. Finally, simulation was done in an environment that is different from the actual clinical setting, which may have distractors and other factors that are not represented by simulation formats.

3.7. Conclusions

This study demonstrated that there was no statistically significant difference in time to triage by advance care paramedic students using the STM or the START triage methods in a simulated MCI scenario based on a train crash. While a difference was found for ranking order for priority to triage, this difference was due to one of 10 victims, and not based on the victims' physiologic parameters. This study was significantly limited by a sample of convenience and the research question merits further evaluation by employing a larger sample size to verify the results.

4. Study 3

4.1. Rationale of the study

Disasters and mass casualty incidents (MCI) create an imbalance between the immediate need for medical care and the available resources, which is not the case in normal emergency medicine. Disaster medicine is "the science for analysis and development of the methodology requested to handle situations where available resources are insufficient in relation to the immediate need of medical care".[15] The setting where disaster medicine is applied is usually characterized by a high number and variety of casualties, lack of medical resources and the need to operate in multidisciplinary teams with different tasks. In particular, specific knowledge of organization, logistics and medical aspects, frequently far from one's normal activities, are required, and mass casualty triage (MCT) is inevitable.

MCT consists in a rapid patient assessment in order to set the most appropriate level of care and treatment, in the light of the limited availability of resources. Having an impact on the global outcome of the involved population and on the efficiency of the emergency services chain of medical system, the extreme restraint of errors and a good speed in performing MCT are important objectives to be achieved by health rescuers.[56,57]

The relatively limited series of disasters and MCI prevent operators to gain experience in the field, and particularly those aspects of life wrongly considered secondary, as the chaos, the emotional impact and the acute stress responses that the disaster inevitably generates. For these undisputable reasons, the medical scientific community has become very sensitive toward disaster research and education, and has been working to improve teaching and training methods in this field. Simulation is the current cornerstone of modern disaster medicine education, with a strong potential for generating positive learning outcomes, as in other medical branches. Live simulation, whilst accepted to be both the most effective and realistic simulation methodology, is challenging to organize, expensive and disruptive.[55] In the light of the above, in recent years VR simulation has been demonstrated a valid, clinically appropriate, and cost-effective training method able to achieve a good realism.[40–42,70–73] However, the grade of immersiveness reached by VR simulation scenarios compare to live scenarios was poorly understood. The high degree of realism achieved by live simulation was assumed to produce a more stressful situation to the participants compared to VR simulation. A previous study conducted by CRIMEDIM has demonstrated that the degree of realism achieved by VR produce so realistic acute stress responses in participants that are superimposable to live simulation.[43]

The relationship between stress reactivity and medical performance in a mass casualty event has been rarely studied. Up to now, there are no studies in disaster medicine about performance variation according to the levels of stress perceived by the individual and the team in a simulated scenario.

4.2. Aim of the study

The aim of this study was to assess medical students' acute stress responses and performance during a VR high-stress scenario of a simulated mass casualty incident compared to a VR low-stress scenario. It is hypothesized that a highly stressful VR scenario leads to increase stress responses, as measured by subjective anxiety and modification of blood pressure, heart activity, respiratory rate and corporal temperature, and to decrease the performance in managing the simulated mass casualty event and performing MCT.

4.3. Methods

4.3.1. Study Design

A prospective randomized controlled study was designed. Written informed consent was obtained from each participant before to the start of the study. Since all data were de-identified and reported in aggregate, the study was deemed exempt from institutional review approval by the local Ethics Committee.

4.3.2. Study Setting and Population

Ninety-six medical students in their sixth year of study, attending the emergency and disaster medicine curricular course at the Università degli Studi del Piemonte Orientale "A. Avogadro", Italy, were enrolled.

The study was set at the Research Center in Emergency and Disaster Medicine and Computer Science applied to Medical Practice (CRIMEDIM) of the Università degli

Studi del Piemonte Orientale “A. Avogadro” using the VR simulation room equipped by five desktop computers and five 50-inch LCD screen to run the virtual reality disaster training simulation software.

4.3.3. Study flow

The 96 medical students were randomized in two groups, respectively called group “high stress” or H and group “low stress” or L, each one composed by 48 participants. Each group was subsequently divided in 12 subgroups of 4 students (Fig. 8). The 12 subgroups of group H were exposed to the high-stress VR scenario and the 12 subgroups of group L were exposed to the low-stress VR scenario aiming to manage the simulated mass casualty incidents and to triage the 30 victims in a limited period of time (20 min).

At the beginning of each simulation session, there was an accommodation period during which the principal investigator described the overall study project, introduced the students to the simulator setting and obtained their consent. The medical students were then given a rest period (15 minutes) during which baseline measures of anxiety and physiological parameters were obtained. Following the rest period, a 5-minute orientation scenario was carried out to allow familiarization with the VR software. Right after the familiarization session, a research assistant described the study scenario for allowing students to completely understand their role in the simulation. The students entered four at a time in the simulation room according to the subgroup division. Immediately after the end of the 20-minute simulation scenario post-intervention measures of anxiety and vital signs were assessed. After these measures, the students were asked to complete a final report about critical information got from the scene during their medical disaster response.

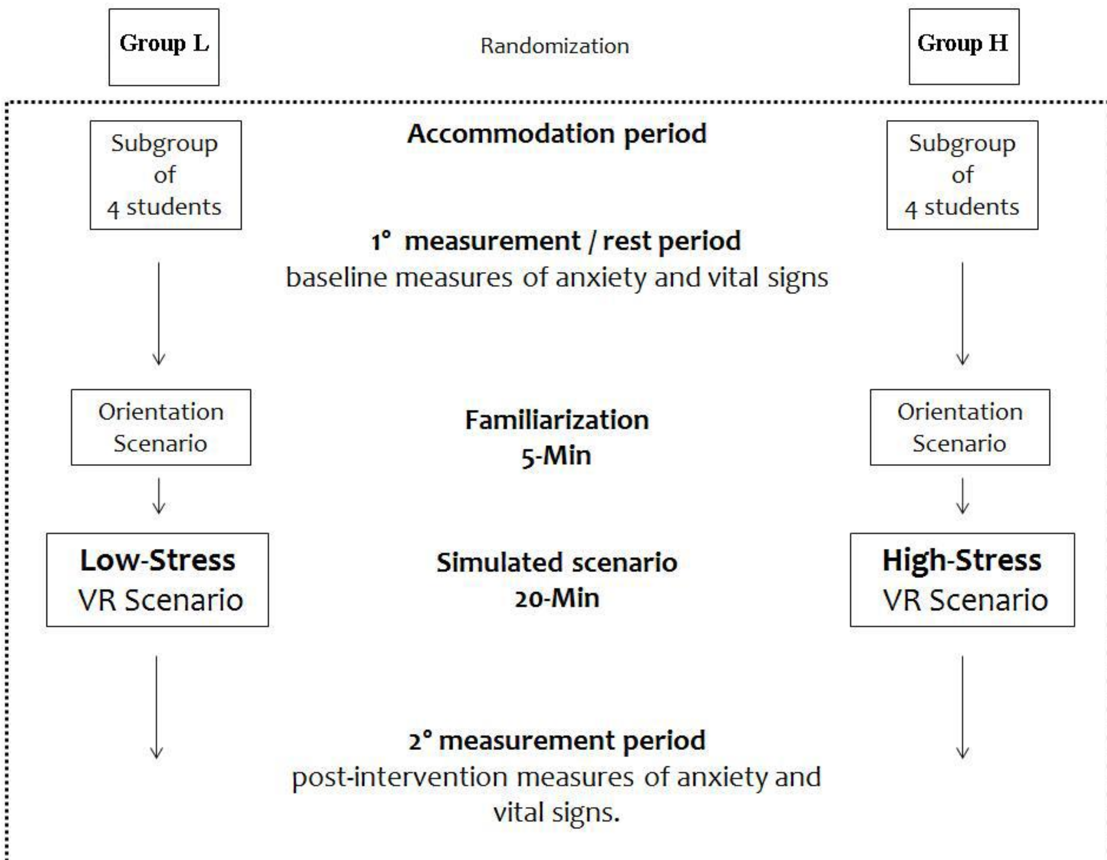

Figure 8 – Study flow

4.3.4. Simulation technology

The XVR training software (E-Semble, Delft, NL) was used for developing the VR environment. XVR is currently used by different institutions and organizations in more than 16 countries and, being used for more than 10 years in the European Master in Disaster Medicine (EMDM) program[74], it has been validated as an effective simulation tool for disaster management training. The XVR library contains dozens of 3D environments and hundreds of virtual objects such as rescue vehicles, rescue staff, buildings, injured and uninjured people, fires, damaged and undamaged vehicles, leaks and countless other static and dynamic objects, and casualties imported from VictimBase. By using a joystick, XVR allows the participant to walk around in the simulated reality of an incident. By clicking on the virtual victims, the Triage Card appears on the screen and the clinical conditions can be retrieved for triage. Time, triage accuracy, time key-points in victims management and applied treatments are automatically recorded by the software.

The set of 30 casualties was created by using VictimBase (www.victimbase.org). VictimBase is a web-based platform designated to create victims and to store them in an online library with the specific aim of facilitating the interchangeable use of these victims across a number of different simulation tools.

For each victim an initial clinical condition was designed, including general victim data, such as gender, age and nature of injury, and physiological parameters, such as respiratory rate, capillary refill time, radial pulse, level of consciousness in terms of ability to follow simple commands, and ability to walk. Based on the initial clinical condition, VictimBase automatically calculated labels (red or immediate, yellow or delayed, green or minor and black or deceased) according to the START triage algorithm.

Disaster Simulation Suite (DSS) software (iNovaria, Novara, IT) was used to collect the pre-designed performance indicators on the fly using tablets. DSS is a web-based multidimensional tool for performing multi-user real time data collection and it has already been demonstrated an effective tool for assessing the medical performance during MCI simulations.[75] (Fig.9)

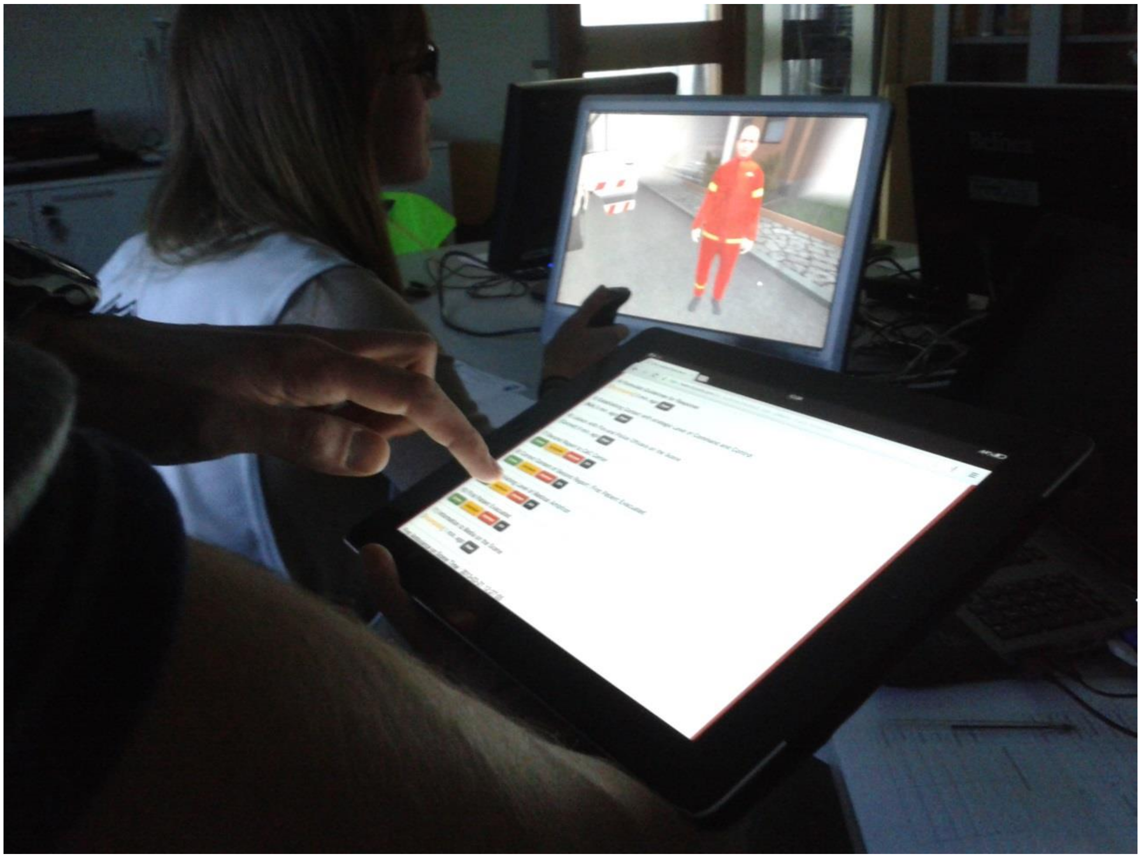

Figure 9 – Evaluation with DSS software during simulation

4.3.5. Scenario Description

The VR study simulation scenario was a multi-vehicle collision involving a city bus, a van and several cars, and resulting in 30 casualties. It was expressly designed for testing medical disaster management abilities and MCT skills of a group of medical students during the first 20 minutes of the early phase of MCI response.

Entering in the scenario at the time ‘zero’ as a group of 4 participants, the students played the role of the first medical responder team arrived on the scene with the first ambulance. The fire brigades and the police were already on the scene and the environment was declared safe at the time ‘5’. The students had a virtual backpack at their disposal, containing triage tags in the four START triage different colors (red or immediate, yellow or delayed, green or minor and black or deceased).

To create the high-stress scenario different stress factors were applied to this baseline scenario.

Virtual stress factor

For virtual factor is meant the modification of the virtual environment using the application presents in the VR software. (Fig.10)

- Auditory noise. A surround sound system has been connected to the four laptops to enable the quality and proper diffusion of the sound. In the scenario, all emergency vehicles had their sirens on, some cars had their alarm on, some victims trapped in cars honking and some victims were screaming, crying and calling for help, the motors and the devices of the firefighters were all turned on and in function.
- Bad climate condition. The entire simulated event took place in a cold, rainy, cloudy and very foggy late evening. The visibility was poor and it was very difficult to explore from far the scene.
- Scene unsafe. The baseline scenario was modified adding developmental risk inside the incident, such as a car fuel tank explosion at the time ‘10’.

Figure 10 - High Stress and Low Stress scenarios

Real stress factor

For real stress factor is meant the application of external stimuli to the VR simulated scenario.

- Pre-determined radio calls. A research assistant playing, the role of the medical operator present at the dispatch center, called via radio the students for getting critical information from the scene at the time ‘5’ and ‘10’.
- Low light. The simulation room was dark with the only light of the monitor.
- Media reporter. A research assistant, playing the role of a media reporter, entered in the simulation room asking the students for information about the incident.

4.3.6. Measures

- Psychological measurement. The State-Trait Anxiety Inventory (STAI) is a psychological inventory and consists of 40 questions on a self-report basis and measures two types of anxiety - state anxiety, or anxiety about an event, and trait anxiety, or anxiety level as a personal characteristic. Higher scores are positively correlated with higher levels of anxiety or stress.[76,64]
- Physiological parameters. Non-invasive blood pressure (NIBP), heart rate (HR), respiratory rate (RR) and corporal temperature (°T) were evaluated just before and after the simulations in each participant.

The goal of the simulation was to assess and to manage the scene, and perform a primary triage and eventually lifesaving treatments of all victims.

- Mass casualty triage. Four outcomes were measured for each group: total triaged victims, triage correctness, time to triage the first victim and time to evacuate the first patient for each subgroup. Triage correctness was measured as accuracy of assigned versus expected triage code according to the START triage algorithm.[14]

- Performance indicators. With the help of DSS software, we assessed, with a score from 0 (not performed) to 2 (properly performed), each of these factors:
  - Tabard Indicating Medical and Ambulance Incident Officer
  - First Report to Dispatch Center
  - Correct Content of First Report: METHANE
  - Formulate Guidelines for Response
  - Establishing Contact with strategic Level of Command and Control
  - Liaison with Fire and Police Officers on the Scene
  - Second Report to C&C Center
  - Correct Content of Second Report: First Patient Evacuated
  - Establishing Level of Medical Ambition
  - First Patient Evacuated
  - Information to Media on the Scene
- Final report (memory). At the end of the simulation, a questionnaire was given to each participant in which they had to give a report about what they seen and done in the scene. In detail the questionnaire asked:
  - Total triaged victims
  - Green, yellow, red and black code assigned
  - Presence of evolutive risk
  - Presence of other rescue team

4.3.7. Data Analysis

Data were analyzed by means of GraphPad Prism version 5.0 (GraphPad Software, San Diego, CA USA), tested for normality by Kolgomorov-Smirnov test. Results compatible with the normal distribution were expressed as mean ± standard deviation, while others were expressed as median and interquartile range [IQR]. Treatment accuracy will be presented as percentage of correctly applied treatments out of the total number of expected treatments. Likert scale results are presented as Median and interquartile range.

4.4. Results

4.4.1. Stress Response

The analysis of the anxiety scores revealed that the participants had an increase of anxiety after both the simulations, but the increment after the high-stress scenario was significant higher than after the low-stress scenario (Tab. 4).

STAI test				
	Average Pre-test	Average Post-test	Difference Post-Pre	p-value
Group L Low-Stress	38,89583	39,20833	-0,3125	<0.001
Group H High-stress	42,48837	35,79070	6,6977	

Table 4 – STAI test

As shown in Table 5, from the baseline to the post-exercise measure, systolic blood pressure showed a marked increase in the group H ($p<0.05$). On the contrary, there was no statistical difference between baseline and post-exercise diastolic blood pressure in the same group. In the group L, the difference between the pre- and post-exercise measures of both systolic and diastolic blood pressures was not statistically significant (Table 5-6).

Group	Average Baseline systolic BP (mmHg)	Average Post-exercise systolic BP (mmHg)	p value
High stress	121,442	126,023	0.0432
Low stress	119,896	121,417	0.4560

Table 5 – Systolic Blood Pressure

Group	Average Baseline diastolic BP (mmHg)	Average Post-exercise diastolic BP (mmHg)	p value
High stress	78,930	79,419	0.7418
Low stress	74,875	75,417	0.5909

Table 6 – Diastolic Blood Pressure

Median baseline heart rates were 78 bpm for high stress group and 83 bpm for low stress one. Median post-exercise heart rates were 79 bpm for high stress group and 79 for low stress one. No groups showed statistically relevant changes in heart rate (p=0.7641, p=0.1011 respectively).

Group	Average Baseline heart rate (bpm)	Average Post-exercise heart rate (bpm)	p value
High stress	78,581	79,116	0.7641
Low stress	82,708	78,875	0.1011

Table 7 – Heart Rate

Median baseline respiratory rates were 16 bpm for both high and low stress groups. Median post-exercise respiratory rates were 18 bpm for high stress group and 17 for low stress one. In this case both groups showed statistically relevant changes in respiratory rate (p=0.0001, p=0.0065 respectively).

Group	Average Baseline respiratory rate (bpm)	Average Post-exercise respiratory rate (bpm)	p value
High stress	15,860	17,698	0.0001
Low stress	15,938	17,000	0.0065

Table 8 – Respiratory Rate

Median baseline heart rates were 36° C for high stress group and 36,3° C for low stress one. Median post-exercise temperature was 36°C for high stress group and 36,1 for low stress one. The low stress group showed a statistically relevant changes in temperature (p=0.0005).

<table>
<tr><th>Group</th><th>Baseline
temperature (°C)</th><th>Post-exercise
temperature (°C)</th><th>Difference
Post-Pre</th><th>p value</th></tr>
<tr><td>High stress</td><td>36</td><td>36,070</td><td>0,07</td><td rowspan="2">0,008</td></tr>
<tr><td>Low stress</td><td>36,275</td><td>36,125</td><td>-0,15</td></tr>
</table>

Table 9 – Body Temperature

4.4.2. Performance measures

- While only 77,1% of victims were triaged after 20 min in Group H, the percentage of triaged victims in Group L was 88,6%. There was a significant statistical difference between the two groups (p<0.045).

- The triage accuracy was 83,6% in Group H and 86,8% in Group L but there was no statistical difference between the two groups.

	High-Stress	Low-Stress	p-value
Total triaged	77,1%*	88,6%*	0,045
Under triage	8,40%	7,50%	0,907
Over triage	8,00%	5,60%	0,273
Accuracy	83,60%	86,80%	0,313

Table 10 - Total Victims Triaged and Accuracy

- The average time to triage the first victim was 4.8’ and 4,5’ in Group H and in Group L, respectively. There was no statistical difference between the two groups.

First victim triaged (minute)				
	Best	Worst	Average	p value
Low-Stress	2	7	4.5	0.61
High-Stress	3	8	4.8	

Table 11– Time of first triage

- The average time to evacuate the first patient was 15’00’’ in Group H and 13’6’’ in Group L. There was a statistical difference between the two groups ($p<0.05$).

First victim evacuated (minute)				
	Best	Worst	Average	p value
Low Stress	3	Nobody evacuated	13,6	p<0.05
High Stress	10	Nobody evacuated	15	

Table 12 – Time of first victim evacuation

The group H scored worse performance than the group L. The average score was 7 for group H and 10 for group L and this difference was statistically significant ($p = 0.016$) (Tab. 13).

Group	Average performance indicator point	p value
High Stress	7	0,016
Low Stress	10	

Table 13 – Average Performance Indicator score

	Average Group L	Average Group H
Tabard Indicating Medical and Ambulance Incident Officer	2	2
First Report to Dispatch Center	1,667	1,444
Correct Content of First Report: METHANE	1,500	1,222
Formulate Guidelines for Response	1,417	0,889
Liaison with Fire and Police Officers on the Scene	1,833	1,222
Second Report to C&C Center	1,167	1,222
Correct Content of Second Report: First Patient Evacuated	1,091	1,000
Establishing Level of Medical Ambition	1,091	0,444
First Patient Evacuated	1,000	0,375

Table 14 - Detailed performance indicator score

The high stress group had a significant decrease in visual and perceptual memory after the simulation. This decrease was statistically significant about the memory on the presence of developmental risks ($p = 0.013$) and about the presence of other rescue teams on the scene ($p = 0.007$). (Tab. 16)

Regarding memory on the triaged victims, there are no statistically significant differences between the two groups with the exception of the memory on the triage of victims with code yellow (p = 0.021). (Tab. 15)

Triage memory										
	Number of triaged victims		Red code assigned		Yellow code assigned		Green code assigned		Black code assigned	
Group	H	L	H	L	H	L	H	L	H	L
Average remembered	21,535	22,128	4,558	4,522	6,818	7,609	7,907	7,930	2,512	2,778
Average Done	23,023	26,646	4,591	4,917	6,977	9,542	9,318	9,625	2,136	2,563
Difference (remembered - done)	-1,488	-4,518	-0,033	-0,395	-0,159	-1,933	-1,411	-1,695	0,375	0,215
p value	0,311		0,69		0,021		0,725		0,196	

Table 15 – Memory and triage

Scene memory				
	Presence of evolutive risk		Presence of other rescue team	
Group	H	L	H	L
Average remembered	0,681	0,895	1,705	1,938
Correct	1,000	1,000	2,000	2,000
Difference (remembered - done)	-0,319	-0,105	-0,295	-0,063
p value	0,013		0,007	

Table 16 – Memory and Risk at scene

4.5. Discussion

In this study, the physiological stress response and the medical disaster response performance in medical students during two different simulation scenarios with diverse degree of stress were analyzed.

When exposed to acute stressors during a simulated mass casualty event medical students demonstrated an increase anxiety and physiological stress responses as measured by systolic blood pressure. These stress responses were accompanied by impairments in important aspects of performance as revealed by a decrease in speed to complete triage and to evacuate the first victim, and in the total score of performance indicator. These findings might indicate that clinical and management performances in disasters are vulnerable to stress.

Analyzing the results in details, the significant increase of STAI scoring in the high stress level group is a very important issue, since it demonstrates a real increase of the stress level that students perceive in that kind of scenario. This result is in line with other studies on the importance of perceived stress in different scenarios in the context of health care.[77]

The rise of stress level felt by the students reflects the increase of some vital signs, for example the systolic blood pressure in group H and a significant increase in respiratory rate. These facts lead to the consideration that, exposing students to a high stress level test, both the physical and psychological measures are influenced by stress. Performance indicator score confirmed that also the performances in managing the scene are susceptible to stress. There have been registered a significant decrease in students' performance in all the field action when subjected to a high stress level test, influencing also role managing, coordination in the field, relations with dispatch center, victims management and the interface between many forces present on the scene (police and firemen)

All this had naturally a great influence on the management of the victims.[10]

Although the students demonstrated no impairments in their ability to accurately assign triage color code according to the severity of victims as shown by the global triage accuracy, there was a difference in the number of total triaged victims in the high stress situation.

This has a great importance: the ability to move on the scene, and examine it objectively keeping contact with every victim, is the base of a mass casualty good managing. Even though every student demonstrated a good level of accuracy in low stress level, when pressure grows their precision get significantly lower. We also examined data upon under and over triage: basing on the low number of victims over/under triaged, we noticed a great accuracy in both groups. This may be due to the presence of a simple and universally acknowledged system for triage (START), which is extremely helpful in stressful situations, such as mass casualties, mainly because it helps maintaining rationality, concentration and avoiding accuracy errors. A straight, plain way of thinking leads to an appropriate use of resources, which are constantly insufficient, avoiding wastages but it is not always so simple. The strong desire to save the highest number of people, or simply human compassion, can lead to the misunderstanding of the severity of the patient, overestimating his symptoms, and put medical resources out of balance. It is certainly a terrible mistake, since precious resources are intended to cure subjects that have no real need, and are subtracted from patients in real need. It is unfortunately quite a common situation in mass casualties management.[78]

These findings indicate that clinical performances are vulnerable to stress.

In addition to the impaired performance during the high stress scenario, the students were impaired in their ability to accurately recall information from the higher stress scenarios.

A significant reduction of students' memory consolidation was observed when subjected to stressful tests. Filling the questionnaire, students submitted to a high stress level test had many difficulties while reconstructing the facts, especially remembering the presence or not of evolutive risks and the presence or not of other forces on the field (firemen or police). These results showed important information regarding the effects of stress on memory. Following stressful events, it appears that individuals are not more susceptible to forgetting or failing to remember things or events that did occur.

This has a great impact in mass casualties and disasters because a physician (or other medical operators on the scene) always has to report the evolution of the situation to senior or subjected operators. The findings from this study suggest that the information included may be inaccurate after high-stress calls. If informations are not correctly or completely transmitted, we encounter the great risk of the worsening of the general outcome of the situation. This highlights the importance of developing programs and training interventions aimed at supporting and preparing emergency workers to face stressful events as major incidents. Currently, training of health professionals is primarily focused on equipping them with the competences, skills and knowledge required to manage major incidents. There is less focus on the emotional or psychological preparation for acute events.[79]

However, the results from this study indicate that skills and knowledge can be impaired significantly in critical events where health care providers exhibit stress responses.

Disaster educators should consider complementary training aimed at the minimization or management of stress responses.

4.6. Limitations

Limitations of this study can be related to the parameters used for stress response measurement. Blood pressure and heart rate have been successfully used for this purpose[80]; they are inexpensive and non-invasive indicators, but there are more sensitive markers of stress response, like salivary cortisol and urinary catecholamine excretion; however, these are more expensive and slightly invasive markers. Nevertheless, since this study showed interesting data according to the simulation-related stress response, this could be a possible improvement for the collection of more precise data.

Another limitation of this study is its inability to register transient variations in physiological parameters; even high peaks of stress might have been missed if they lasted for few moments and were not present at the time of the measurement. Therefore, a possible improvement in further studies could be the use of continuous blood pressure and heart rate recording devices.

A limitation probably pointed out from this study could be related to the setting of the virtual reality simulation; in order to reach a higher reality, and probably induct an actual stress response, it should probably be more immersive, and include a wide 360° projection of the scenario, sounds, noises and other stressors.

4.7. Conclusions

In this study, medical students exposed to a high stress mass casualty virtual simulation demonstrated a real perception of this stress in STAI test and increased physiological parameters in stress response, precisely systolic blood pressure and respiratory rate.

Stress also causes an important decrement of performance with a slowdown evacuation of the victims from the scene.

Their triage accuracy was not impaired by the stress response but during high stress simulation, fewer victims were triaged.

Also memory is compromised in a high stress situation. We have in fact demonstrated that is high “pressure” situation, there is an important decrement of memory recall.

This study stands out as one of the few researches about stress reactivity in a disaster medicine simulation environment.

The results of this study highlights the importance to perform further analysis in this field, in order to create a more immersive environment to expose healthcare providers to realistic stressful situations and to better understand different traits of various simulation models.

5. Study 4

5.1. Background

As a World Health Organization (WHO) Level 3 Public Health Emergency of International Concern, the Ebola epidemic requires an unprecedented coordinated international response to contain and control the lethal virus. This response includes effective pre-deployment education and training of an expatriate health care workforce called to fill the requirements of foreign medical teams. Clinicians feel uneasy about treating a highly transmissible infection for which there is no vaccine, for which there is no specific therapy, and which is highly lethal. Unwillingness to respond to infectious emergencies, such as pandemic influenza, is already well documented. In this regard, prevent preparation and training plays a determinant role.[1] Unfortunately, secondary infections among indigenous and expatriate health care workers is extremely high, which highlights the inadequate infection control practices and protections in many treatment centers.[2] Being prepared requires the attainment of several operationallevel public health skills that are beyond the experience and knowledge base of most practitioners not familiar with public health emergencies arising from infectious disease outbreaks. This suggests that a concerted effort must be made to reaching a level of operational public health professionalization through more effective education and training.[3] Unfortunately, such training is expensive and may be unrealistic in content and experience outside the affected country. If such hurdles are overcome, it is suggested that there would be a greater willingness of health care workers to engage in direct care delivery.

5.2. Current training initiatives

For obvious reasons, the international medical community is very sensitive to the development of effective pre-deployment training programs to ensure the adequate safety of humanitarian workers. WHO and Médecins Sans Frontières (MSF) have worked to create standard training center units and to multiply these units across the world to enlarge the number of workers equipped through advanced knowledge and operational skills. To understand the working principles and protocols currently used in a generic Ebola treatment center (ETC) or Ebola treatment unit (ETU), these organizations have built mock ETCs and ETUs to better expose humanitarian workers to a realistic environment. Scheduled single training courses are designed to improve technical skills in the application of personal protective equipment (PPE) in unfamiliar settings. However, these courses are challenging to organize, standardize, and fund and may be disruptive to already compromised clinical settings. Moreover, little is known about the assessment measures presently used during these training sessions, because there is no validated way to measure the humanitarian workers' learning process or operational understanding of specific treatment protocols. A rigorous evaluation methodology designed to detect potential errors and to verify the technical skills acquired by the participant (e.g., ability to apply and remove the PPE) is crucial for both the safety and confidence of humanitarian workers.

5.3. Virtual reality simulation

Simulation training is a recognized efficient and effective cornerstone of modern medical education and training, with a strong potential for generating positive learning outcomes.[4] With increasing frequency, simulation-based medical education is being used for formative and summative evaluations including showing the efficacy of live simulation in the assessment of technical skills after a disaster medicine training session.[5] Moreover, virtual reality (VR) simulation has been shown to be a valid, clinically appropriate, and cost-effective training method by achieving a quality degree of projected realism.[5] As such, VR simulation has uniquely allowed health care providers and humanitarian workers to train for various emergency and disaster scenarios. Currently, the Research Center in Emergency and Disaster Medicine and Computer Science applied to Medical Practice (CRIMEDIM) is in partnership with Save the Children International (SCI) and their Ebola response team in replicating one of SCI's ETCs. Staff are walked through a VR version of the ETC, which allows them to familiarize themselves with the high-risk environment and to practice complex protocols "in place" at the actual ETC setting.

Figure 11 illustrates the VR model in action. The VR model includes an aerial view that allows the simulation master to explain the layout and site plan of the ETC and a first-person perspective that is controlled by using a "games controller."

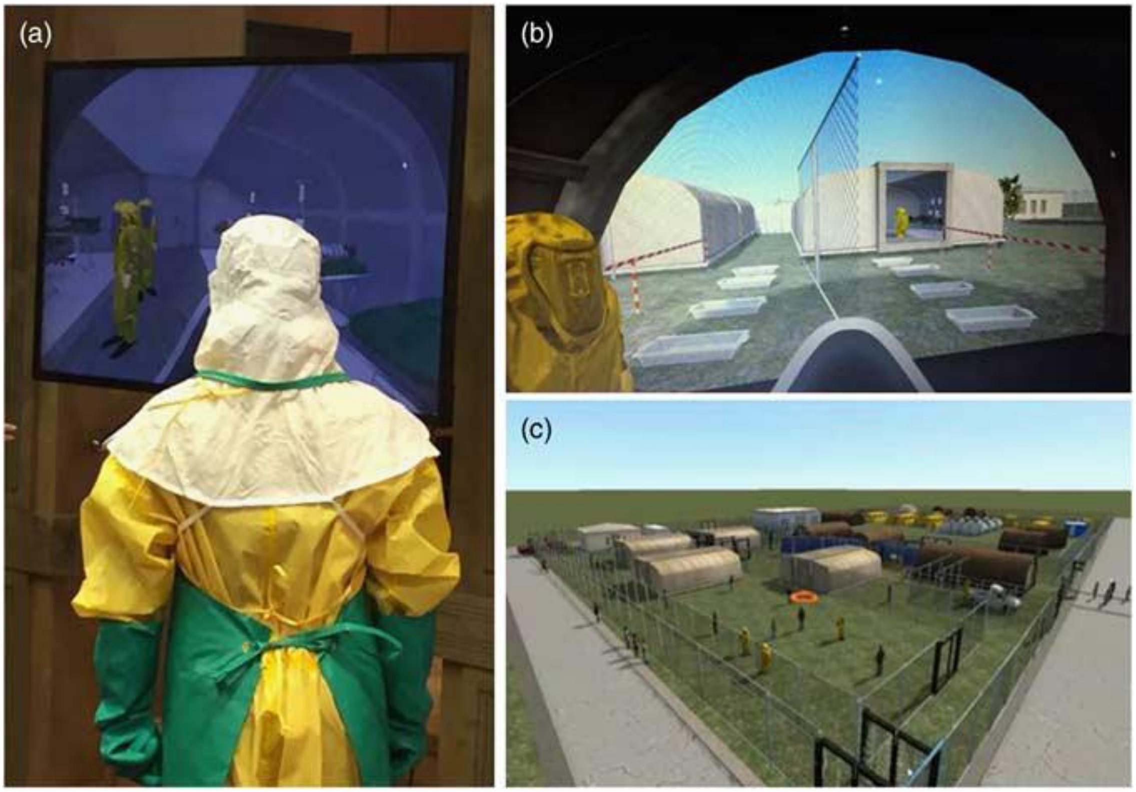

Figure 11 - Pilot Hybrid Simulation at a Save the Children International Pre-deployment Induction Training Program. (a) Health care worker during a pre-deployment training simulation; (b) view of trainee walking through the virtualized ETC; (c) aerial view of the virtual reality version of the ETC.

The trainee takes a virtual walk through the intricacies of the ETC while receiving immediate oversight training by experienced educators. The achievable learning objectives and the time needed to accomplish them are listed in Table 1. CRIMEDIM is additionally capitalizing on the potentialities of the VR simulation model by running hybrid skills training exercises through its integration with mannequins, tasktrainers, and actual equipment. The hybrid approach can effectively raise the educational target level from a level of understanding to a level of training. By immersion in a highly realistic environment through the visualization of the virtual ETC on a screen or on the wall, the trainees are asked to accomplish competency-based specific tasks and to hone precise operational skill sets by using real equipment and performing procedures on mannequins. These skill sets focus on the use of PPE, peripheral venous cannulation, isolated blood drawing, cleaning and bathing the patient, the removal of bodily remains, and the safe disposal of dead bodies. It is anticipated that by increasing the levels of simulation fidelity, this innovative combination of tools with procedures will lead to a positive impact on the learning outcomes by facilitating greater knowledge gain and procedural skill acquisition. Furthermore, the hybrid simulation model provides the trainees the opportunity to integrate different evaluation methodologies, such as web-based assessment tools customized to the protocols used, the use of fluorescent nontoxic liquid or powder that glows under ultraviolet light to measure the degree of exposure by photographing the amount of fluorescence present on the worker’s skin,[6] and video cameras for educational replay and educational analysis. These tools allow for valid delivery and detailed feedback immediately during and after the exercise by the definitive detection of small but critical breaches in protections and protocols that have led to safety violations and potential transmission of the virus. Lastly, this simulation-based training is also intended to deliver team training exercises and to run emergency case scenarios in order to develop transversal skills, such as problem-solving, critical thinking, and the ability to work in teams. In detail, the VR scenario allows several trainees to walk around in the same virtual ETC; to communicate and cooperate, like they would in real life; and to analyze and contain the event and activate procedures. A key benefit is that VR training is cost-effective and can be conducted in the field. In fact, the VR scenario requires only a common laptop, on which the XVR Software (E-Semble, Delft, the Netherlands) has been previously installed, along with a joypad to allow users to walk around in the simulated reality and to interact with the virtual objects. Both the software and the scenario are small files that can be easily transferred from one computer to another. A training unit to run the hybrid scenarios could be easily implemented in any room or in any tent equipped with a number of laptops equal to the number of trainees to train at the same time. Additionally, once a trainer has worked with the system, he or she can train others. The location flexibility of the training means that protocol can be easily standardized and coordinated across regions and repeated as many times as necessary without added expense.

5.4. Limitations

Limitations of the VR system have been identified. The hybrid model might be difficult in training a large group of people in a short period of time, because each trainee will need an individual computer station to ensure the effectiveness of the VR simulation. Moreover, the version of the XVR Software used to replicate the ETC has a library of virtual items with a finite number of objects and environments.

5.5. Conclusions

VR training is designed to increase staff safety and create a safe and realistic environment in which trainees can gain realistic basic and advanced skills. The goals are to accomplish complex task-performance behaviors, many of which carry life-or-death risks, and receive vital yet objective feedback before taking on the risk of working within the treatment center itself. While this is the first training of its kind, SCI plans to immediately roll out the training to staff in Sierra Leone, Liberia, and Guinea. Additionally, hybrid simulation training incites an even more realistic and effective educational opportunity. Hybrid simulation training provides for “virtual exposure” to new operational public health skills essential for infection control and Ebola treatment management while reducing the exposure rate among health care providers. This awareness can instill confidence and greater willingness to engage in care delivery and strengthen operational public health skills for controlling and containing the outbreak.

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