Interactive Virtual Reality Real-Time Avatar for Military Rehabilitation in the Canadian Forces

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ABSTRACT

Introduction/Relevance: The rehabilitation of injured and seriously injured military personnel and their return to function is a challenge faced by all NATO partners. Innovative methods for assessment and intervention are required to meet this challenge. This presentation highlights the first stages of a proof of principle project for the development of a virtual reality (VR) real-time interactive avatar system to optimize the training and assessment in order to improve return to function of military personnel of the Canadian Forces (CF).

Rationale: For the military health care providers, knowing how best to help an injured soldier and deciding whether or when the soldier is ready to safely and efficiently go back to the rigors of combat is a significant challenge. This is especially true for two highly prevalent military injuries, chronic non-specific low back pain (CNSLBP) and mild traumatic brain injury (mTBI), for which current assessment tools and treatment modalities are limited and often not effective. Therefore, alternatives to conventional management of these injuries need to be developed. Virtual Reality (VR) technology now provides researchers and clinicians with the ability to alter the perception of one’s own body and its movements with controlled Virtual Environments (VEs) with and without a military context. The objective of this project is to develop a generic avatar that can be controlled from both 1st person (mimicking the person) and 3rd person (another individual interacting with the person) perspectives within general military based virtual environments (VEs).

Methods: The avatar developed here, based on an initial prototype from Motek Medical (Amsterdam, Netherlands), was interactively controlled through subject movement using a motion capture system (Vicon, Oxford, UK) consisting of nine infrared cameras and 41 reflecting markers placed on the entire body. Motion data were sent to a computer running software (Caren’s D-Flow, Motek Medical) to map, in real time, subject movement onto a three-dimensional mesh representing the avatar. This software also controlled the VE and managed any user-defined interactions between the avatar and the VE.

Results: The generic avatar system has been developed to support two configurations: a first-person avatar (FPA) and a third-person avatar (TPA). The FPA is interactively controlled by the subject in real time in the VE, and the subject can see its avatar from varying distances using a head-mounted display (HMD) or screen projection. The viewing distances range from the avatar being positioned within the subject to provide vision of one’s own limb movements through the HMD, to allowing the subject to view him/herself from any distance. Movements can also be scaled to exaggerate one’s real motion. In the TPA configuration, the avatar system is used to record a library of predefined movements that can be used to control avatars that react to the subject’s movements.

Conclusions: At this first development stage, we have been able to show how, from a military rehabilitation perspective, the avatar system can be used for more ecological and innovative means of assessing and treating military injuries such as CNSLBP and mTBI. More specifically, we have developed a prototype VR avatar system with future potential to enhance the Common Military Task Fitness Evaluation, which is the gold standard of the Universality of services of the CF and more sensitive indicators of dysfunction following mTBI.
1.0 INTRODUCTION
The new conflicts that Canada and NATO are involved in are very demanding and require ever-greater physical and mental efforts from our soldiers. The tempo of Ops has also significantly increased leaving very short periods of rest for several Canadian Forces (CF) members between two ROTOs. As a direct result, the number and complexity of injuries and health conditions in both combat and in garrison has significantly increased\(^1,2,3\), which adds to the pressure on health care providers to promote the rapid recovery of soldiers to their required level of operational readiness as soon as possible.

Two specific injuries suffered both in combat and during training and that are of increasing concern to the CF are chronic non-specific low back pain (CNSLBP) and mild traumatic brain injury (mTBI or concussion). These two health conditions that incapacitate military personnel both in garrison and in theatre, affect operational readiness and mission success, and specifically challenge the CF Health Services (CFHS) with respect to assessment, optimal intervention and prediction of recovery.

Low back pain is the primary chronic complaint of approximately 20% of regular and 8% of reserve Canadian military force members. Pain control is essential to enable optimal rehabilitation, as pain interferes with motor performance and motor learning. CF members with chronic pain often develop a pain-related fear of movement (kinesiophobia) that may become very difficult to treat resulting in a high level of disability.\(^6,7\) To treat CNSLBP, clinical guidelines recommend cognitive therapy to modify maladaptive thoughts as well as exercise therapy to improve various aspects of fitness.\(^8,9\) Research demonstrates that targeting of modifiable thoughts and behaviours in combination with exercise can lead to improved outcomes in patients with CNSLBP.\(^10,11,12,13\) However, considering the nature of the physical and mental demands that CF members must meet to prepare for the rigors of combat, it is not possible to reproduce, in a clinical setting, a well-controlled operational military environment that provides progressive exposure while integrating components of cognitive therapy and physical exercises. An innovative and motivational means of providing such combined therapy to CF members is the use of Virtual Reality (VR) technology. For example, with VR feedback about patients movements can be manipulated to increase their confidence in their ability to move without increasing pain.

Traumatic brain injury (TBI) is obviously different from CNSLBP, but also presents a great challenge to evaluate and treat. A majority of TBI cases are mild.\(^14\) There is some controversy about the prevalence of mTBI or concussion in a military population with estimates ranging from being a significant injury in the US\(^15\) to a problem but to a lesser extent in the UK.\(^16\) Yet, mild TBI or concussion is a condition that is believed to be underestimated and even misdiagnosed\(^17,18\) in the general public and thus probably still difficult to judge in the CF where it has only recently started to be tracked. Mild TBI has become a trademark of the wars in Afghanistan and Iraq due to the high rate of exposure to roadside bombs that can jar the brain and cause long-term health problems. CF soldiers are exposed to Improvised Explosive Devices (IEDs) and most soldiers are reporting a mild traumatic injury mTBI as the result of blast exposure, with other causes due to falls, fragment wounds, motor vehicle accidents or bullet penetration. Of all cases of mTBI diagnosed, about 19% of veterans\(^19\) are believed to have suffered concussions. Given new research that is showing that even in the absence of symptoms (such as headaches, nausea, dizziness, etc) and other sequelae noted from traditional testing, residual problems in cognition\(^20\) and executive functioning for mobility\(^11,22\) persist for a long time. The number of cases of mTBI in military personal and veterans is thus likely much greater than we believe. As such, we would benefit from a better way to objectively measure physical and mental integrity and thus make better decisions about severity and deployability.

The rehabilitation of the injured soldier requires that their physical and mental health be optimized to ensure a maximal functional outcome. For the CF health care providers, knowing how best to help an injured soldier and deciding when the soldier is ready to safely and efficiently go back to the rigors of training and combat remains a significant challenge. The main issue affecting return to function in CF personnel, regardless of the injury, is their physical mobility (military personnel must be very mobile).
Mobility is directly related to sensory, motor and cognitive factors. The two injuries chosen as focus for this project encompass these factors and present obstacles to optimal recovery. They are thus logical choices to target for the development of robust and powerful tools to enable improved assessments and optimal therapeutic approaches to promote combat-ready recovery.

While VR has begun to be explored for the rehabilitation of persons post stroke, with vestibular dysfunction or chronic pain, it is still a relatively young technology. For TBI, VR has been used for cognitive training of activities of daily living (ADLs) as a unique test of attention by directly controlling distractions, and even to differentiate attentional deficits including for military personnel. Although using a different technique of projecting the person into a scene, Thornton et al. have shown similar results for balance training following a TBI. Little, however, has been developed for the assessment of mTBI and nothing is yet available for populations with CNSLBP.

The integration of avatars, although used extensively in gaming and arts, is still rare in rehabilitation, and has just started to emerge in the VR rehabilitation sites of the CF or NATO. Rizzo et al. noted the advantage of integrating these “virtual humans” into VEs in order to better serve training, assessment and rehabilitation. Some studies have included avatars of body parts to create better immersion such as for upper limb control following TBI and training after amputation. Yet, only one study, to our knowledge, has looked at using avatars to train locomotor-like behaviour in a manner similar to that proposed here. Koritnik et al. recently created a protocol in which healthy subjects stepped in place using a “virtual mirror” in which subjects saw their own movements superimposed onto a third person avatar. Haptic feedback from a robotic exoskeleton gait trainer was also used. It was concluded that although combined haptic and visual feedback was the best, visual feedback was better than just providing a third person view. Certainly the type of haptic feedback explored would be difficult to apply during full walking or other body displacement proposed here. For low back pain, the use of avatars for pain rehabilitation has not to our knowledge been used.

From a military rehabilitation perspective, avatars will open the door for more ecological and innovative means of assessing task fitness, thus enhancing the Common Military Task Fitness Evaluation (CMTFE). The use of avatars also has the potential of providing the desired intense and challenging military rehabilitation for today’s soldier and also leads to more realistic and sensitive evaluations of combined physical and mental abilities. The objective of this study is to develop a generic avatar with basic movement and expressive capabilities that can be controlled from both 1st person (mimicking the person) and 3rd person (another individual interacting with the person) perspectives within general military based virtual environments (VEs).
2.0 METHODS
2.1 Materials
The “Virtual Reality Real-Time Interactive Avatar (VRai) System” consists of four main components: 1) motion capture (mocap) system, 2) 3D development environment (DE), 3) interaction and rendering system (IRS), 4) projection system. Figure 1 below illustrates the VRai system that was used.

![Diagram of VRai System](image)

**Figure 1 – Virtual Reality Avatar Interaction System**

2.2 Specific Procedures
**Developing the generic avatar and VEs:**
The generic versatile avatar was developed to be controlled with respect to its movements to allow: a) real-time mimicry of one’s recorded movements to provide first-person perspectives (first person avatar (FPA)); and b) the creation of an autonomous avatar with human-like physical and social interactions within ecological environments (third person avatar (TPA)). The FPA is interactively controlled by the subject in real time in the virtual scene. It is programmed to produce the same lower and upper limb, trunk, and head movements of the subject in real time, and the subject is able to see his/her avatar from varying distances using the HMD or a normal screen. In this way, the distance of the avatar can be varied from being part of the person himself/herself (allowing the person to virtually view his/her body parts) to any distance ahead (allowing the person to view his/herself interacting with the VE). The TPA embeds different pre-recorded movements and animations that can interactively respond to external cues or subject’s movements.

The mocap system (Vicon, Oxford, UK) is used to acquire a subject’s movements, that are then mapped to an avatar in real time by the IRS. The system consists of 8 or 9 infrared cameras (Vicon’s Bonita or T-series) connected to a computer running Vicon’s Nexus acquisition software. The movements are captured using a set of 41 markers placed on the subject’s entire body (Figure 2a). The placement of the markers is determined by a Vicon Skeleton Template (VST; Figure 2b) file defining segment positions and orientations and mapping them onto the skeleton of the person based on a previous calibration procedure. Segment positions and orientations are then sent to the IRS through a local network.
Figure 2. Marker placements (n=41; 2A) used to capture movements and Vicon Skeleton Template (VST; 2B).

This segment information is also used to create the animation rig of the first person avatar model. The 3D modeling software, Softimage (Autodesk, San Rafael, CA, USA) or Blender (Blender Foundation, Amsterdam, The Netherlands), is used to model, and provide texture for, the virtual scenes and the avatars as well as to create predefined animations for different objects in the scenes. All models, animations and rigs are converted to the Ogre (Object-Oriented Graphics Rendering Engine, ogre3d.org) format to be used in the IRS.

The IRS consists of 5 computers running D-Flow™ (Motek Medical, Amsterdam, The Netherlands) in a master-slave configuration. The master computer receives the mocap data and maps it to the avatar rig so that the avatar can follow the subject’s movements in real time. The master also manages user-defined interaction between the avatar and any object in the scene, and sends the processed information to the 4 slave computers whose only task is to render the scene for the projection system. VEs can be projected in a head-mounted display (HMD) or onto a normal (silver-coated) screen using 2 slave computers to drive 2 projectors, one for each eye. For the latter case, polarized filters are used in front of the projectors and the images are superimposed on the screen. Wearing polarized glasses, the subjects then perceive a 3D image. Depending on the complexity of the scene, the IRS runs at refresh rates ranging from 30 to 60 Hz.

3.0 DATA COLLECTION & ANALYSIS
To provide evidence that avatars can be used and integrated into the military based VEs, we measured avatar movement fluidity in response to a person’s movements (1st and 3rd person avatars), the refresh rates of VEs and the overall quality of images. This is important to allow us to create realistic protocols that will later be applied to specific cohorts of subjects.

General behavioural responses in the VEs were first described with respect to quality of movements, scaling of segment displacements and range of motion, and changes in dependent variables describing posture and mobility over time (e.g., speed of movement and angular displacements).
4.0 RESULTS
The present work is the first step of a proof of principle study that will allow us to establish an innovative VR system with avatars that has wide application. This is particularly evident by its application to two different but important types of injuries of military personnel.

4.1 First Person Avatar
A military FPA was created (Figure 3a). We are now working on the ability to modify the morphology of the avatar in accordance with the subject. For this FPA, we have implemented two major functions related to training real-time movements. First the avatar is able to grab and move virtual objects as required in military training tasks (Figure 3b). Through collision detection and preservation of the relative position of the objects with respect to the others, we can maintain very good movement fluidity. The second function is the capacity to scale the movements of the avatar with respect to the patient’s actual movements. The mocap system provides rotational movement data for each segment of the skeleton. These rotations can then be scaled such that the subject will see his/her movements either amplified or reduced. This function will be specifically important for training patients with fear of pain due to CNSLBP. The subject movements will be amplified to provide the impression of a greater range of motion with reduced pain.

Figure 3. Military avatar in a calibration position (3A) and First Person Avatar (FPA) from a distance in action in his virtual environment (3B).

4.2 Third Person Avatar
The TPA is earlier in its development at this point. A generic mobile avatar has been developed using pre-defined movements. However, work is continuing to program the TPA to react to the subject’s movements creating greater interactivity and more realistic scenarios. In this way, we will use these complex but ecological environments to assess subtle executive function deficits following mTBI.

4.3 Virtual Scenes
To allow the use of avatars in the development of more ecological and innovative means of assessing and treating CNSLBP and mTBI, different virtual scenes were created. A military scene resembling a village located in a desert zone can be used to mimic the specific tasks of the CMTFE, such as sand bag handling, to be performed by persons with CNSLBP. In the sand bag-handling task, the subject is placed in the centre of the village between a pallet of sand bags and a military truck ready to be loaded (Figure 4a). The task consists of moving the sand bags, one by one, from the starting point (floor pallet) to the loading zone (the truck box trailer), which determines the height of the virtual load, as shown in Figure 4b.
For assessing persons with mTBI, the heart of this same village has visual and auditory stimuli such as military vehicles, and civilians and military persons that can be combined with the TPA to create both distractions and multi-tasking.

Figure 4. Military FPA performing a simulated sand bag-handling task. A) patient sees themselves between a pallet of sand bags and a military truck ready to be loaded; B) example of the loading zone (the truck box trailer) determining the height of the virtual load; C) Point of view with the eyes of the FPA and patient aligned.
A second scene for assessing mTBI has also been created (Figure 5). It consists of a beach with nearby houses that can be converted from a civilian into a military context. The subject walks through this environment in both contexts. The civilian context serves as the control environment for the experiment. The military context includes the same kind of visual and auditory stimuli as in the village to create distraction.

Figure 5. Second scene created for assessing mTBI consisting of a beach (5A) with nearby houses (5B) that can be converted from a civilian into a military context.

5.0 DISCUSSION

The VRai system presented in this paper is a platform that we will continue to develop for the rehabilitation of injured soldiers with both physical and psychological impairments. This work has already met its first objective of developing generic avatars with a military rehabilitation context specific to the Canadian Forces. Preliminary results are showing the VRai system’s feasibility and flexibility and has opened the door for projects related to pain rehabilitation for CLBP, the assessment of executive function following mTBI and even to providing more sophisticated and tailored ecological and innovative means of
assessing overall task fitness and readiness (thus enhancing the Common Military Task Fitness Evaluation).

The scalable FPA has been successfully tested proving its potential have been to be applied in innovative protocols for rehabilitating military members with kinesiophobia interfering with their ability to return to duty. Work is continuing on the choice of specific parameters for scaling (segment specific amplitudes, timing in tasks, etc) to allow the patient to optimally benefit from such real time experience to gain more movement confidence.

The TPA is still in its early stages and future work will concentrate on giving it more intelligence for human interaction as well as potential facial expression for greater social interaction. This will create VE that are more realistically complex and provide a better means for assessing functional capacity and any residual motor-psycho-social sequel.

Virtual military scenes have been created and synchronized to patient movements for both the FPA and TPA contexts. For the TPA, scenes are presently static with simple distracters. Future scenes will progress in complexity from basic walking around static objects with no distractions or stressors to demanding greater executive functioning with interactive avatars. The most complex scenes will also introduce additional stress within a military context by adding ambient features to the environment related to combat situations with extraneous vehicle (terrestrial and air) traffic, unpredictable obstacles on the road, explosions, and simulated changes of weather conditions.

6.0 LIMITATIONS
The present results are preliminary. Further work is required to show the extent to which the current platform can provide the desired level of intensity and challenge for the rehabilitation of the targeted injuries experienced by today’s soldier. Cost in this development stage is high and there is a need for highly trained personnel and technical assistance to operate the system. However, these factors will improve as such technology develops to become more automated and cheaper. Thus, cost-efficiency cannot be measured at this time.

7.0 CONCLUSION
In this study, we have been able to show how, from a military rehabilitation perspective, the avatar system offers a potential for more ecological and innovative assessments and rehabilitation approaches for treating military injuries such as CNSLBP and mTBI. More specifically, we have developed a prototype VR avatar system with future potential to enhance the Common Military Task Fitness Evaluation, which is the gold standard of the Universality of services of the CF as well as a more sensitive assessment of mTBI.

First person avatars within VR protocols provide a means of enhancing military rehabilitation related to mobility following low back pain by incorporating innovative perceptual tools such as an avatar trainer based on the person’s own movements, not possible to incorporate into more conventional rehabilitation. VR allows us to address specific biomechanical requirements related to the CMTFE such as lifting, handling, and carrying loads. For their part, third person avatars interacting with the patient provide more ecological and innovative means of assessing motor and cognitive functions that are more sensitive than traditional tests to reveal impairments following mild traumatic brain injury.

The use of avatars also has the potential of providing more intense and challenging military rehabilitation for today’s soldier and also lead to more realistic and sensitive evaluations of combined physical and mental abilities.

Our future work will be to develop specific protocols with the existing VR platforms related to the assessment and rehabilitation of functional limits in mobility related to chronic pain or cognitive factors.
and to test and show proof of principle of the protocols using the two targeted cohorts in CF members.

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9.0 REFERENCES


