Manitoba WCB Research and Workplace Innovation Program Final Report "Serious games to decrease injury in the fire service by training safer movement patterns and decision making skills: development and piloting"

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1.0 Executive summary of the project report

1.1 Introduction

This report summarizes the methodology, findings and knowledge transfer of the 2011 RWIP proposal, "Serious games to decrease injury in the fire service by training safer movement patterns and decision making skills: development and piloting." The University of Ontario Institute of Technology acknowledges the financial support of the Workers Compensation Board of Manitoba through the Research and Workplace Innovation Programme in the preparation of this project. However, the content of the report and/or resource responsibility of the University of Ontario Institute of Technology and the views expressed in it are those of the authors.

Firefighters have high injury rates. Musculoskeletal injuries due to lifting, twisting and bending, often in awkward positions while under mental and physical strain contribute greatly to these high rates with up to 1/3 of these injuries being low back injuries. Additionally, 1/3 of firefighter injuries are due to contact or exposure to fire with many being preventable by better decision making. Safe working limits while wearing fire protective clothing in hot/ humid environments exist, but it's unclear whether the increased physiological strain associated with use of such clothing alters cognitive function at an incident scene and impairs decision making. This specific aims of this project developed and test two serious game modules focusing on these two areas of significant health risks to firefighters: i) safe lifting and ii) decision-making.

The project incorporated known principles from the motor learning literature in the development of serious games which are realistic and engaging. The idea is that by practicing movements and decision making while under similar stressful situations as encountered in their job, that both movement and decision making will become more robust under stress.

The specific objectives of this research program were to:

1. Acquire information from subject matter experts and focus groups regarding the nature of lifting movements and decision making required in the fire hall and on the fire ground,
2. Determine the effects of heat stress on cognitive function in firefighters using a 'traditional' neuropsychological assessment battery,
3. Develop a serious game that simulates the decisions that are required of firefighters in order to assess cognitive function while under heat stress,
4. Develop different levels of difficulty for the decision-making serious game for assessment purposes, and

5. Develop a serious game that would assess the movement patterns of firefighters during various lifting techniques to determine the level of risk associated

1.2 Methodology

Serious games are engaging simulations adapted for teaching and/or training. This project developed two serious game modules focusing on two areas of significant health risks to firefighters: i) safe lifting and ii) cognitive decision making. The game will provide firefighters with a virtual safe working environment allowing for proper techniques to be visualized and practiced The developed game provides a means of measuring and training decision making skills in a physiologically challenging environment.

1.2.1 Objective 1- Consultation with Subject Matter Experts

Focus groups, subject matter experts, and ergonomic evaluations were used to determine which lifting tasks performed by firefighters represent the greatest risk for back injury as well as which decision making scenarios to incorporate in the initial version of the game. The decision-making game module was qualitatively assessed by senior training personnel and active firefighters at Toronto Fire Services and Winnipeg Fire and Paramedic Services to ensure they meet current training needs and are engaging. The information gathered from incumbent firefighters provided evidence that the decision-making scenario captured many of the tasks that would be required of a firefighter at a two-storey residential fire. The development of the low back lifting game required technical expertise in modifying the Microsoft Kinect™ which provided a breakthrough in August 2015 as to the most effective and efficient procedure to gather information from the user (i.e. person performing the lift).

1.2.2. Objective 2-Impact of Heat Stress on Cognitive Function

In order to obtain information on the effects of exercise-induced heat stress on cognitive function, an exercise protocol was developed using a treadmill to elicit increasing rates of core body temperature to determine if there is a critical point where cognition is impaired. The study utilized a work to rest ratio and the independent variable of core body temperature to determine at which points participants would undergo cognitive assessment. In general, participants exercised until obtaining core body temperatures of 37.8, 38.5, and 39.0 °C before undergoing the cognitive assessment battery. Participants also performed the battery before and after exercise, and following an active cooling recovery protocol with hands and forearms submerged in 15-20 °C water to reduce core body temperature to 37.8°C.

1.2.3 Objective 3-Development of serious game and testing in hot environment

Once the initial version of the decision-making serious game was completed, a similar protocol to section *1.2.2 Objective 2* was conducted to elicit core body temperatures of 37.8, 38.3, and 38.5 °C. Participants played a particular scene from the decision-making game at the start of exercise, following the core body temperatures elicited above, and following the same active cooling recovery as in section *1.2.2 Objective 2.*

1.2.4 Objective 4 Game Enhancement with Additional Levels of Difficulty

Using the decision-making game developed in *1.2.3 Objective 3,* game developers modified the layout and toggled the level of 'distraction' in the game to create an easy, medium, and hard difficulty. This provided a template for versions of a training game that could be played by firefighters to simulate a two-storey residential fire which, in theory, could improve decision-making an allow it to become more automated and robust under conditional of heat stress.

1.2.5 Objective 5 Movement Assessment Game-Proof of Principle

The development of the low-back lifting game was initiated from the information acquired from the subject matter expert interviews and focus groups. The most difficult lifting tasks were determined and used as a framework to design an assessment tool using the Microsoft Kinect^{TM}. The Unity software engine was used to create the serious game while a 3D Investigator motion capture system was implemented to validate the data obtained using the serious game. The information collected by the Kinect and 3D Investigator were entered into a series of regression equations (Potvin, 1997), that were based on the National Institue of Occupational Safety and Health (NIOSH) lifting equation (Waters, Putz-Anderson, Garg, & Fine, 1993) to estimate the amount of spine compression associated with a lifting task. These values can then be used to assess the level of injury risk placed on the individual. Six participants performed 3 different lifting tasks (squat lift, stoop lift, and a lift involving twisting). Comparisons were made between the calculated spine loads from both the Kinect and 3D investigator.

1.3 Results

1.3.1 Objective 1-Consultation with Subject Matter Experts

The subject matter expert interviews and focus groups identified the top 5 most difficult lifts that occur in the fire hall and predominantly revolve around tasks on the fire truck. In addition, typical decision-making tasks were uncovered which drove the framework and storyboard for the decision-making game. The top 5 lifts (and the subsequent weight required to be lifted) were determined to be: i) lifting a bucket filled with chains weighing 130 lbs, ii) lifting a hydraulic generator weighing approximately 100 lbs, iii) lifting tool boxes weighing approximately 30lbs to 80lbs, iv) lifting auto extrication tools weighing 40lbs, and v) pushing/pulling of fire truck cabinet drawer with a push force equal to 132lbs of lift due to the 45 degree nature of the slider. (For further details see abstract in Review of Work Completed and draft article beginning in Appendix B)

1.3.2. Objective 2-Impact of Heat Stress on Cognitive Function

Data from nineteen fire fighters who completed the 30°C/50% and 35°C/50% determined that visuospatial memory and visual episodic memory were impaired when core body temperature reached a level of 38.5 °C, with additional impairments in visuospatial memory at a core body temperature of 39.0 °C. The active cooling recovery protocol was able to restore cognitive function in all measures back to initial values.

1.3.3. Objective 3- Development of serious game and testing in hot environment

The different levels of difficulty for the decision-making game can be viewed at URL: https://www.youtube.com/playlist?list=PLU97-xZpaaYYTvPBerNZCr0TxX8QVSJ13 .

Preliminary data using our first prototype of the cognitive serious game suggested that decision-making tasks similar to those made on the fire ground are not affected by heat stress in experienced firefighters. On the surface, this could be because firefighters are already highly trained to react to these decisions and may not require the same amount of cognitive resources to complete these tasks as someone who is at a novice level. However, as the game only involved a single scenario of a single level house fire, it could be that the scoring system we developed only measured the more straightforward aspects of decision-making tasks that were more robust against any negative impacts of thermal strain on cognitive function. Interestingly, following approximately twenty minutes of active cooling recovery, long term memory recall appeared to be impaired when compared to initial exercise performance, indicating that thermal strain is having an impact on cognitive function.

1.3.4. Objective 4-Game Enhancement with Additional Levels of Difficulty

The various levels of the cognitive serious game can be found at the following URL: https://www.youtube.com/playlist?list=PLU97-xZpaaYYTvPBerNZCr0TxX8QVSJ13 .

The serious game has been modified to incorporate three levels, easy, medium, and hard, that simulates increasing psychological distressors (i.e. intense smoke, increasing number of victims) that allow the user to acquire the skills as they progress through the levels.

1.3.5. Objective 5 Development of Movement Assessment Game-Proof of Principle

Results from 6 participants demonstrated that the Microsoft Kinect did a reasonable job estimating spine compression as compared to the 3D Investigator (laboratory grade motion capture system). The average calculated spine load difference between the two systems was below 400N. Squat lifts produced the closest estimates between the two systems. The twisting condition produced the greatest difference between the two systems.

1.4 Conclusions

1. There are a number of modifiable ergonomic risk factors that could decrease injury risk in firefighters. There is a clear need to institute education to modify these risk factors both in the hall and at callouts. The development of a training game to decrease injury risk will need to include training on modifying ergonomic and psychological risk factors as well as training correct movements.
2. Cognitive function decreased in firefighters at a core temperature of 38.5°C, likely due to the cognitive resources required to maintain performance being overloaded as a result of increasing task complexity and distraction due to sensory input from exercise-induced heat stress. The addition of an active cooling recovery restored cognitive function to initial levels.
3. Testing the pilot version of one scenario of the decision making game demonstrated that room search time was prolonged at 38.3°C (Cog 3), although errors did not increase. Additionally, following an active cooling recovery regimen, memory recall was impaired compared to initial performance. The prolonged search time suggests possible cognitive impairment that should be tested in the future with a more refined scoring system and more advanced scenarios.
4. Following on from *Objective 3,* additional levels of the decision-making game scenario were developed enabling a user to play through an easier scenario prior to progressing to the more difficult scenarios. The creation of these various levels of difficulty mean that the serious game technology can be employed as a training tool. Starting with the simplest scenario, recruit firefighters can learn the tasks required of a two-storey

residential fire and progress to the more difficult scenario once the basics have been acquired.

5. We have be able to, in real time, calculate spine loading and thus injury risk using the tracking coordinates from the Kinect software. Behind the scenes in the software, we have added equations from the literature to estimate spine loading and injury risk based on the Kinect's data. This suggests that the Kinect has the potential to be used as both an assessment and training tool to decrease injury risk during lifting.

2.0 Knowledge Transfer and Awards Received during Grant

The findings uncovered through the various objectives in this research project have been disseminated through national (Canadian Society for Exercise Physiology) and international conferences (American College of Sports Medicine), provincial firefighting published newspaper articles through UOIT, Oshawa This Week, the Toronto Star, and online video through UOIT's ACE facility. The following list outlines the various knowledge transfer initiatives that were conducted throughout the duration of the grant. Copies of posters presented can be found in Appendix A.

Firefighter Serious Game Knowledge Dissemination Session held at Manitoba Workers Compensation Board, Winnipeg June 8th, 2015

Meeting Facilitators: Steve Passmore (U of Manitoba) and Michael Williams-Bell (UOIT)

Virtual Presenters: Bernadette Murphy (UOIT), Silvano Mior (CMCC), Michael Holmes (UOIT)

<u>Attendees:</u>

<u>Researchers</u>

<u>University of Ontario Institute of Technology</u>

1. Michael Williams-Bell (Grant Manager)
2. Dr. Bernadette Murphy (Co Principal Investigator)-Via ON-LINE participation
3. Dr. Michael Holmes PhD (Ergonomics Research Lead)-Via ON-LINE participation

<u>Canadian Memorial Chiropractic College</u>

4. Dr. Silvano Mior DC, PhD (Qualitative Research Lead)-Via ON-LINE participation

<u>University of Manitoba</u>

5. Steven Passmore (Co Principal Investigator)

<u>United Fire Fighters of Winnipeg</u>

6. TJ Belluk (Executive Board Member)

<u>Safe Work Manitoba</u>

7. Veronica Suszynski (Portfolio Leader, Support Services)
8. *Cheryl Harvie (*Prevention Consultant)

<u>Winnipeg Fire and Paramedic</u>

9. John Lane (Chief)
10. Joe Seewald (Deputy Chief, Professional Development)
11. Lianne Mauws
12. Rolfe Kajpust
13. Ken Dobson
14. Dave Naaykens
15. Russ Morrow

WCB office

16. Agatha Chandran-Manitoba WCB
17. Bruce Cielen-Manitoba WCB
18. Cheryl Wieclawski

Office of the Fire Commissioner (Firefighting Instructors)

19. Kevin Oman
20. Chad Penner

2.1 Conference Presentations

Presenting Author: Michael Williams-Bell

1. **Canadian Society for Exercise Physiology (CSEP) Annual Conference, St. John's, NF, October 2014 (oral presentation)**
   Title: Is cognitive function impaired while working in 35°C and wearing Personal Protective Ensemble and Self-Contained Breathing Apparatus in fire fighters?
2. **Ontario Professional Fire Fighters Association (OPFFA) Conference, Toronto, ON, February, 2015 (oral presentation)** *Title: Is cognitive function impaired while working in the heat and wearing Personal Protective Ensemble and Self-Contained Breathing Apparatus in fire fighters?*
3. **American College of Sports Medicine (ACSM) Annual Conference, San Diego, CA, May, 2015 (poster presentation)**
   Title: Is Cognitive Function Impaired while Working in a Climate Chamber at 30°C in Fire Fighters?
4. **Ontario Association of Fire Chiefs (OAFC) Conference, Toronto, ON, May, 2015 (oral presentation)**
   Title: Who should understand SCBA Air Management? And Why?
5. **American College of Sports Medicine (ACSM) Annual Conference, Boston, MA, May, 2016 (thematic poster presentation)**
   Title: The effects of exercise-induced heat stress on cognitive function assessed using serious game technology.

2.2 Doctoral Awards

1. **NSERC Alexander Graham Bell Canada Graduate Scholarship**
   - Value: $35,000 per year
   - Duration: 3 years

Synopsis: The Alexander Graham Bell Canada Graduate Scholarships-Doctoral Program (CGS D) and NSERC Postgraduate Scholarships-Doctoral Program (PGS D) provide financial support to high calibre scholars who are engaged in a doctoral program in the natural sciences or engineering. The CGS D will be offered to the top-ranked applicants and the next tier of meritorious applicants will be offered an NSERC PGS D. This support allows these scholars to fully concentrate on their studies and seek out the best research mentors in their chosen fields. NSERC encourages interested and qualified Aboriginal students to apply.

2. **Queen Elizabeth II Ontario Graduate Scholarship**
    - Value: $15,000
    - Duration: 1 year

Synopsis: ***The Queen Elizabeth II graduate scholarships in science and technology have been created to encourage and support the best students involved in science and technology research.***

3. **Australian Endeavour Research Fellowship Award**
    - Value: $18,500
    - Duration: 4 months

Synopsis: Endeavour Scholarships and Fellowships are internationally competitive, merit-based scholarships provided by the Australian Government that support citizens around the world to undertake study, research and professional development in Australia and for Australians to do the same overseas.
The Endeavour Scholarships and Fellowships build Australia's reputation for excellence in the provision of education and research, support the internationalisation of the Australian higher education and research sectors and offer high-achieving Australians opportunities to increase their knowledge and expertise in their field. As a scholarship or fellowship recipient, you will gain invaluable international experience in study, research or professional development.

The department has engaged a contractor to provide post-selection support services to all recipients including: a dedicated case manager, pre-departure briefings, advice on health, travel insurance, accommodation, security; payment of allowances, and reporting to the department on the recipient's progress.

4. **UOIT Dean's Graduate Scholarship**
    - Value: $1,500
    - Duration: N/A

Synopsis: The In-program scholarships are awarded by the Office of Graduate Studies to high-ranking current students with a track record of excellence.

5. **UOIT Three Minute Thesis (3MT) Winner**
    - Value: $1,000
    - Duration: N/A

ynopsis: http://gradstudies.uoit.ca/current_students/three-minute-thesis/

6. **American College of Sports Medicine International Award**
    - Value: $1,000
    - Duration: N/A

Synopsis: ACSM international awards provide funding for professionals and students to participate in clinical and research exchange opportunities

7. **Canadian Society for Exercise Physiology Graduate Award Finalist**
    - Value: $250
    - Duration: N/A

Synopsis: For many years the CSEP has honoured a graduate student with an award based on their research contribution to the AGM. Up to four finalists are invited to present their research at the Graduate Student Award Symposium, scheduled for the first evening of the conference.

Until 1999, a panel of judges selected one winner from the candidate papers, and the winner was announced at the CSEP AGM. From 2000 onwards, four finalists are invited present at the Graduate Student Symposium at the CSEP AGM and the winner is selected by a panel convened by the convened by the VP-Research.

2.3 Media Links

Durham Region Newspaper:

http://www.durhamregion.com/news-story/5783067-when-is-hot-too-hot-uoit-research-could-make-firefighting-safer/

ACE Videos:

http://youtu.be/qC8vmxvv1m0
http://youtu.be/WmE58ljxqsc
http://youtu.be/I4sPH7Mp6sI

UOIT Articles:

http://news.uoit.ca/archives/2015/05/uoit-phd-students-research-examining-how-firefighters-take-the-heat.php
http://news.uoit.ca/archives/2015/04/graduate-students-show-academic-flair-at-uoits-3mt-finals.php
http://news.uoit.ca/archives/2015/07/uoit-leads-interactive-technology-roundtable-at-toronto-global-forum.php
http://news.uoit.ca/archives/2015/07/ace-helping-to-make-firefighting-a-safer-occupation.php

Toronto Star Articles:

1. Can firefighters take the heat?: http://www.thestar.com/news/gta/2015/08/22/can-firefighters-take-the-heat-and-think-straight-too.html
2. Toronto Star Reporter takes heat stress test: http://www.thestar.com/news/gta/2015/08/22/our-reporter-takes-the-firefighters-heat-stress-test.html
3. Q & A with Geoff Boisseau: http://www.thestar.com/news/gta/2015/08/22/qa-firefighter-geoff-boisseau-on-applying-science-to-a-dangerous-job.html

2.0 Review of Work Completed: Compilation of Findings Summary

Objective 1: A description of the nature and risks of musculoskeletal injury among firefighters. (see draft manuscript in Appendix A)

INTRODUCTION: 66% of firefighters have experienced occupational injuries and 56% report multiple injuries, with an annual incidence rate of 17.7%. 58% of injured firefighters are placed on "off-duty" and 46% need modified return to work duties following injury. A large number of these workplace injuries arise from movement related activity that are physically demanding, including, patient transport, training drills and fire ground operations. Clearly, ways of decreasing injury rates are needed. Serious games (games used for training) and virtual reality simulations have grown as a form of teaching in many occupational settings and have great potential to improve training so that the correct movements and lifts are performed even under challenging conditions. Due to the complexity of many firefighting tasks and the varying scenarios that may be encountered on any given shift, characterization of job tasks that require various bending, lifting and overhead techniques within the confines of the fire hall and at live fire drill operations is a necessary first step to developing a serious game used for training purposes.

AIM: The aim of this exploratory study was to describe the nature and risks of musculoskeletal injury among firefighters using a variety of data collection methods in order to inform the development of a serious game to help educate firefighters on safe lifting and movement guidelines to reduce their risk of injury.

METHODS: This study used a mixed methods approach. Fire hall observations in urban firehalls were performed by an ergonomist who identified activities with the greatest potential for injury, and then quantified the loads involved in those activities. Focus group interviews were used to explore the firefighters' perceptions of activities representing the greatest injury risk, their awareness of how to perform these activities safely, and possible reasons for utilizing incorrect movement patterns.

RESULTS: Firehall observations: The most ergonomically risky tasks observed during firehall and fireground observations involve pushing and pulling shelves on the truck to get a desired tool, lifting of very heaving objects such as 450N generators, awkwardness of extraction tools with uneven weight distribution and poor handle position, uneven lifting such as heavy single handled buckets and rolling up uncharged hoses at the fireground.

Focus group interviews: Participants reported that injuries primarily include back, neck, shoulder and knee pain. The injuries were often sustained at the fire scene but also occurred around the hall. Injuries at the fire scene were reported being more varied due to the uncontrolled environment. Environmental factors at the scene also play a role in injury onset, as rescue situations also create unexpected circumstances that unintentionally place the firefighter in harms-way. The "No-fail" attitude of firefighters also creates dangerous situations that generate scenarios for injuries. Despite all participants understanding the consequences of advocating a "no-fail" attitude, it appears there is an inherent cultural attribute interwoven into the very fabric of firefighters.

DISCUSSION AND CONCLUSION: There are a number of modifiable ergonomic risk factors that could decrease injury risk. Firefighters are clearly in need of education to modify these risk factors both in the hall and at callouts. The "no fail" attitude was also seen as a contributor to injury risk. Development of a serious game to decrease injury risk will need to include training on modifying ergonomic and psychological risk factors as well as training correct movements.

Objective 2: The effects of exercise-induced heat stress on cognitive function in firefighters (see draft manuscript in Appendix A).

Objectives: The aim of this study was to determine the effects of differing rates of increasing core temperature on cognitive function during exercise-induced heat stress.

Design: Nineteen male firefighters were exposed to repeated cognitive assessments, randomized and counter-balanced, in 30°C and 35°C and 50% humidity.

Methods: Participants performed treadmill walking (4.5 $km \cdot h^{-1}$ and 2.5% grade) with cognitive function assessed before exercise (PRE), after mounting the treadmill (Cog 1), at core temperatures of 37.8°C (Cog 2), 38.5°C (Cog 3), and 39.0°C (Cog 4), after dismounting the treadmill (POST), and following an active cooling recovery to a core temperature of 37.8°C (REC). The cognitive tests implemented at PRE and POST were spatial working memory (SWM), rapid visual information processing (RVP), and reaction time (RTI) while paired associates learning (PAL) and spatial span (SSP) were assessed at Cog 1, Cog 2, Cog 3, and Cog 4. All five cognitive tests were assessed at REC.

Results: Planned contrasts revealed that SSP and PAL were impaired at Cog 3, with SSP also impaired at Cog 4 compared to Cog 1. REC revealed no difference compared to Cog 1, but increased errors compared to Cog 2 for PAL.

Conclusions: The decrements in cognitive function observed at a core temperature of 38.5°C are likely attributed to the cognitive resources required to maintain performance being overloaded due to increasing task complexity and external stimuli from exercise-induced heat stress. The addition of an active cooling recovery restored cognitive function to initial levels.

Objective 3: Part A: Using serious games and virtual simulation for training in the fire service: a review (see published manuscript in Appendix B).

Fire fighting is an extremely physically and physiologically demanding occupation, requiring tremendous resources for training personnel as well as incurring significant workplace safety and insurance board (WSIB) costs. Approximately 33% of fire fighter injuries result from exposure to fire leading to the possibility of reducing these injuries through training fire fighters to make better decisions, particularly when under stress. Simulation (and virtual simulation in particular) offers a safe and cost-effective alternative to practice with real fire, offering entry level training to aid fire fighters to reach a specific competency level. With the ubiquity of video-game play and advent of new consumer-level physical interfaces for video-games (e.g., the Nintendo Wii Fit balance-board and the Microsoft Kinect), serious games (games whose primary purpose is education and training), are able to provide users with innovative interactive techniques that are highly engaging and immersive. This paper reviews the development of serious games and virtual simulation applications that may be utilized for training in the fire service. Current technology allows for the simulation of fire spread and smoke movement along with training certain fire fighting skills and incident command co-ordination. To date, gaming technology is not capable of providing a real world scenario that is completely and faithfully accurate in a dynamic virtual environment. Although additional work remains to overcome current issues associated with serious games and virtual simulations, future work should focus on utilizing the benefits of gaming environments and virtual simulations to recreate the decision making processes and physical task requirements that individual fire fighters encounter in an emergency situation and incorporate them into a simulation environment where the physical and psychological stresses are analogous to live fire fighting situations.

Objective 3: Part B: Memory recall is impaired following exercise-induced heat stress using a serious game in firefighters (see draft manuscript in Appendix A).

Objectives: The purpose of this study was to assess cognitive function in firefighters while exposed to exercise-induced heat stress using a firefighter task level serious game that simulates the cognitive demands of an individual firefighter.

Design: Cognitive performance was tested at repeated intervals while ten male firefighters exercised in 35°C and 50% humidity while performing a game-based simulation.

Methods: Participants performed treadmill walking (4.5 $km \cdot h^{-1}$ and 2.5% grade) with cognitive function assessed at the start of exercise (Cog 1), at core temperatures of 37.8°C (Cog 2), 38.3°C (Cog 3), and 38.5°C (Cog 4), and following an active cooling recovery to a core temperature of 37.8°C (Cog 5). Cognitive Function was assessed using a firefighter task level serious game developed to represent tasks (search and rescue, spatial awareness, memory recall) required during a two-storey residential fire.

Results: Planned contrasts revealed percent change of correct responses was impaired at Cog 5 compared to Cog 1. Room search time for the last two rooms (4 and 5) searched in Cog 3 was significantly longer than room 3 in Cog 2.

Conclusions: This study revealed that the percent of correct decisions was not impaired during an exercise-induced heat stress protocol assessed using a serious game but room search time was prolonged at 38.3°C (Cog 3). However, following an active cooling recovery regimen, memory recall was impaired compared to initial performance. The presence of long-term memory impairments may be troubling for subsequent incidents or during fire scene investigation following an emergency.

Objective 4: Develop different levels of difficulty for the decision-making serious game for assessment purposes.

Following up on *Objective 3*, additional levels of the decision-making game were developed so that a variety of difficulties could be created. The development of additional levels allows for the user to play through an easier scenario prior to progressing to the more difficult scenarios. By creating these various difficulties, we have determined that the use of serious game technology can be employed as a training tool. Starting with the simplest scenario, recruit firefighters can learn the tasks required of a two-storey residential fire and progress to the more difficult scenario once the basics have been acquired.

Prior to developing the various levels of difficulty for the scenario, feedback was obtained from subject matter experts to determine which aspects of the game could be altered. The main consensus was that alterations in the number of tasks required to perform during each aspect of the scenario and also the intensity of the smoke could lend to increasing difficulty. From this information, an easy, medium, and hard level was created with increasing number of victims required to be rescued and thicker, denser smoke impairing visibility as the difficulty increased. Similar to the process conducted to develop the initial serious game scenario, bi-weekly meetings were scheduled with the game development team to determine progress and plan future steps. This process maintained communication and ensured effective and efficient game creation. Once developed, these new scenarios were shown to subject matter experts who provided feedback on the potential usability for training.

Feedback that was provided by subject matter experts from the Fire Service revealed that there is a growing need for more technological advancements in training and that the various levels of difficulty would provide a gradual learning process for recruits and incumbent firefighters. Future research should quantify the effectiveness of implementing serious games training for fire service personnel and its potential benefits on reducing the impact of heat stress. The impact of harnessing new technology for training may provide an efficient and cost-effective means to optimize the future of learning.

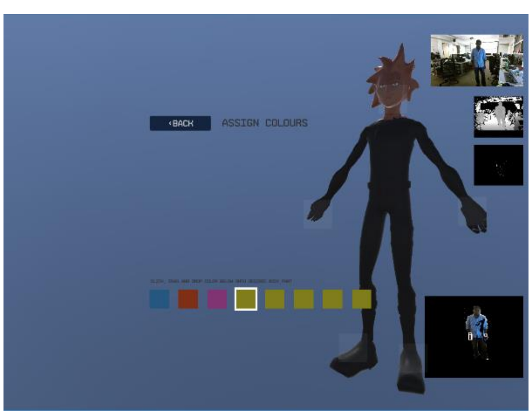
Objective 5: Develop a serious game that will assess the movement patterns of firefighters during various lifting techniques to determine the level of risk associated.

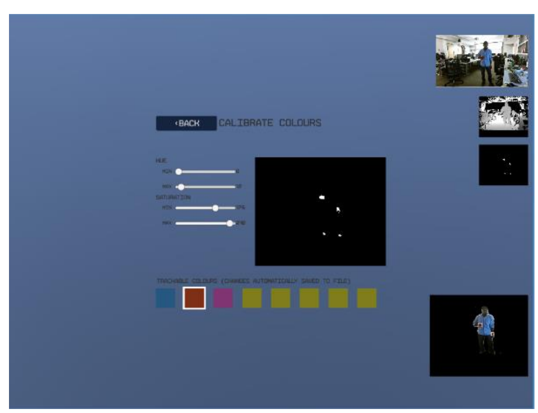
The previous challenges associated with implementing the Kinect as a postural tracking tool have been well documented in previous reports. We have worked to find appropriate solutions to this problem and have come up with a unique solution that will actually guide the development of a future real-time ergonomic assessment tool for lifting tasks in the workplace. Current ergonomic guidelines for the assessment of safe lifting tasks often revolve around a biomechanical analysis of the task to evaluate the amount of loading on the lower back. Using sophisticated biomechanical models we are able to very accurately estimate spine loads and thus injury risk in the workplace. However, the complexity of these methods have led to the development of lifting equations in the literature that only require the tracking of a person's hands and feet to do a reasonable job of estimating spine loads. Therefore, we have now implemented this literature and have developed a means for the Kinect to track only the basic information required for spine loading estimates.

Over the term of this grant, we have found that while the Microsoft Kinect is very suitable for developing games, the built-in software for skeletal tracking is not robust enough for dynamic posture analysis in many realistic lifting scenarios. The skeletal fitting algorithm used is not easily adapted to allow the use of props or weights in view as they block key elements needed for tracking, causing significant errors in the resulting pose estimates. Building on the knowledge gained by this effort, our second prototype focused on developing a robust method for analyzing dynamic posture for comparison with ground truth using state-of-the-art kinematic analysis sensing technologies. Using computer vision techniques, we have now developed a method for tracking dynamic posture robustly, and this will be incorporated into the development of an ergonomic assessment tool.

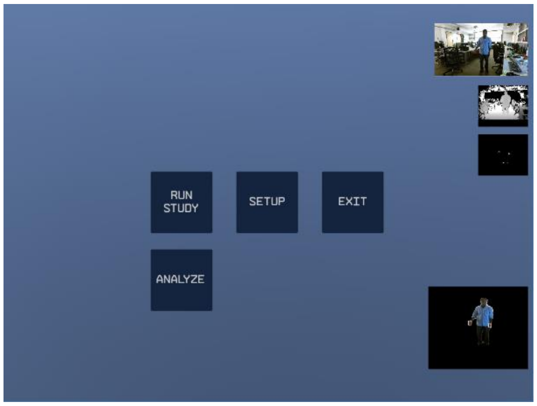
Using a depth sensor coupled with an RGB camera (such as the Microsoft Kinect) we are able to determine the distance from the camera of almost every pixel in view. This allows us to isolate the individual within the imagery and focus computational resources on determining their posture. Using computer vision techniques we are able to identify key points on the individual as they move. Using a combination of the estimated postural data and locations of these key points, we apply a kinematic model to determine the risk to injury based only on the tracking of the three dimensional locations of the individuals hands and feet.

Below are some examples of the interface for the current program. There are some initial calibration and setup steps required prior to tracking. As a first step, the user is required to tell the software what color gloves the person is wearing. This step initiates the color tracking algorithm and provides us with accurate information on the three dimensional location of the persons hands and feet.





Next, the program has a setup menus where you can be prompted with a window that asks for inputs of gender, height, weight and the mass of the object being lifted.



Finally, the program is run, and the Microsoft Kinect tracks the three dimensional location of the persons hands and feet throughout a lifting task. The user is provided with a frontal, sagittal and coronal view of the mannequin representing the posture of the person performing the lift.

There is a need to be able to, in real time, calculate spine loading and thus injury risk using the tracking coordinates from the software. Behind the scenes in the software, we have added equations from the literature to estimate spine loading and injury risk based on the Kinect's data. A more detailed overview of that procedure is detailed in Appendix B.

3.0 LESSONS LEARNED

This research grant has provided a lot of new and exciting findings that can be translated not only to the fire services but also to all emergency services across Canada. We have determined that the use of serious game technology can be employed for assessing decision making skills of various tasks during a two-storey residential fire simulation. In addition, by developing various difficulty levels of the scenario, these can be utilized as subsequent training tools to aid in the task level training of recruit firefighters. Furthermore, our breakthrough with using the Microsoft Kinect hardware as a potential ergonomic assessment tool has allowed us to validate the technique with a laboratory system to evaluate spine loads during various lifting postures. Overall, these findings have the potential to supplement the training techniques that can be delivered to emergency service personnel to provide a safe and effective addition in acquiring the task level knowledge.

Throughout the development of the serious games during the duration of the grant, many unexpected findings became apparent. The interdisciplinary nature of the research team made it necessary to setup particular communication strategies to manage project development. Following data acquisition from focus groups and subject matter expert interviews to determine the task level decision making required at an emergency scenario and the lifting tasks associated within the fire hall, weekly meetings were established with the game development team. Initially, a storyboard was created by the research team and communicated to the game development team. This began in May, 2014 and weekly meetings were established to review progress on game development and determine next steps to be included for each subsequent week. In addition, the research team liaised with fire personnel on a monthly basis to provide prototypes of game development and receive feedback from experts in the field. This information was then relayed to the game development team at the weekly meetings. Following 4 months of game development, a focus group was arrange with fire personnel to elicit feedback on the first version of the serious game. Comments and feedback were recorded and reviewed by the research and game development teams. Bi-weekly meetings were established to implement the modifications suggested of fire personnel experts. In January, 2015, a second focus group was established to determine if the game development had reached a level for research purposes. In June, 2015, a third focus group was organized with Winnipeg Fire and Paramedic Services to determine the transferability of the serious game with another Fire Department. This process provided valuable information for future research in that project management between interdisciplinary teams is critical for the effective and efficient development of a serious game. Future studies employing this process will be able to create, develop, and implement serious game technology for emergency service personnel and a timely manner.

4.0 APPENDIX A: Conference Presentation Abstracts and Posters

1. **Canadian Society for Exercise Physiology (CSEP) Annual Conference, St. John's, NF, October 2014 (oral presentation)**

   Title: Is cognitive function impaired while working in 35°C and wearing Personal Protective Ensemble and Self-Contained Breathing Apparatus in fire fighters?

F.M. Williams-Bell, T.M. McLellan, and B.A. Murphy

Faculty of Health Sciences, University of Ontario Institute of Technology, Oshawa, ON, L1H 7K4

Firefighting requires adequate levels of mental function and acuity requiring the firefighter to be alert, make critical decisions, and be aware of their surroundings while working under life-threatening conditions. To date, the few studies which have examined cognitive function during exertional heat stress in firefighters have utilized simple mental performance tasks, such as reaction time, to determine any changes during situations of increasing core temperature. The purpose of this study was to examine the effects of thermal strain on various aspects of cognitive function during low-intensity treadmill walking. Ten firefighters were tested at 0800 hours and nine were tested at 1200 hours to balance the effects of circadian rhythm. Core temperature, skin temperature, and heart rate were continuously monitored and 5 $mL \cdot kg^{-1}$ of water was provided throughout the protocol. Firefighters walked on a motorized treadmill at 4.5 $km \cdot h^{-1}$ and 2.5% grade, in a climate chamber controlled at 35 °C and 50% relative humidity, for a maximum of thirty minutes followed by a five minute break or until they reached each of the following core temperatures, 37.8, 38.5, and 39.0 °C. Cognitive function was tested using the CANTABeclipse battery (SWM, RTI, RVP, SSP, and PAL) at baseline, immediately following completion of exercise, and after attaining an active recovery core temperature of 37.8 °C, while SSP and PAL were also evaluated at each of the aforementioned core temperatures. Compared to baseline,

SWM search time was longer at post-test along with five choice RTI, whereas simple RTI was faster. At increasing core temperatures, errors at the final level of the PAL test significantly increased at a 38.5 °C, while performance on the SSP test declined at 38.5 and 39.0 °C compared to baseline. Taken together, it appears that certain aspects of cognitive function start to decline at a core temperature of 38.5 °C with an average increase in core temperature of 1.40 ± 0.33 $°C{\cdot}hr^{-1}$.

2. **American College of Sports Medicine (ACSM) Annual Conference, San Diego, CA, May, 2015 (poster presentation)**

Title: Is Cognitive Function Impaired while Working in a Climate Chamber at 30°C in Fire Fighters?

Firefighting requires cognitive abilities, such as attention, vigilance, spatial awareness, decision making, and air management, under extreme life-threatening working conditions. To date, cognitive function during exertional heat stress in firefighters has been conducted utilizing simple mental performance tasks, such as reaction time, or lacking cognitive assessments while core temperature was increasing to detect any changes.

PURPOSE: The purpose of this study was to examine the effects of thermal stress on various aspects of cognitive function during moderate-intensity treadmill walking. **METHODS:** Nineteen fire fighters were tested (age 35.6 ± 8.7 years, BMI 27.3 ± 3.2 $kg \cdot m^{-1}$, body fat 16.7 ± 5.8 %, VO_{2peak} = 45.2 ± 5.5 $mL \cdot kg^{-1} \cdot min^{-1}$). Core temperature, skin temperature, and heart rate were continuously monitored and 5 $mL \cdot kg^{-1}$ of water was provided throughout the protocol. Firefighters walked on a motorized treadmill at 4.5 $km \cdot h^{-1}$ and 2.5% grade, in a climate chamber controlled at 30 °C and 50% relative humidity for 84.3 ± 13.4 min. Cognitive function was tested using the CANTABeclipse battery (spatial working memory - SWM, reaction time - RTI, rapid visual information processing - RVP, spatial span - SSP, and paired associates learning - PAL) at baseline, immediately following completion of exercise, and after attaining a hand and forearm immersion recovery core temperature of 37.8 °C, while SSP and PAL were also evaluated during exercise when core temperatures of 37.8, 38.5, and 39.0 °C were attained. **RESULTS:** Compared to baseline, post-tests for RVP revealed improvements in correct rejections (262.9 ± 8.6 vs 267.2 ± 5.9 rejections; $p < 0.05$), latency (380.3 ± 83.7 vs 334.9 ± 42.2 ms; $p < 0.05$), and simple reaction time (286.8 ± 35.1 vs 270.0 ± 31.2 ms; $p < 0.05$), while performance on the PAL test showed significantly more errors during the final level (5.7 ± 5.5 vs 9.6 ± 8.7 errors; $p < 0.05$) when core temperature reached 38.5°C. **CONCLUSIONS:** Taken together, it appears that visual memory and new learning is impaired when core temperature reaches 38.5°C without decrements in spatial information, sustained attention, or working memory capacity when the average rate of increase in core temperature is 0.87 ± 0.24 $°C \cdot h^{-1}$.

Supported by a grant from the Research and Workplace Innovation Program of the Workers Compensation Board of Manitoba"

Is cognitive function impaired while working in a climate chamber at 30°C in firefighters?

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

F.M. Williams-Bell[1], S.R. Passmore[2], T.M. McLellan[1,3], FACSM, B.A. Murphy[1]

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FIRE SERVICES TORONTO

ABSTRACT

Firefighting requires cognitive abilities in areas such as attention, vigilance, spatial awareness, decision making, and air management, under extreme life-threatening working conditions. To date, cognitive function during exertional heat stress in firefighters has either been conducted utilizing simple mental performance tasks, such as reaction time, or failed to assess cognitive function while core temperature (T_{core}) was increasing, to measure potential changes in function.

PURPOSE: The purpose of this study was to examine the effects of thermal stress on various aspects of cognitive function during moderate-intensity treadmill walking. METHODS: Nineteen fire fighters were tested (age 35.6 ± 8.7 years, BMI 27.3 ± 3.2 kg·m^{-2}, body fat 16.7 ± 5.8%, VO_{2peak} 45.2 ± 5.5 mL·kg^{-1}·min^{-1}). T_{core}, skin temperature, and heart rate were continuously monitored and 5 mL·kg^{-1} of water was provided throughout the protocol. Firefighters walked on a motorized treadmill at 4.5 km·h^{-1} and 2.5% grade, in a climate chamber controlled at 30 °C and 50% relative humidity for 84.3 ± 13.4 min. Cognitive function was tested using the CANTAB assessment battery (spatial working memory - SWM, reaction time - RTI, rapid visual information processing - RVP, spatial span - SSP, and paired associates learning - PAL) at baseline, immediately following completion of exercise, and after attaining a hand and forearm immersion recovery T_{core} of 37.8°C, while SSP and PAL were also evaluated during exercise when T_{core} of 37.8, 38.5, and 39.0°C were attained. RESULTS: Compared to baseline, post-tests for RVP revealed improvements in correct rejections (262.9 ± 8.6 vs 267.2 ± 5.9 rejections; $p < 0.05$), latency (380.3 ± 83.7 vs 334.9 ± 42.2 ms; $p < 0.05$), and simple reaction time (286.8 ± 35.1 vs 270.0 ± 31.2 ms; $p < 0.05$), while performance on the PAL test showed significantly more errors during the final level (5.7 ± 5.5 vs 9.6 ± 8.7 errors; $p < 0.05$) when T_{core} reached 38.5°C. CONCLUSIONS: Taken together, it appears that visual memory and new learning is impaired when T_{core} reaches 38.5°C without decrements in spatial information, sustained attention, or working memory capacity when the average rate of increase in T_{core} is 0.85 ± 0.06°C·h^{-1}.

INTRODUCTION

Firefighters are exposed to live fire environments that can exceed 200°C as well as ambient temperatures over 30°C (1). Firefighting activities, such as victim search and rescue, require the firefighter to maintain adequate performance levels of cognitive function and acuity while performing tasks under conditions of extreme heat and emotional stress (2). Firefighters must be alert, make critical decisions, and be aware of their surrounding environment in order to determine the safest means of egress, all while working under life-threatening conditions (2). To date, the few studies which have examined cognitive function during exertional heat stress in firefighters have predominantly utilized simple mental performance tasks, such as reaction time, to determine changes with increasing T_{core}.

Purpose: To determine the effects of rising T_{core} on cognitive performance using more complex cognitive assessments

METHODS

Subjects:

- 19 firefighters (35.6 ± 2.0 years of age) with corresponding service as a firefighter of 10.0 ± 2.1 years volunteered to participate in the study
- The physiological profile of the firefighters revealed a VO_{2peak} of 45.2 ± 1.3 mL·kg·min^{-1}, height of 176.3 ± 1.6 cm, body mass of 85.1 ± 2.9 kg, and body fat of 16.7 ± 1.3%

Experimental Protocol:

- Firefighters wore full personal protective clothing (PPC) consisting of bunker pants, jacket, flash hood, face-piece, helmet, and self contained breathing apparatus (SCBA), while walking on a treadmill in 30°C and 50% humidity
- Five tests from the Cambridge Neuropsychological Automated Battery (CANTAB) were implemented to assess cognitive function in areas particularly relevant to firefighters
  - Spatial Working Memory (SWM)
  - Rapid Visual Information Processing (RVP)
  - Reaction Time (RTI)
  - Paired Associates Learning (PAL)
  - Spatial Span (SSP)

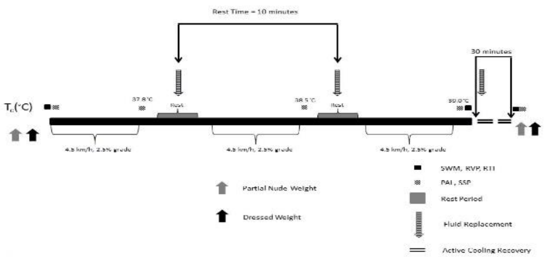


Figure 1: Illustration of the exertional heat stress experimental protocol in environmental conditions of 30°C and 50% humidity eliciting at rate of rise in T_{core} of 0.85 ± 0.06°C·h^{-1}.

COGNITIVE ASSESSMENT BATTERY

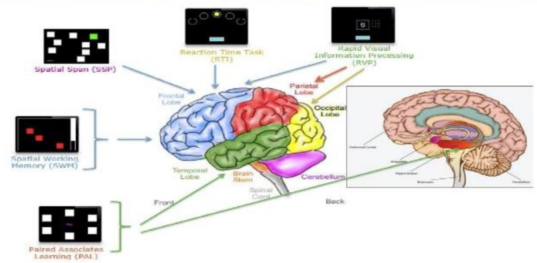


Figure 2: Illustration of brain regions assessed through the CANTAB cognitive assessment battery. Adapted from Cambridge Cognition (Cambridge, UK).

RESULTS

Age (years)	Height (cm)	Body Mass (kg)	Body Mass Index (kg·m^{-2})	Body Fat (%)	VO_{2peak} (mL·kg^{-1}·min^{-1})	HR_{peak} (beats·min^{-1})
35.6 ± 2.0	176.3 ± 1.6	85.1 ± 2.9	27.3 ± 0.7	16.7 ± 1.3	45.2 ± 1.3	184 ± 3
Combined Handgrip (kg)	**1-RM Bench Press (kg)**	**1-RM Leg Press (kg)**	**1-RM Shoulder Press (kg)**	**1-RM Biceps Curl (kg)**	**Bench Press Endurance (# of reps)**	**Leg Press Endurance (# of reps)**
47.3 ± 1.4	86.5 ± 3.9	249.9 ± 11.0	53.3 ± 2.1	40.2 ± 2.3	28.8 ± 1.7	24.1 ± 3.3

Table 1: Anthropometric and physiological profile of the nineteen firefighters. Data are mean ± SEM.

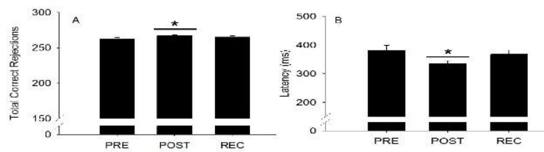


Figure 3: Data from the RVP test before (PRE) and after (POST) the exertional heat stress trial, as well as following active cooling recovery (REC) to 37.8°C. There was a main effect of cognitive trial ($p < .05$) with planned contrasts revealing improved sustained attention (A) and latency reaction time (B) at POST ($p < .05$).

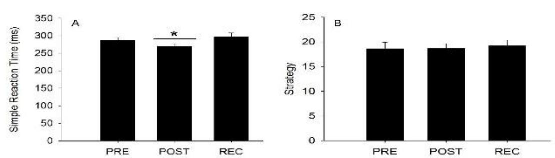


Figure 4: Data from the RTI (A) and SWM (B) tests before (PRE) and after (POST) the exertional heat stress trial, as well as following active cooling recovery (REC) to 37.8°C. There was a main effect of cognitive trial in the RTI test ($p < .05$) with planned contrasts revealing improved simple reaction time at POST ($p < .05$).

RESULTS

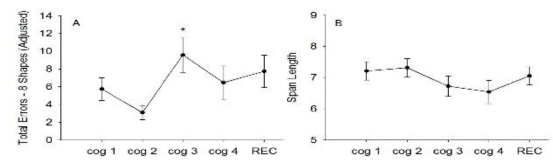


Figure 6: Data from the PAL (A) and SSP (B) tests at beginning of exercise (cog 1), at 37.8°C (cog 2), 38.5°C (cog 3), 39.0°C (cog 4), and following active cooling recovery (37.8°C). There was a main effect of cognitive trial in the PAL test ($p < .05$) with planned contrasts revealing impaired visual episodic memory at cog 3 ($p < .05$). REC revealed more errors compared to cog 2 ($p < .05$) but not cog 1 ($p > .05$). Six of the nineteen firefighters terminated exercise due to volitional fatigue prior to cog 4.

SUMMARY

- Sustained attention (RVP) was improved at post-test along with a decrease latency reaction time when compared to pre-test performance. This improvement in sustained attention may be due to increased activity in right frontal and parietal cortices of the brain (3).
- Simple reaction time (RTI) and latency reaction time (RVP) were faster at post test compared to pre test, which may be due to improved nerve conduction velocity with decreased latency of transmission of the motor drive to the firefighter's finger (4).
- Visual episodic memory (PAL) was impaired once firefighters attained a T_{core} of 38.5°C possibly resulting in an overload of the cognitive resources required to maintain performance due to increasing task complexity and external stimuli from heat stress increasing T_{core} (5). At 39.0°C there were no significant decrements; however, only thirteen firefighters attempted cog 4 and were able to tolerate the heat stress more effectively, which may account for the lack of decrement.
- Visuospatial memory (SSP) was not significantly impaired at any level of T_{core}, despite showing reductions in span length at 38.5°C and 39.0°C. The cognitive resources required to maintain performance appear to not be overloaded despite the increase in thermal stress.
- Improvements in aspects of cognitive function may be the result of the negative direction of T_{core} movement, whereas impairments are potentially linked to the positive direction of T_{core} (6).
- Despite observing decreases in visuospatial memory and significant impairments in visual episodic memory, implementing a forearm submersion active cooling recovery to a T_{core} of 37.8°C restored cognitive function to pre-exercise levels.
- Previous research has revealed that the tolerance time of firefighters working in full PPC and SCBA at 30°C and 50% humidity at moderate-intensity exercise is 65.4-min, with the time to attain a T_{core} of 38.5°C being 57-min (7).
- Taken together, these data reveal that Incident Commanders should be aware of the time spent working at moderate-intensity firefighting tasks (victim search and rescue, vehicle extrication, ventilation), in 30°C and 50% humidity conditions with prolonged work over 57-min possibly being accompanied with impairment of cognitive function.

REFERENCES

1. Baker SJ, Grice J, Roby L, Matthews C. Cardiorespiratory and thermoregulatory response of working in fire-fighter protective clothing in a temperate environment. Ergonomics. 2000;43(9):1350-8
2. Barr D, Gregson W, Reilly T. The thermal ergonomics of firefighting reviewed. Applied Ergonomics. 2010;41(1):161-72
3. Lawrence N, Ross T, Hoffmann R, Garavan H, Stein E. Multiple neuronal networks mediate sustained attention. Cognitive Neuroscience, Journal of. 2003;15(7):1028-38
4. Racinais S, Gaoua N, Grantham J. Hyperthermia impairs short term memory and peripheral motor drive transmission. The Journal of physiology. 2008;586(19):4751-62
5. Baars BJ. Global workspace theory of consciousness: toward a cognitive neuroscience of human experience. Progress in brain research. 2005;150:45-53
6. Hancock P, Vasmatzidis I. Human occupational and performance limits under stress: the thermal environment as a prototypical example. Ergonomics. 1998;41(8):1169-91
7. Selkirk GA, McLellan TM. Physical work limits for Toronto firefighters in warm environments. J Occup Environ Hyg. 2004;1(4):199-212

ACKNOWLEDGEMENTS

WCB Workers Compensation Board of Manitoba

NSERC CRSNG

3. **American College of Sports Medicine (ACSM) Annual Conference, Boston, MA, May, 2016 (thematic poster presentation)**

Title: The effects of exercise-induced heat stress on cognitive function assessed using serious game technology

F.M. Williams-Bell, S.R. Passmore, T.M. McLellan, FACSM, B.A. Murphy

Firefighting requires adequate cognition under heat stress to accurately make decisions, remain vigilant, and remember important locations within the fire scene. With emerging advancements in game technology, occupations such as the fire service have the potential to provide assessment and training tools using game-based simulations. **PURPOSE:** The purpose of this study was to assess aspects of cognitive function while exposed to exercise-induced heat stress using a serious game that simulates the task-level activities of an individual firefighter. **METHODS:** Ten male firefighters (height: 177.9 ± 1.7 cm, body mass: 89.8 ± 2.3 kg, percent body fat: 17.8 ± 1.6%, VO_{2peak}: 44.5 ± 2.0 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) with a mean age of 39.4 ± 3.0 years and 15.3 ± 1.8 years of service participated in the study. Core temperature, skin temperature, and heart rate were continuously monitored and 5 $mL{\cdot}kg^{-1}$ of water was ingested throughout the protocol. Firefighters walked on a motorized treadmill at 4.5 $km{\cdot}h^{-1}$ and 2.5% grade, in a climate chamber controlled at 35 °C and 50% relative humidity for 74.4 ± 5.0 min. Cognitive function was tested using the Firefighter Task-Level serious game (FFTL), a computerized simulation of a two-story residential house fire. The FFTL was designed to incorporate 5 scenes in order to have participants complete them at differing levels of T_{core}: i) scene 1 (cog 1, initial T_{core}), ii) scene 2 (cog 2, 37.9°C), iii) scene 3 (cog 3, 38.2°C), iv) scene 4 (cog 4, 38.5°C), and v) scene 5 (cog 5, 37.8°C) following active cooling recovery. **RESULTS:** Post-hoc analyses indicated that the time to search the 2 rooms at cog 4 (61.1 ± 4.6 s) was significantly longer than room 3 (35.0 ± 5.4 s) at cog 3 but not different than room 1 or 2. Cog 5 showed a significant decrease in memory recall relative to cog 1 (-19.8 ± 6.4%). **CONCLUSIONS:** This study revealed that performance was not impaired during an exercise-induced heat stress protocol assessed using a serious game but room search time was prolonged at 38.5°C (cog 4). However, following an active cooling recovery regimen, memory recall was impaired compared to initial performance. The presence of long-term memory impairments may be troubling for subsequent incidents or during fire scene investigation following the emergency.

Supported by a grant from the Research and Workplace Innovation Program of the Workers Compensation Board of Manitoba"

5.0 APPENDIX B: Review of work completed: Compilation of Completed and Draft Manuscripts

The following section provides complete details on the findings from each of the research objectives. Manuscripts have been written and are presented in draft form either awaiting response from the submitted journal or in preparation to be submitted. The list, below, provides information on the title of the manuscript, journal submitted or will be submitted to, and current progress.

Objective 1. A description of the nature and risks of musculoskeletal injury among firefighters - to be submitted to *Fire Safety Journal* – in preparation (draft manuscript).

Objective 2. The effects of exercise-induced heat stress on cognitive function in firefighters – submitted to the *Journal of Medicine and Science in Sport* – awaiting decision from journal.

Objective 3. Using serious games and virtual simulation for training in the fire service: a review – published in *Fire Technology* – accepted.

Objective 3. Memory recall is impaired following exercise-induced heat stress using a serious game in firefighters – to be submitted to the *Journal of Medicine and Science in Sport* – in preparation (draft manuscript).

Objective 5. Develop a serious game that will assess the movement patterns of firefighters during various lifting techniques to determine the level of risk associated

Objective 1: A description of the nature and risks of musculoskeletal injury among firefighters - **to be submitted to *Fire Safety Journal* – in preparation (draft manuscript).**

A description of the nature and risks of musculoskeletal injury among firefighters

To be submitted to The Fire Safety Journal

Diane E. Grondin[1,2], Silvano Mior[1,2], Michael Williams-Bell[2], Michael Holmes[2], Peter Kim[1] Bernadette Murphy[2],

[1] Canadian Memorial Chiropractic College (CMCC)

[2]University of Ontario Institute of Technology

Abstract

INTRODUCTION: 66% of firefighters have experienced occupational injuries and 56% report multiple injuries, with an annual incidence rate of 17.7%. 58% of injured firefighters are placed on “off-duty” and 46% need modified return to work duties following injury. A large number of these workplace injuries arise from movement related activity that are physically demanding, including, patient transport, training drills and fire ground operations. Clearly, ways of decreasing injury rates are needed. Serious games (games used for training) and virtual reality simulations have grown as a form of teaching in many occupational settings and have great potential to improve training so that the correct movements and lifts are performed even under challenging conditions. Due to the complexity of many firefighting tasks and the varying scenarios that may be encountered on any given shift, characterization of job tasks that require various bending, lifting and overhead techniques within the confines of the fire hall and at live fire drill operations is a necessary first step to developing a serious game used for training purposes.

AIM: The aim of this exploratory study was? to describe the nature and risks of musculoskeletal injury among firefighters using a variety of data collection methods in order to inform the development of a serious game to help educate firefighters on safe lifting and movement guidelines to reduce their risk of injury.

METHODS: This study used a mixed methods approach. Fire hall observations in urban firehalls were performed by an ergonomist who identified activities with the greatest potential for injury, and then quantified the loads involved in those activities. Focus group interviews were

used to explore the firefighters' perceptions of activities representing the greatest injury risk, their awareness of how to perform these activities safely, and possible reasons for utilizing incorrect movement patterns.

RESULTS: Firehall observations: The most ergonomically risky tasks observed during firehall and fireground observations involve pushing and pulling shelves on the truck to get a desired tool, lifting of very heaving objects such as 450N generators, awkwardness of extraction tools with uneven weight distribution and poor handle position, uneven lifting such as heavy single handled buckets and rolling up uncharged hoses at the fireground.

Focus group interviews: Participants reported that injuries primarily include back, neck, shoulder and knee pain. The injuries were often sustained at the fire scene but also occurred around the hall. Injuries at the fire scene were reported being more varied due to the uncontrolled environment. Environmental factors at the scene also play a role in injury onset, as rescue situations also create unexpected circumstances that unintentionally place the firefighter in harms-way. The "No-fail" attitude of firefighters also creates dangerous situations that generate scenarios for injuries. Despite all participants understanding the consequences of advocating a "no-fail" attitude, it appears there is an inherent cultural attribute interwoven into the very fabric of firefighters.

DISCUSSION AND CONCLUSION: There are a number of modifiable ergonomic risk factors that could decrease injury risk. Firefighters are clearly in need of education to modify these risk factors both in the hall and at callouts. The "no fail" attitude was also seen as a contributor to injury risk. Development of a serious game to decrease injury risk will need to include training on modifying ergonomic and psychological risk factors as well as training correct movements.

Introduction

Musculoskeletal conditions such as low back pain are a leading cause of pain and disability.(Lagacé, Perruccio, DesMeules, & Badley, 2003) The total costs related to low back pain pose a significant economic burden on organizations as well as on municipal, provincial and federal governments.(Hsiao et al., 2014; Stokes, Desjardins, & Perruccio, 2003) In Canada, the total economic burden of musculoskeletal conditions ranks second only to cardiovascular disease and is the most costly disease for women and third most costly for men.(Stokes et al., 2003) Work-related risk factors for the development of musculoskeletal injury include high force, awkward postures, repetitive movements, complex and asymmetric motions and the unexpected loading/shifting of weight.(DB, GBJ, & BJ, 1999; FA, WS, & P, 1998; WS & W, 2006) It has long been established that these risk factors can lead to higher muscle activations, joint loading, tissue deformation and sub-optimal movement patterns.(DB et al., 1999; FA et al., 1998; WS & W, 2006)

A number of occupations are associated with an increased risk of injury due to the physical nature of the job. For instance, nurses, emergency medical services personnel and firefighters are at an increased risk of developing musculoskeletal injury due to the physical nature of the occupation.(Gentzler & Stader, 2010; Hansen, Rasmussen, Kyed, Nielsen, & Andersen, 2012; Hong, Chin, Phelps, Feld, & Vogel, 2012; Jang et al., 2007) Regular firefighting duties involve heavy and repetitive lifting, complex asymmetric motions and sudden loading. The strength and endurance requirements involve lifting and carrying up to 80 lbs, pulling up to 135 lbs and working with objects in front of the body (up to 125 lbs).(Gledhill & Jamnik, 1992)

A recent US survey which asked about work-related accidents or injuries reported that 66% of firefighters have experienced occupational injuries and 56% report multiple injuries (Hong et al., 2012). The most common injuries are strains and sprains (74%), with the back affected 54% of the time.(Hong et al., 2012) Following an injury, 58% of firefighters are placed on “off-duty” and 46% have to modify their duties (Hong et al., 2012). Another study on firefighters demonstrated an annual injury incident rate of 17.7%.(Poplin, Harris, Pollack, Peate, & Burgess, 2012) Sprains and strains are the most prevalent type of injury (40.2-85.2%) followed by contusions and lacerations (7.7-26.1%).(Poplin et al., 2012) One-third (33%) of all these reported injuries result from physical exercise activities and between 10-17% of injuries result from patient transport (16.9%), training drills (11.1%) and fire ground operations (10.2%).(Poplin et al., 2012)

Given the high rate of musculoskeletal injury among firefighters, efforts have been undertaken to design intervention programs to attempt to reduce injury risk. For instance, one intervention involving didactic education, practical, hands-on demonstration and instruction on exercise for core strength and other healthy lifestyle habits resulted in a significant reduction in the rate of injury and in the overall duration of sick-days.(Huijg et al., 2014) It was also estimated that there was a financial savings of about $60,000 over a six-month period related to direct costs associated with implementation of the program and the impact it had on the injury rates.(Huijg et al., 2014)

Additional recent studies have also noted the potential for positive outcomes when implementing interventions. For instance, a wellness program tailored for firefighters that included assessment, education, instruction, personal coaching and training led to improvements in traditional measures of fitness, such as blood pressure, heart rate, aerobic fitness, body mass index and back flexibility.(McDonough, Phillips, & Twilbeck, 2015) Poston et al. compared the health of firefighters from departments with well-established health promotion programs to those without and noted that those belonging to a department with such a program were less likely to be obese, more likely to meet endurance capacity standards and have higher VO2 max.(Poston, Haddock, Jahnke, Jitnarin, & Day, 2013) Yet, these individuals were also more likely to make a worker's compensation claim.(Poston et al., 2013) Furthermore, improvements in physical fitness may not necessarily translate into a reduction in the rate or severity of injuries.

Not all measures of fitness may improve with the implementation of intervention programs. Mayer et al. noted that a worksite exercise training program involving supervised back and core exercises was not effective in attaining hypertrophy of the lumbar multifidus muscle in healthy firefighters.(Mayer & Nuzzo, 2014) It is possible that the relevance and type of intervention programs that are used, impact their effectiveness. Previous authors have urged for innovative strategies to address the barriers to physical fitness and the high number of injuries in firefighting.(Jahnke, Poston, Jitnarin, & Haddock, 2012) The use of realistic video games may be one such solution. Education can range from a simple information session to multiple sessions and exercise classes over a longer duration (Koes, van Tulder, van der Windt, & Bouter, 1994). However, long term sessions are expensive, especially for smaller fire departments. With the emergence of virtual reality environments for training and education, development of this type of training tool for low back care would fill a need and be transferable throughout fire departments without the increased costs and resources of conducting numerous in-class sessions.

Serious games and virtual reality simulations have grown as a form of teaching in many occupational settings, including medicine(Deutsch, 2009; Fairhurst, Strickland, & Maddern, 2010; Kron, Gjerde, Sen, & Fetters, 2010; Marsh et al., 2010), rehabilitation(Cox et al., 2010; Kamper et al., 2010; Lange et al., 2010; Rand, Weiss, & Katz, 2009), baseball (Fink, Foo, & Warren, 2009), and firefighting(Boulet, 2009; Sowndararajan, Wang, & Bowman, 2008; St.Julien & Shaw, 2003; Zachary O. Toups, Kerne, Hamilton, & Blevins, 2009). It has become recognized by educators, researchers, and game developers that console-based video and computer games could provide an enhanced learning experience.(Gee, 2003; D. Norman, 2001; Prensky, 2003; Stapleton, 2004) Current literature on the use of games and virtual reality for firefighting is related to improving team communication and decision making(Boulet, 2009; Sowndararajan et al., 2008; St.Julien & Shaw, 2003; Zachary O. Toups et al., 2009), not to movement related skills such as appropriate materials-handling techniques. Given the large economic burden associated with occupational low back pain it is imperative that appropriate materials-handling techniques be transferred to firefighters in an engaging yet educational manner.

Due to the complexity of many firefighting tasks and the varying scenarios that may be encountered on any given shift, characterization of job tasks that require various bending, lifting and overhead techniques within the confines of the fire hall and at live fire drill operations is a necessary first step. To this end, the current investigation is an exploratory study aimed to inform the development of a serious game to help educate firefighters and reduce their risk of injury. Specifically, the current study describes the nature and risks of musculoskeletal injury among firefighters. This is critical as knowing what the injuries are and how they occur will help to inform the development of a serious game that is both relevant and effective at reducing injury risk. Essentially, this study allows for the assessment of the context in which a game can be developed and implemented which is a critical step in promoting the uptake and success of an innovation.(Huijg et al., 2014; Simpson et al., 2013) Therefore, the aim of the current study is to describe the nature and risks of musculoskeletal injury among firefighters using a variety of data collection methods in order to inform the development of the novel training strategy.

2.0 Materials and methods

REB approval was obtained from the University of Ontario Research Ethics Board (12-076). This study used a mixed methods approach. Fire hall observations in urban firehalls were performed by an ergonomist who identified activities with the greatest potential for injury, and then quantified the loads involved in those activities. Focus group interviews were used to explore the firefighters' perceptions of activities representing the greatest injury risk, their awareness of how to perform these activities safely, and possible reasons for utilizing incorrect movement patterns.

2.1 Characterization of Firefighters' Tasks:

Due to the complexity of many firefighting tasks and the varying scenarios that may be encountered on any given shift, we examined the characterization of job tasks that required lifting techniques within the confines of the fire hall. Characterization of job tasks included those requiring various bending, lifting and overhead techniques within the fire hall and at live fire drill operations. The primary focus was on tasks that required loading and unloading various items onto and from the truck.

Firefighters from an urban fire hall were observed during active drills and routine fire hall activities. The observation-based data involved observing a complete set of tasks that firefighters may perform, taking select quantitative measurements of the tasks that appeared to present the greatest risk for musculoskeletal injury. Tasks within the fire hall were observed and characterized based on the nature of the task, the type of task, and the number of times the task was performed. The observations were digitally captured using still images and video, and when appropriate, force measurements were taken. Active fire suppression tasks, but also post-fire equipment maintenance and clean-up activities were also documented for quantitative analysis. The firefighters were recruited from fire hall information sessions, with the only inclusion criteria being that the firefighter be on active duty. All participants were briefed on the aims, methodology and potential risks and provided informed consent prior to participation. Observations were performed on two separate visits to the same fire hall.

While no standardized risk assessment tool was employed, the process of conducting observations, quantitative measurement and determination of tasks, as described, is a method commonly used by ergonomic analysts in the field (**ref**). When tasks were performed that required interaction with the fire truck, all truck dimensions of the particular compartment were determined (compartment size, vertical location from ground, location of pull out trays). When the firefighter was required to lift or manoeuvre an object, horizontal and vertical measurements were obtained by measuring from the location of the mid-point of the hands to the mid-point of the feet. All push and pull forces, as well as the mass of all objects manipulated, were measured using a digital force gauge (Mark-10, Series - **……** capacity 1000lbs, Copiague, NY, USA) and the Advanced Ergonomics Testing Kit (Nexgen Ergonomics Inc., Pointe Claire, Quebec, Canada).

All fire hall observations were conducted by a PhD student in occupational physiology and a kinesiology professor with a PhD in Occupational Biomechanics. All observational data was compiled by a graduate student.

2.2 Exploring Experiences of Firefighters

We explored firefighters' experiences and understanding of their knowledge of low back pain and injury prevention, level of education of the mechanisms and prevention of injuries, common causes and sites leading to back injury, and role of worker, employer, insurers and providers in facilitating prevention and return to work strategies using qualitative research. We created specific interview guides with open-ended questions to gather data from participants using semi-structured interviews that were subsequently used to inform the focus group interview guide. All interviews and focus group interaction were audio-taped and then transcribed verbatim.

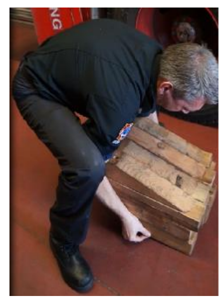
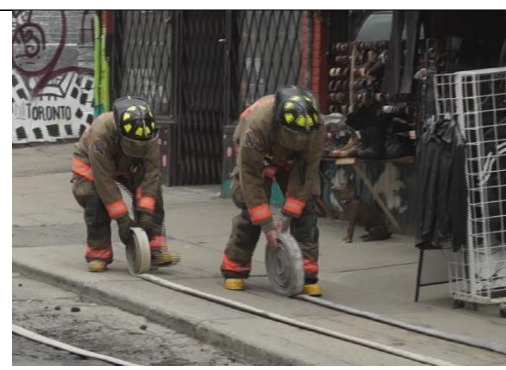
We used a convenience sample of firefighters from two large urban fire halls. We ensured that a range of years of experience and tenure were included in the focus group. Transcript-based analysis[(Morgan & Krueger, 1998)] using an interpretative approach[(Verhoef, Mulkins, & Boon, 2005)] was used to explore the meaning of participants' experiences and thoughts. Transcripts were analyzed using constant comparative methodology[(Sandelowski, 2000)]. This provided meaning and explanation of patterns identified in the data[(Barbour, 2005)] and would inform future instructional strategies by ensuring we captured key issues identified by participants. We did not attempt to attain saturation due to the pilot nature of this study.

3.0 Results

3.1 Characterization of Firefighters' Tasks:

We compiled a document that consisted of all pictures, videos and force measurements. One hundred and ninety three pictures and 53 videos were collected. Each picture was labelled with the measurements of specific tools and components. The following is a description of five tasks that were deemed the most physically demanding and performed regularly. All tasks focus on the firefighter's interaction with the truck.

Task Description	Image
• Most tasks involve pushing and pulling shelves on the truck to get a desired tool. • Firefighters regularly push/pull shelves that are located very low to the ground, placing them in an awkward posture. • In the representative image to the right, the vertical distance from the floor is 36.2 cm. • The push/pull forces required for the low shelves with minimal equipment was 69N/53N, respectively.	
• Firefighters regularly use generators and this particular model was 450N. • It was located on a low shelf, approximately 52.1 cm from the ground. • The shelf was pushed/pulled a distance of 71.1 cm.	 
• Extraction tool objects are extremely awkward to manipulate as the weight of the tool is unequally distributed and handles are located in positions for optimal use, not removal from the truck. • Extraction tools ranged from 66N to 191N • Objects were located on the low and mid-level shelves. • Horizontal push/pull forces for the shelves were 590N and 111N respectively.	 

• A vertical force is required to begin pushing and finally securing the shelf that ranged from 362N for the start and 110N for the finish.	
• Firefighters regularly lift objects that have unequal weight distributions and in this case poor coupling and poorly designed handles. • This bucket of chains was 581N and was loaded onto and off of the truck.	
• Another example of the awkward objects being manipulated. This stack of wooden blocks has no coupling mechanism and is extremely awkward to move.	
• Firefighters are required to roll up uncharged hose lines following a fire scenario. The position of the firefighter results in possible increased forces on the lower back which may lead to low back injuries after repetitive actions over many years.	

3.2 Exploring Experiences of Firefighters

We interviewed three firefighters with varying degrees of experience. We also held a focus group with 12 firefighters recruited from a convenience sample from a busy urban fire hall. We coded the data into categories, which were subsequently collapsed into themes. The data were characterized the various firefighting tasks performed by fire fighters at typical call scenarios and the nature of their injuries. In addition, we explored the attributes required for the strategies to be receptive by users.

Contextualizing firefighters' experiences

Firefighters' job demands are unique in that they involve different physical and mental activities dependent upon their situation. Their levels of alertness and awareness change upon their perceived understanding of a call or work situation. As a consequence, their ability to avoid dangerous and physically challenging situations varies and is situationally determined. They come to rely on their instincts, which are developed by training and experience. Eventually experience guides most actions and these become reactionary leading to unintended consequences and new learned experiences. This is highlighted by the following quote,

> *"So the academy teaches you the text book things and the basics which are always a little bit different than real life because there might be a few extras steps that take a bit longer."* (F1)

The above summary sets the context for the human, physical and occupational complexities that participants experience in their day-to-day lives as firefighters. It also provides a sense of the challenge faced in developing a game that is realistic and meets the needs of firefighters in preventing injuries.

Nature of acquired injuries

Reported injuries by participants varied but involved primarily back, neck, shoulder and knee pains. The injuries were often sustained at the fire scene but also occurred around the hall. The latter often involved maintenance activities such as conducting a truck check. The truck check involves assessing generators, fans, hoses, extrication tools, and ladders. Hall related maintenance involves cleaning and other related activities. Injuries incurred were reported as related to inattention and sloppy lifting techniques.

> *"I will be the guy who admits to bad technique and that kind of stuff you probably want for your game. It kind of comes down to especially on the fire ground, if you see something like a medium size generator that to has to go back into the truck and there is not a guy within 50 feet, you just want to pack up and get out of there, you hoist it up."* (F2: 151)

Injuries at the fire scene were reported being more varied due to the uncontrolled environment. At a fire scene, similar truck-related activities were accentuated by the urgency of the situation, the environment and available resources. Injury related activities included lifting, such as lifting and moving objects from tight fitting compartments and storage bins with "lips"; removing ladders from the truck; placement of ladders for secondary egress on site where location may not be ideal; people lifts; carrying of Powell packs up numerous flights of stairs; and manipulating charged hoses around corners or tight spaces. These are highlighted in the following quotes:

> *"I think there is the element where you can see and you know about lifting the generator, you know about moving the hose; but when you are on the inside you are actually at the fire, anything can happen." (F1:191)*
>
> *"One thing that did affect me is bouncing in an older spare aerial and it caused… I have a problem in my neck as well where I have two compressed discs, and that got pretty sore for a while." (F4: 77)*
>
> *"In small departments that guy doesn't show up and you have to do it yourself. I think we are all members of a large team and we know that we count on taking certain risks because someone is going to have our back and help us. We are taught you don't do anything by yourself. If there is a tough job, you are going to have someone there to help you and that is not always the case in small departments."* (F5: 454)

Environmental factors at the scene also play a role in injury onset. Such factors include: working or moving about in small cramped spaces; stepping or walking onto icy surfaces or slippery floors; entering or working in buildings with structural deficiencies and weaknesses; and moving about in intense smoke where visibility is reduced. These are highlighted in the following quotes:

> *"I have twisted a knee a couple of times, different call; once just getting off the truck and another time in a fire situation. Sometimes the floors get wet; get a restaurant fire that is slippery."* (F3; 94)
>
> *"The environment we find ourselves in is not conducive to, you know, we are not always on our feet. If the room is hot and there is limited visibility we are on our knees. We may be trying to push furniture out of the way or try to drag somebody or drag a hose but it is on your knees in the dark under duress of the heat and adrenaline. "* (F5: 211)

Rescue situations also create unexpected circumstances that unintentionally place the firefighter in harms-way. Such situations require reactionary movements or actions to prevent personal injury, the need to extinguish or control a fire, or save a life. Although the firefighter may be cognizant of the threat of personal injury, their instincts produce an immediate reaction, which may predispose them to injury. For example,

"… when you are on the inside, you are actually at a fire and anything can happen. The fire the other night on (location)*; they put a ladder right next to the window to break the window and as soon as they broke the window, they threw a lady out at him, and he caught her holding onto the ladder with one arm out the side. So he was holding her. You know she is off the ladder and holding her like this; it is obviously not good for your back but that was never his intention when he got there."* (F5:195)

"There is a real fine line because we all know, that the guys who have done this for a while, that the first in, the initial actions when we are quick, we can turn a potential disaster into something that is manageable. If we don't get something done in time, it develops into something much more difficult to deal with. I think that is where we rush and that is the danger of those injuries." (F7:252)

"… you see big red and you know, 'Hey, there are people in the apartments above these stores. It is 1:30 in the morning, so we know we have to act fast.' And that is how he got injured and didn't realize until a couple of days later that he had broken his hand." (F5:27)

Influence of the inherent competitive firefighter culture:

No-fail attitude creates dangerous situations that generate scenarios for injuries. Despite all the participants understanding the consequences of advocating a no-fail attitude, it appears there is an inherent cultural attribute interwoven into the very fabric of firefighters.

"I had a deputy that completely did his disc in the back and it was because he was racing over to a hydrant and it wouldn't budge. So being the monster he was, he tried to force it and then the spindle let go and he just went flying and he said he felt his whole back let go." (F6: 203)

"But we approach this job also with a 'do not fail attitude.' So if the guy can't open the hydrant, he doesn't want to come back and tell his Captain he can't open a hydrant. So he is going to do as much as he can to keep working at that, even though there may be no way that he is opening it." (F5: 292)

"The jaws can weigh quite a bit but he doesn't want to give up the jaws even though he could get a little relief and get his muscles back into a relaxed state and regenerate his muscles and the he gets back on it. But just for them to say I'm done - no, that is not the firefighter mentality." (F1: 325).

In addition to the no-fail attitude, was another attitudinal factor reported as a critical to contributing to injury and limiting adherence to preventive strategies. This other attitude could be considered the antithesis of the no-fail attitude, namely complacency. Several participants, mostly the veterans in the focus group, suggested that complacency was the enemy of the firefighter:

> *"… so as the years roll by firefighters allow themselves to become deconditioned by not having calls every time they are at work. And looking around the room, there are good firefighters and good experienced firefighters, and they know the enemy is not fire or smoke, it is complacency."* (F6:484)

Importance of education and injury prevention:

Education and training programs were considered to be important by all participants in informing them of new procedures and preventing injuries. The nature and quality of these programs are key determining factors to their uptake and implementation. In particular, providing examples of activities carried out in *'controlled atmospheres'* were considered by participants as unrealistic and not representative of real life. As a consequence, participants reported they established their own processes and protocols. For example,

> *"The textbook teaches the rule but you have to use the exceptions, right, because he was taught how to put a ladder up in controlled atmosphere. He is not taught how to put a ladder up if there is an air conditioning unit in the way, a tree in the way, a bush in the way, overhead wires, or the house next door."* (F2:353)

In addition to formal education and training programs, firefighters experience plays a very important role in informing strategies to prevent, when possible, musculoskeletal injuries. Their experiences influence behaviour over time and in part, become a measure of the firefighter's ability to adapt to the situation. This is illustrated by the following veteran participant's comment:

> *"I think this profession is all about adaptability. We will take the best training in the perfect scenario, which we will try to teach the young guys coming out of the academy, but then we have to adapt it to every situation. Whether it is the environment, the incident itself, how many people we have to help us at that moment, we will make it work the best we can."* (F1: 380)
>
> *"He is going to think the extra things: is there someone below that I am going to injure, am I going to hurt my back, am I going to wear myself out, a bigger picture will help ultimately decrease injury."* (F6:969)

And this experience not only influences the individual firefighter but also their colleagues. The experienced firefighter appeared to act as a mentor, directly or indirectly, imparting their learned knowledge to younger recruits. This was noted by the youngest of the firefighters in the focus group:

> *"So the academy teaches you the textbook things and the basics, which are always a little bit different than real life 'cause they might be few extra steps that take a bit longer. So they teach you the way things are supposed to be done in the textbook and then you learn the real life by doing things that these guys have been doing for years."* (F9: 232)

However, participants' reflections suggest a more complex interplay between numerous factors. The combination of formal training, experience and commitment to deliver, can result in unsafe and dangerous actions. Thus, despite the best intentions of education and training programs, the inherent adaptability and no-fail attitude significantly influences firefighter's behaviour and actions. This is summarized in the following quote from an experienced participant:

> *"We get training to do things a certain way, a safe way but in the situation, and there are a lot of motivators that cause us to deviate from the safe slow way to do something, we put ourselves in harm's way and we will risk twisting a knee, twisting a back because we are committed to delivering a service. And if someone is asking for help on the worst day of their life, he we are very focused on helping them."* (F5:449)

4.0 Conclusion

There are a number of modifiable ergonomic risk factors that could decrease injury risk. Firefighters are clearly in need of education to modify these risk factors both in the hall and at callouts. The "no fail" attitude was also seen as a contributor to injury risk. Development of a serious game to decrease injury risk will need to include training on modifying ergonomic and psychological risk factors as well as training correct movements.

References

1. Lagacé C, Perruccio A, DesMeules M, Badley E. The impact of arthritis on Canadians. Arthritis in Canada. An ongoing challenge. Ottawa: Health Canada; 2003.

2. Stokes J, Desjardins S, Perruccio A. Economic Burden. Arthritis in Canada. An ongoing challenge. Ottawa: Health Canada; 2003.

3. <Kim et al_2004_cost-effectiveness of a back education prog for FF - a case study.pdf>.

4. DB C, GBJ A, BJ M. Occupational Biomechanics, 3rd ed. New York, NY: John Wiley & Sons; 1999.

5. FA F, WS M, P M. The role of complex, simultaneous trunk motions in the risk of occupation-related low back disorders. Spine. 1998;23(9):1035-42.

6. WS M, W K. The Occupational Ergonomics Handbook: Fundamentals and Assessment Tools for Occupational Ergonomics, 2nd ed. Boca Raton, FL: Taylor & Francis; 2006.

7. Hong O, Chin DL, Phelps S, Feld J, Vogel S. Occupational injuries, duty status, and factors associated with injuries among firefighters. Workplace Health Saf. 2012;60(12):517-23.

8. Jang R, Karwowski W, Quesada PM, Rodrick D, Sherehiy B, Cronin SN, et al. Biomechanical evaluation of nursing tasks in a hospital setting. Ergonomics. 2007;50(11):1835-55.

9. Hansen CD, Rasmussen K, Kyed M, Nielsen KJ, Andersen JH. Physical and psychosocial work environment factors and their association with health outcomes in Danish ambulance personnel -- a cross-sectional study. BMC public health. 2012;12:534.

10. Gentzler M, Stader S. Posture stress on firefighters and emergency medical technicians (EMTs) associated with repetitive reaching, bending, lifting, and pulling tasks. Work. 2010;37:227-39.

11. Gledhill N, Jamnik VK. Characterization of the physical demands of firefighting. Can J Sport Sci. 1992;17(3):207-13.

12. Poplin GS, Harris RB, Pollack KM, Peate WF, Burgess JL. Beyond the fireground: injuries in the fire service. Inj Prev. 2012;18(4):228-33.

13. Huijg JM, Gebhardt WA, Dusseldorp E, Verheijden MW, van der Zouwe N, Middelkoop BJ, et al. Measuring determinants of implementation behavior: psychometric properties of a questionnaire based on the theoretical domains framework. Implementation science : IS.

2014;9:33. PubMed PMID: 24641907. Pubmed Central PMCID: 4000005. Epub 2014/03/20. eng.

14. McDonough SL, Phillips J, Twilbeck T. Determining best practices to reduce occupational health risks in firefighters. J Strength Cond Res. 2015;Jan 6 [Epub ahead of print].

15. Poston WS, Haddock CK, Jahnke SA, Jitnarin N, Day RS. An examination of the benefits of health promotion programs for the national fire service. BMC public health. 2013;13:805.

16. Mayer JM, Nuzzo JL. Worksite back and core exercise in firefighters: effect on development of lumbar multifidus muscle size. Work. 2014;Jan 21 [Epub ahead of print].

17. Jahnke SA, Poston WS, Jitnarin N, Haddock CK. Health concerns of the U.S. fire service: perspectives from the firehouse. Am J Health Promot. 2012;27(2):111-8.

18. Koes BW, van Tulder MW, van der Windt WM, Bouter LM. The efficacy of back schools: a review of randomized clinical trials. J Clin Epidemiol. 1994 Aug;47(8):851-62. PubMed PMID: 7730888. Epub 1994/08/01. eng.

19. . !!! INVALID CITATION !!!

20. Deutsch JE. Virtual reality and gaming systems to improve walking and mobility for people with musculoskeletal and neuromuscular conditions. Stud Health Technol Inform. 2009;145:84-93. PubMed PMID: 19592788. Epub 2009/07/14. eng.

21. Fairhurst K, Strickland A, Maddern G. The LapSim virtual reality simulator: promising but not yet proven. Surgical Endoscopy. 2010:1-13.

22. Kron F, Gjerde C, Sen A, Fetters M. Medical student attitudes toward video games and related new media technologies in medical education. BMC medical education. 2010;10(1):50.

23. Marsh R, Hao X, Xu D, Wang Z, Duan Y, Liu J, et al. A Virtual Reality-Based FMRI Study of Reward-Based Spatial Learning. Neuropsychologia. 2010.

24. Cox DJ, Davis M, Singh H, Barbour B, Nidiffer FD, Trudel T, et al. Driving rehabilitation for military personnel recovering from traumatic brain injury using virtual reality driving simulation: a feasibility study. Mil Med. 2010 Jun;175(6):411-6. PubMed PMID: 20572473. Epub 2010/06/25. eng.

25. Kamper D, Connelly L, Jia Y, Toro M, Stoykov M, Kenyon R. A Pneumatic Glove and Immersive Virtual Reality Environment for Hand Rehabilitative Training after Stroke. IEEE Trans Neural Syst Rehabil Eng. 2010 Apr 8. PubMed PMID: 20378482. Epub 2010/04/10. Eng.

26. Lange BS, Requejo P, Flynn SM, Rizzo AA, Valero-Cuevas FJ, Baker L, et al. The potential of virtual reality and gaming to assist successful aging with disability. Phys Med Rehabil Clin N Am. 2010 May;21(2):339-56. PubMed PMID: 20494281. Epub 2010/05/25. eng.

27. Rand D, Weiss PL, Katz N. Training multitasking in a virtual supermarket: a novel intervention after stroke. Am J Occup Ther. 2009 Sep-Oct;63(5):535-42. PubMed PMID: 19785252. Epub 2009/09/30. eng.

28. Fink PW, Foo PS, Warren WH. Catching fly balls in virtual reality: a critical test of the outfielder problem. J Vis. 2009;9(13):14 1-8. PubMed PMID: 20055547. Epub 2010/01/09. eng.

29. Boulet G. Knowledge Transfer from Virtual Environments. eLearn. 2009;2009(8).

30. St. Julien TU, Shaw CD. Firefighter command training virtual environment. Diversity in computing; Atlanta, Georgia, USA. 948549: ACM; 2003. p. 30-3.

31. Sowndararajan A, Wang R, Bowman DA. Quantifying the benefits of immersion for procedural training. Proceedings of the 2008 workshop on Immersive projection technologies/Emerging display technologiges; Los Angeles, California. 1394672: ACM; 2008. p. 1-4.

32. Toups ZO, Kerne A, Hamilton W, Blevins A. Emergent team coordination: from fire emergency response practice to a non-mimetic simulation game. Proceedings of the ACM 2009 international conference on Supporting group work; Sanibel Island, Florida, USA. 1531725: ACM; 2009. p. 341-50.

33. Gee J. What video games have to teach us about learning and literacy. Computers in Entertainment (CIE). 2003;1(1):20.

34. Norman D. The future of education: Lessons learned from video games and museum exhibits. 2001;16(2004):2004.

35. Prensky M. Digital game-based learning. Computers in Entertainment (CIE). 2003;1(1):21.

36. Stapleton A. Serious games: Serious opportunities. 2004.

37. Simpson KM, Porter K, McConnell ES, Colon-Emeric C, Daily KA, Stalzer A, et al. Tool for evaluating research implementation challenges: a sense-making protocol for addressing implementation challenges in complex research settings. Implementation science : IS. 2013;8:2. PubMed PMID: 23281623. Pubmed Central PMCID: 3598718. Epub 2013/01/04. eng.

38. Morgan DL, Krueger RA. Focus Group Kit. In: Morgan D, editor. The focus group guidebook. Thousand Oaks, CA: Sage 1998.

39. Verhoef MJ, Mulkins A, Boon H. Integrative health care: how can we determine whether patients benefit? Journal of Alternative & Complementary Medicine. 2005;11(supplement 1).

40. Sandelowski M. Focus on Research Methods-Whatever Happened to Qualitative Description? Research in Nursing and Health. 2000;23(4):334-40.

41. Barbour RS. Making sense of focus groups. Medical Education. 2005;39(7):742-50.

Objective 2. The effects of exercise-induced heat stress on cognitive function in firefighters – **being finalized for submission**

Title: The effects of exercise-induced heat stress on cognitive function in firefighters

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ABSTRACT

Objectives: The aim of this study was to determine the effects of differing rates of increasing core temperature on cognitive function during exercise-induced heat stress.

Design: Nineteen male firefighters were exposed to repeated cognitive assessments, randomized and counter-balanced, in 30°C and 35°C and 50% humidity.

Methods: Participants performed treadmill walking (4.5 $km \cdot h^{-1}$ and 2.5% grade) with cognitive function assessed before exercise (PRE), after mounting the treadmill (Cog 1), at core temperatures of 37.8°C (Cog 2), 38.5°C (Cog 3), and 39.0°C (Cog 4), after dismounting the treadmill (POST), and following an active cooling recovery to a core temperature of 37.8°C (REC). The cognitive tests implemented at PRE and POST were spatial working memory (SWM), rapid visual information processing (RVP), and reaction time (RTI) while paired associates learning (PAL) and spatial span (SSP) were assessed at Cog 1, Cog 2, Cog 3, and Cog 4. All five cognitive tests were assessed at REC.

Results: Planned contrasts revealed that SSP and PAL were impaired at Cog 3, with SSP also impaired at Cog 4 compared to Cog 1. REC revealed no difference compared to Cog 1, but increased errors compared to Cog 2 for PAL.

Conclusions: The decrements in cognitive function observed at a core temperature of 38.5°C are likely attributed to the cognitive resources required to maintain performance being overloaded due to increasing task complexity and external stimuli from exercise-induced heat stress. The addition of an active cooling recovery restored cognitive function to initial levels.

Keywords: decision making, working memory, executive function, reaction time, emergency responders, occupational injuries

Introduction

Firefighting requires tremendous physical and cognitive resources to perform safe and effective operations(Barr, Gregson, & Reilly, 2010). Cognitive demands for firefighters include assessing and executing critical decisions along with situational awareness to determine the safest means of exiting the emergency scene (Barr et al., 2010). Research about the effects of thermal stress on cognitive function for firefighters is limited.

A limitation of previous work using simple cognitive tasks is they are not sensitive to the changes in cognitive function that occur during or following firefighting activities in the heat (D. L. Smith & Petruzzello, 1998). One study addressed this by using a standardized testing battery, the Cambridge Neuropsychological Test Automated Battery (CANTAB), which assesses more complex cognitive tasks, such as sustained attention and working memory capacity, as well as reaction time (Rayson et al., 2005). No impairments in cognitive function were revealed with the live-fire simulation, however, the cognitive tests were administered 30 min after the heat stress protocol, which may have allowed any negative effects of heat stress to dissipate(Rayson et al., 2005).

Despite limited research on firefighters, numerous studies have examined the effect of heat stress on cognitive function within the general population. Early data suggested it was the dynamic change in core temperature that limited cognitive function and not the absolute core temperature attained (Allan & Gibson, 1979). In a review of the literature, P. Hancock and Vasmatzidis (1998) proposed new threshold curves for the dynamic rise in deep body temperature for vigilance, dual-task demands, neuro-muscular co-ordination tasks, simple mental performance, and the physiological tolerance limit at 0.055, 0.22, 0.88, 1.32, and 1.65 $^{\circ}C \cdot h^{-1}$, respectively. Further, it appears that task complexity is a major factor on performance in the heat (P. Hancock & Vasmatzidis, 2003). In a subsequent review, P. Hancock and Vasmatzidis (2003) suggested that more complex tasks including vigilance, tracking, and multiple tasks conducted simultaneously are more vulnerable to heat stress than simple tasks, such as reaction time and mental transformation.

This study aimed to examine the effects of exercise-induced heat stress (EIHS) on cognitive function using core temperature (T_{core}), rather than time of exposure, as the independent variable (Wright, McLellan, Friesen, Casa, & Kenny, 2012). The impact of differing rates of increase in T_{core} were studied together with an active cooling recovery similar to that performed on the fire ground (G. Selkirk, McLellan, & Wong, 2004). We hypothesized that aspects of cognitive function relevant to firefighting would be impaired with increasing levels of T_{core} and subsequently restored following active cooling recovery.

Methods

The research protocol was approved by the Office of Research Ethics at the University of Ontario Institute of Technology (REB #13-076) and informed written consent was obtained prior to participation in the study. Nineteen male firefighters were recruited to take part in each phase of testing. Participants were requested to refrain from vigorous exercise, alcohol, non-steroidal anti-inflammatories, and sleep medication in the 24 hours prior to testing and to refrain from consuming alcohol or nicotine 12 hours prior to arrival. Inclusion criteria were (1) incumbent firefighter, (2) age less than 50 years, (3) not currently taking medication, and (4) urine specific gravity (USG) less than 1.030,(values higher indicate serious dehydration(Casa et al., 2000)), prior to the EIHS protocol.

Testing was conducted on 3 separate days, 1 day for familiarization of the CANTAB battery, and 2 days for the EIHS and cognitive function protocols. All EIHS trials were conducted at the University of Ontario Institute of Technology’s ACE climate chamber at 30°C or 35°C and 50% relative humidity, with wind speed maintained at $\leq 0.1\ m \cdot s^{-1}$. The EIHS trials were randomized and at least 28 days apart during the winter months (January through April) to limit any potential effects of acute heat acclimation by the firefighters (G. A. Selkirk & McLellan, 2004).

Nine participants attended the climate chamber at 0800 h and 10 participants began testing at 1200 h on both testing days after ingesting a core temperature (T_{core}) radio-pill (HQ Inc, Palmetto, FL) approximately 6 to 9 hours prior to attending the EIHS trials. Upon arrival, each participant had their nude body mass measured on a digital scale (Tanita, Arlington Heights, IL) to 0.1 kg and USG analyzed (Atago Co., LTD., Tokyo, Japan). Physiological measurements included T_{core}, heart rate (HR) using a transmitter (Polar, Kempele, Finland) attached around the chest with a wearable strap, and percent body fat was evaluated by four skinfold sites (triceps, subscapular, abdomen, and thigh) and then calculated using a specific formula developed by Jackson, Pollock, and Ward (1980). Subjective measures of thermal sensation (Gagge, Stolwijk, & Hardy, 1967) and rating of perceived exertion (RPE) (Borg, 1970) were recorded immediately following cognitive tests (Cog, 2,3 and 4).

Once instrumented, participants (wearing station gear consisting of pants and short-sleeved t-shirt) donned their bunker pants (PPC1) and completed the pre-test (PRE) cognitive assessment. Then, participants donned their jacket, flash hood, gloves, helmet, and self-contained breathing apparatus (SCBA) with face-piece (PPC2). Participants began treadmill walking at 4.5 $km \cdot h^{-1}$ and 2.5% grade while performing Cog 1. Treadmill walking continued until they either completed: (i) 30 min of exercise, at which time they would receive a 5-min rest break and wear PPC1and jacket or (ii) reached a level of 37.8°C where they would then complete Cog 2. Following Cog 2, participants were seated for 10-min wearing only PPC1 and jacket. After, participants donned PPC2 and completed the same work to rest ratio until T_{core} reached levels of 38.5°C (Cog 3) and 39.0°C or declaring 10-min of exercise remaining until volitional fatigue (Cog 4). Participants removed PPC2 and performed the post-test (POST) while seated. Next, participants were placed in active cooling recovery by sitting in a chair (DQE, Inc., Fishers, IN) and submerging their hands and forearms in 15-20°C water until their T_{core} returned to 37.8°C and then completed the recovery (REC) cognitive assessment trial. Previous work has suggested that the final T_{core} of firefighters in similar ambient conditions is approximately 39.0°C (G. A. Selkirk & McLellan, 2004). This study utilized T_{core} as the independent variable rather than time of exposure(Wright et al., 2012) with similar targets of T_{core} as investigated by Gaoua, Grantham, El Massioui, Girard, and Racinais (2011).

Due to volitional fatigue, only 13 and 12 participants were able to reach Cog 4 in the 30°C and 35°C conditions, respectively. To mitigate the potential for dehydration, participants were given
5 $mL \cdot kg^{-1}$ (G. A. Selkirk & McLellan, 2004) of warm water (37°C) before PRE and following Cog 2, 3, 4, and active cooling recovery to avoid influencing measurements with the radio-pill. Upon completion of REC, participants removed their PPC within 5-min and toweled off any remaining sweat to determine final nude mass.

Cognitive function was assessed using the CANTAB battery (Cambridge Cognition, Cambridge, UK), specifically (i) visual episodic memory, PAL (paired associates learning), ii) processing and psychomotor speed, RTI (reaction time), (iii) visuospatial working memory, SSP (spatial span), iv) working memory and strategy, SWM (spatial working memory), and v) sustained attention, RVP (rapid visual information processing). During exercise (Cog 1, 2, 3, 4) only PAL and SSP were assessed, whereas before (PRE) and after exercise (POST and REC) the complete CANTAB battery was performed. A more comprehensive description of each cognitive assessment can be found in Bourke et al. (2012) and Rayson et al. (2005).

There was no main effect of time of day on the performance of cognitive function. As a result, all participants were grouped together for subsequent analyses. Normality for each of the dependent variables was confirmed using the Shapiro-Wilks test. A one-within (cognitive trial) and one-between (condition) repeated measures ANOVA was conducted on dependent measures for RTI, SWM, RVP, TS, RPE, and overall $\Delta T_{core.}$ Simple effects analysis using a Bonferroni correction was conducted when a significant interaction effect was found. Linear mixed model (LMM) analysis was performed for PAL, SSP, PSI, and ΔT_{core} during each cognitive trial. Condition and cognitive trial were entered into the model as fixed factors, with subjects entered as a random factor for the PAL, SSP, and PSI analysis, whereas condition and time were entered as fixed factors for ΔT_{core}. The covariance structure for repeated measures was auto-regressive (AR1) with the interaction removed from the final model when nonsignificant. *A-priori* planned contrasts were analyzed compared to PRE (for SWM, RVP, RTI) or Cog 1 (for PAL, SSP) for each cognitive assessment trial and Cog 2 for all trials to determine effects of active cooling recovery.

The dynamic change in T_{core} (ΔT_{core}), the initial $T_{core,,}$ the final T_{core}, pre-nude body mass, percent change in body mass, hydration, USG, and end-point HR were each compared between conditions using paired t-tests. Statistical significance for all analyses was set at an alpha level of ≤ 0.05. Data are presented as the mean ± standard error of the mean.

Results

Mean vales for age, years of firefighting service, body mass, height, body mass index (BMI), and percent body fat were 35.6 ± 2.0 years, 10.0 ± 2.1 years, 85.1 ± 12.6 kg, 1.76 ± 0.07 m, 27.3 ± 3.2 $kg \cdot m^{-2}$, and 16.7 ± 5.8%, respectively. Data for initial and final T_{core}, ΔT_{core}, T_{core} at the start of each cognitive trial, exposure time, work duration, end-point HR, change in body mass, and fluid intake are depicted in table 1. Final T_{core}, ΔT_{core}, exposure time, and work duration were all significantly greater in 35°C ($p \leq 0.05$). Figure 1 reveals data for ΔT_{core} (normalized to the percent of the protocol completed to account for varying exposure times between participants) over the duration of heat exposure (Figure 1A) and during the individual cognitive trials (Figure 1B). ΔT_{core} over the duration of heat exposure revealed an interaction effect (condition x cognitive trial) with simple effects revealing 35°C was elevated at 40, 50, 60, and 70% of the protocol completed ($p \leq 0.05$). Individual LMMs of ΔT_{core} at each cognitive trial revealed a main effect of condition with 35°C greater at Cog 2, 3, 4, and POST ($p \leq 0.05$).

Simple reaction time (Figure 2A) revealed a main effect of cognitive trial ($p \leq 0.05$) with planned contrasts revealing a faster reaction time at POST ($p \leq 0.05$). SWM token search time (Figure 2B) revealed a main effect of cognitive trial ($p \leq .05$). Total correct rejections (Figure 2C) for the RVP test revealed a main effect of cognitive trial ($p \leq 0.05$) with planned contrasts showing increases in correct rejections at POST ($p \leq 0.05$) compared to PRE. RVP latency (Figure 2D), indicating the time to respond following a correctly identified three-digit sequence, revealed a main effect of cognitive trial ($p \leq 0.05$) with planned contrasts indicating a faster latency at POST ($p \leq 0.05$) compared to PRE.

PAL total errors at the 8-object level, adjusted for test termination prior to this level, (Figure 2E) revealed a main effect of cognitive trial ($p \leq 0.05$) with planned contrasts indicating at Cog 3 there were significantly more errors compared to Cog 1 (p 0.05). Planned contrasts revealed a difference between Cog 2 and REC ($p \leq 0.05$) with no difference between Cog 1 and REC. Span length (Figure 2F) observed during the SSP test revealed a main effect of cognitive trial ($p \leq 0.05$) with planned contrasts indicating a significantly shorter length achieved at Cog 3 and Cog 4 ($p \leq 0.05$) compared to Cog 1. All other cognitive variables revealed no main effects.

TS revealed a main effect of time ($p \leq 0.05$) with post-hoc analysis indicating that participants reported feeling hotter at Cog 3 (3.2 ± 0.2 vs 3.4 ± 0.1) and Cog 4 (3.4 ± 0.2 vs 3.6 ± 0.1) compared to Cog 2 (2.5 ± 0.2 vs 2.8 ± 0.2) in the 30°C and 35°C conditions, respectively ($p \leq 0.05$). RPE revealed a main effect of condition, time, and interaction ($p \leq .05$) with values in the 30°C condition of 12.2 ± 0.3, 15.4 ± 0.6, 16.4 ± 0.7 and in the 35°C condition of 13.6 ± 0.6, 15.5 ± 0.6, 16.4 ± 0.7 for Cog 2, Cog 3, and Cog 4, respectively. Simple effects analysis between conditions revealed a significantly lower RPE at Cog 2 in the 30°C condition, while within-group analysis indicated that Cog 2 was significantly lower than both Cog 3 and Cog 4 ($p \leq 0.05$) for both conditions.

Discussion

This study found impairments in visuospatial working memory, visual episodic memory, and executive function once a core temperature of 38.5°C was attained at two different rates of increasing T_{core} (0.85 and 1.40 °C·hr^{-1}), with accompanying elevations in HR and psychophysiological indices. The implementation of an active cooling recovery restored cognitive function to initial levels. Firefighters performing moderate-intensity activities at an emergency scene in a hot, humid environment will be challenged with increased metabolic rate, impaired thermoregulation due to PPC, as well as elevated T_{sk} and HR. The current data reveal that reaching a core temperature of 38.5°C may impair aspects of cognitive function.

One explanation for the impairments observed in cognitive function is the Global Workplace Theory (GWT) suggested by Baars (Baars, 2005). The GWT suggests that the cognitive capacity of humans is limited by the various external stimuli constantly competing for the limited conscious processes available to successfully execute the proper outcome of a task [16]. Similarly, the inclusion of a motor task (treadmill walking) during the SSP and PAL tests resulted in a motor plus cognitive task. Dietrich [17] proposed the transient hypofrontality theory, stating that dynamic movements of the body require an increase in brain activation, which appears to specifically affect the prefrontal cortex by reallocating neural resources to perform cognitive tasks. Previous studies have shown that Corsi Block Test, analogous to the SSP test, generates significant activation in the ventro-lateral prefrontal cortex [18] as well as a neural network encompassing the visual occipital, posterior parietal, and dorsolateral prefrontal cortices [19], and the hippocampus during encoding of spatial locations [20]. The potential reallocation of neural resources from the prefrontal cortex may provide an explanation for the impaired performance in the SSP test.

In addition, the PAL test has been shown to increase activity in the hippocampus (during encoding of a newly shown object) and parahippocampal gyrus (during retrieval of the location of the object) with increasing task complexity [21]. Previous research has found that exercise and hyperthermia resulted in reduced middle cerebral blood flow (L. Nybo & Nielsen, 2001) with regional decreases in the hippocampus and prefrontal cortex (Qian et al., 2014). However, subsequent research showed that the reduction in global cerebral blood flow (gCBF) during exercise, producing an increase in T_{core} of 1.6°C, resulted in a 7% increase in cerebral oxygen uptake, likely attributed to a Q_{10} effect of higher tissue temperature (Lars Nybo, Møller, Volianitis, Nielsen, & Secher, 2002). In addition, Qian et al. (2014) found regional blood flow decreases in the hippocampus and prefrontal cortex following passive heat stress in 50°C. The current findings suggest the increase in cognitive resources required to perform the SSP and PAL tests at a T_{core} of 38.5°C combined with exercise resulted in the impaired cognition.

Active cooling recovery to a T_{core} of 37.8°C resulted in restoration of visuospatial memory and visual episodic memory to initial levels. Previous work has reported decrements in memory recall 60 and 120-min following treadmill exercise at 33-35°C (Morley et al., 2012) as well as impairments in visual declarative memory immediately following a simulated fire emergency with reductions in working memory 20-min post simulation (Robinson, Leach, Owen-Lynch, & Sunram-Lea, 2013). Cognitive impairments following an emergency scenario can put firefighters in increased danger upon performing additional duties, re-exposure at the scene, or emergency calls later in their shift. The data from the current study reveal the importance of an active cooling recovery protocol not only to reduce physiological strain but also improve cognitive function to perform duties within the same work shift.

The direction of T_{core} declined during the POST and REC cognitive assessments. Allan and Gibson (Allan & Gibson, 1979) have shown that the direction of ΔT_{core} may have a substantial impact on cognitive function, with greater impairments observed when T_{core} is rising compared to falling between T_{core} of 37.9 and 38.5°C. The cognitive task implemented took 60s to complete, and, although not specifically stated by the authors, T_{core} would have been falling up to 0.3°C during each assessment, similar to the changes in the current study. Hancock (P. A. Hancock, 1986) has also suggested that achieving heat balance, separate from the degree of T_{core} increases, can result in restoration of cognitive function. In contrast, similar to previous findings, simple reaction time (D. L. Smith & Petruzzello, 1998) and latency reaction time on the RVP (Schlader et al., 2015) test were faster immediately post-heat stress and then returned to initial levels following active cooling recovery.

The findings in this study have potential applications for Incident Commanders who are in charge of strategic and tactical planning while at an emergency scenario. Based on the "Incident Commander's Guide" developed by McLellan and Selkirk (McLellan & Selkirk, 2006), firefighters performing moderate-intensity work (such as primary search, overhaul, ladder setup, and vehicle extrication) at 35°C and 50% humidity would attain a T_{core} of 38.5°C in 53-min. Firefighters in the current study required 58.2 ± 4.5-min to reach a T_{core} of 38.5°C. These findings suggest that aspects of cognitive function are impaired after performing specific job tasks in this condition for approximately 50 to 60-min. With this knowledge, Incident

Commanders will be able to move firefighters to an active cooling recovery station before sending them back into the emergency scenario. Furthermore, this is the first study to show that cognitive function appears to be restored to initial levels after an active cooling recovery following EIHS, emphasizing the need for active cooling recovery during firefighting job tasks in hot environmental conditions (G. Selkirk et al., 2004).

Conclusion

This study found that at two different rates of increasing T_{core} visuospatial working memory, visual episodic memory, and executive function, were impaired when T_{core} reached a level of 38.5°C, with continued impairments in visuospatial working memory and executive function at T_{core} of 39.0°C. These data, combined with previous findings, can be applied to any emergency scenario while working in the heat to provide the Fire Service with information regarding the length of time firefighters can perform job tasks before reaching levels that may result in impaired cognition. This study confirms the necessity of an active cooling protocol following work in the heat to not only reduce T_{core} but to simultaneously reduce the impact on cognitive function before performing further job tasks.

Practical Implications

- Impairments in certain aspects of cognition may occur as early as a core temperature of 38.5°C given that the dynamic rate of increase is at least $0.85°C \cdot hr^{-1}$.
- Performing moderate intensity work can elicit this level of core temperature in under one hour.
- Implementing an active cooling recovery protocol using forearm submersion in a water bath can return cognitive function to pre-exercise levels.

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References

Allan, J. R., & Gibson, T. M. (1979). Separation of the effects of raised skin and core temperature on performance of a pursuit rotor task. *Aviation Space and Environmental Medicine, 50*(7), 678-682.

Arthur, E., & Hancock, P. (2001). Navigation training in virtual environments. *International Journal of Cognitive Ergonomics, 5*(4), 387-400.

Austin, C. C., Dussault, G., & Ecobichon, D. J. (2001). Municipal firefighter exposure groups, time spent at fires and use of self-contained-breathing-apparatus. *American Journal of Industrial Medicine, 40*(6), 683-692.

Baars, B. J. (2005). Global workspace theory of consciousness: toward a cognitive neuroscience of human experience. *Progress in Brain Research, 150*, 45-53.

Backlund, P., Engström, H., Gustavsson, M., Johannesson, M., Lebram, M., & Sjörs, E. (2009). SIDH: A Game-Based Architecture for a Training Simulator. *International Journal of Computer Games Technology, 2009*.

Backlund, P., Engstrom, H., Hammar, C., Johannesson, M., & Lebram, M. (2007). *Sidh-a game based firefighter training simulation*.

Backlund, P., Engstrom, H., Hammar, C., Johannesson, M., & Lebram, M. (2007, 4-6 July 2007). *Sidh - a Game Based Firefighter Training Simulation.* Paper presented at the Information Visualization, 2007. IV '07. 11th International Conference.

Baker, S. J., Grice, J., Roby, L., & Matthews, C. (2000). Cardiorespiratory and thermoregulatory response of working in fire-fighter protective clothing in a temperate environment. *Ergonomics, 43*(9), 1350-1358.

Barbour, R. S. (2005). Making sense of focus groups. *Medical Education, 39*(7), 742-750.

Barr, D., Gregson, W., & Reilly, T. (2010). The thermal ergonomics of firefighting reviewed. *Applied Ergonomics, 41*(1), 161-172.

Becker, K., & Parker, J. R. (2011). *The Guide to Computer Simulations and Games*: Wiley.

Bellotti, F., Kapralos, B., Lee, K., Moreno-Ger, P., & Berta, R. (2013). Assessment in and of Serious Games: An Overview. *Advances in Human-Computer Interaction, 2013*.

Bente, G., & Breuer, J. (2009). Making the implicit explicit. Embedded measurement in serious games. *Serious Games: Mechanisms and Effects. Routledge*.

Blascovich, J., & Bailenson, J. (2011). *Infinite reality: Avatars, eternal life, new worlds, and the dawn of the virtual revolution*: William Morrow & Co.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine, 2*(2), 92.

Born, M., & Wolf, E. (1999). *Principles of optics: electromagnetic theory of propagation, interference and diffraction of light*: CUP Archive.

Boulet, G. (2009). Knowledge Transfer from Virtual Environments. *eLearn, 2009*(8). doi: http://doi.acm.org/10.1145/1595390.1597816

Bourke, C., Porter, R. J., Carter, J. D., McIntosh, V. V., Jordan, J., Bell, C., . . . Joyce, P. R. (2012). Comparison of neuropsychological functioning and emotional processing in major depression and social anxiety disorder subjects, and matched healthy controls. *Australian and New Zealand Journal of Psychiatry, 46*(10), 972-981.

Bukowski, R., & Sequin, C. (1997). *Interactive simulation of fire in virtual building environments*.

Casa, D. J., Armstrong, L. E., Hillman, S. K., Montain, S. J., Reiff, R. V., Rich, B. S., . . . Stone, J. A. (2000). National Athletic Trainers' Association position statement: fluid replacement for athletes. *J Athl Train, 35*(2), 212.

Cassell, J., McNeill, D., & McCullough, K. E. (1999). Speech-gesture mismatches: Evidence for one underlying representation of linguistic and nonlinguistic information. *Pragmatics &# 38; Cognition, 7*(1), 1-34.

Cha, M., Han, S., Lee, J., & Choi, B. (2012). A virtual reality based fire training simulator integrated with fire dynamics data. *Fire safety journal, 50*, 12-24.

Chen, S., & Michael, D. (2005). Proof of learning: Assessment in serious games. *Retrieved October, 17*, 2008.

Chittaro, L., & Ranon, R. (2009). *Serious games for training occupants of a building in personal fire safety skills.* Paper presented at the Games and Virtual Worlds for Serious Applications, 2009. VS-GAMES'09. Conference in.

Cian, C., Barraud, P., Melin, B., & Raphel, C. (2001). Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration. *International Journal of Psychophysiology, 42*(3), 243-251.

Cian, C., Koulmann, N., Barraud, P., Raphel, C., Jimenez, C., & Melin, B. (2000). Influences of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration. *Journal of Psychophysiology, 14*(1), 29.

Clark, W. E. (1991). Chapter 5: Firefighting Tactics *Firefighting Principles and Practice, 2nd edition* (pp. 87). Saddlebrook NJ: PennWell Books.

Coleman, J. (2002). Strategy vs. Tactics. *Fire Engineering*. http://www.fireengineering.com/articles/print/volume-155/issue-12/departments/roundtable/strategy-vs-tactics.html

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education, 59*(2), 661-686.

Cox, D. J., Davis, M., Singh, H., Barbour, B., Nidiffer, F. D., Trudel, T., . . . Moncrief, R. (2010). Driving rehabilitation for military personnel recovering from traumatic brain injury using virtual reality driving simulation: a feasibility study. *Military Medicine, 175*(6), 411-416.

Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM, 35*(6), 64-72.

DB, C., GBJ, A., & BJ, M. (1999). *Occupational Biomechanics, 3rd ed.* New York, NY: John Wiley & Sons.

DeChamplain, A., Rosendale, E., McCabe, I., Stephan, M., Cole, V., & Kapralos, B. (2012). *Blaze: A serious game for improving household fire safety awareness.* Paper presented at the Games Innovation Conference (IGIC), 2012 IEEE International.

Deutsch, J. E. (2009). Virtual reality and gaming systems to improve walking and mobility for people with musculoskeletal and neuromuscular conditions. *Studies in Health Technology and Informatics, 145*, 84-93.

Dugdale, J., & Pavard, B. (2002). The complexity of an emergency fire incident: the case of a hotel fire. *Complexity in Social Science (COSI) project report, work task two*.

Dugdale, J., Pavard, B., Pallamin, N., el Jed, M., & Maugan, C. L. (2004). *Emergency fire incident training in a virtual world*.

Duncan, H. W., Gardner, G. W., & Barnard, R. J. (1979). Physiological responses of men working in fire fighting equipment in the heat. *Ergonomics, 22*(5), 521-527.

Environmental Tectonics Corportation. (2012). ADMS-The advanced disaster management simulator. from http://trainingfordisastermanagement.com

FA, F., WS, M., & P, M. (1998). The role of complex, simultaneous trunk motions in the risk of occupation-related low back disorders. *Spine, 23*(9), 1035-1042.

Fairhurst, K., Strickland, A., & Maddern, G. (2010). The LapSim virtual reality simulator: promising but not yet proven. *Surgical Endoscopy*, 1-13.

Farmer, E., Van Rooij, J., Riemersma, J., Jorna, P., & Moraal, J. (1999). Handbook of simulator-based training.
Fink, P. W., Foo, P. S., & Warren, W. H. (2009). Catching fly balls in virtual reality: a critical test of the outfielder problem. *J Vis, 9*(13), 14 11-18. doi: 10.1167/9.13.14
Finney, M. A. (1994). *FARSITE: a fire area simulator for fire managers.* Paper presented at the the Proceedings of The Biswell Symposium, Walnut Creek, California.
Foley, J. D., Dam, A. v., Feiner, S. K., Hughes, J. F., & Carter, M. P. (1997). Computer Graphics: Principles and Practice, in C. *Color Research and Application, 22*(1), 65-65.
Forney, G. P. (2007). Visualization, A Tool For Understanding Fire Dynamics. *NISTIR7431, NIST*, 1-13.
Forney, G. P., & McGrattan, K. B. (2008). User's guide for Smokeview version 5-A tool for visualizing fire dynamics simulation data. *NIST Special Publication, 1017*.
Gagge, A., Stolwijk, J., & Hardy, J. (1967). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. *Environmental Research, 1*(1), 1-20.
Gamberini, L. (2000). Virtual reality as a new research tool for the study of human memory. *Cyberpsychology & Behavior, 3*(3), 337-342.
Gamberini, L., Cottone, P., Spagnolli, A., Varotto, D., & Mantovani, G. (2003). Responding to a fire emergency in a virtual environment: different patterns of action for different situations. *Ergonomics, 46*(8), 842-858.
Gaoua, N., Grantham, J., El Massioui, F., Girard, O., & Racinais, S. (2011). Cognitive decrements do not follow neuromuscular alterations during passive heat exposure. *International Journal of Hyperthermia, 27*(1), 10-19.
Gee, J. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment (CIE), 1*(1), 20.
Gentzler, M., & Stader, S. (2010). Posture stress on firefighters and emergency medical technicians (EMTs) associated with repetitive reaching, bending, lifting, and pulling tasks. *Work, 37*, 227-239.
Gledhill, N., & Jamnik, V. K. (1992). Characterization of the physical demands of firefighting. *Can J Sport Sci, 17*(3), 207-213.
Grimwood, P. (2000). " NEW WAVE" 3-D WATER FOG TACTICS: A RESPONSE TO DIRECT ATTACK ADVOCATES. *Fire Engineering, 153*(10), 89-99.
Hancock, P., & Vasmatzidis, I. (1998). Human occupational and performance limits under stress: the thermal environment as a prototypical example. *Ergonomics, 41*(8), 1169-1191. doi: Doi 10.1080/001401398186469
Hancock, P., & Vasmatzidis, I. (2003). Effects of heat stress on cognitive performance: the current state of knowledge. *International Journal of Hyperthermia, 19*(3), 355-372.
Hancock, P. A. (1986). Sustained attention under thermal stress. *Psychological Bulletin, 99*(2), 263.
Hansen, C. D., Rasmussen, K., Kyed, M., Nielsen, K. J., & Andersen, J. H. (2012). Physical and psychosocial work environment factors and their association with health outcomes in Danish ambulance personnel -- a cross-sectional study. *BMC Public Health, 12*, 534.
Hong, O., Chin, D. L., Phelps, S., Feld, J., & Vogel, S. (2012). Occupational injuries, duty status, and factors associated with injuries among firefighters. *Workplace Health Saf, 60*(12), 517-523.
Houtkamp, J., & Bos, F. (2007). *Evaluation of a virtual scenario training for leading firefighters*.
Hsiao, H., Weaver, D., Hsiao, J., Whitestone, J., Kau, T.-Y., Whisler, R., & Ferri, R. (2014). Comparison of measured and self-reported anthropometric information among firefighters: implications and applications. *Ergonomics*(ahead-of-print), 1-12.
Huijg, J. M., Gebhardt, W. A., Dusseldorp, E., Verheijden, M. W., van der Zouwe, N., Middelkoop, B. J., & Crone, M. R. (2014). Measuring determinants of implementation behavior: psychometric

properties of a questionnaire based on the theoretical domains framework. *Implement Sci, 9*, 33. doi: 10.1186/1748-5908-9-33

Hulusic, V., Harvey, C., Debattista, K., Tsingos, N., Walker, S., Howard, D., & Chalmers, A. (2012). *Acoustic Rendering and Auditory–Visual Cross-Modal Perception and Interaction.* Paper presented at the Computer Graphics Forum.

Jackson, A. S., Pollock, M. L., & Ward, A. (1980). Generalized equations for predicting body density of women. *Medicine and Science in Sports and Exercise, 12*(3), 175.

Jager, M., & Luttmann, A. (1991). Compressive strength of lumbar spine elements related to age, gender, and other influences. *Electromyographical Kinesiology. Amsterdam: Elsevier*, 291-294.

Jahnke, S. A., Poston, W. S., Jitnarin, N., & Haddock, C. K. (2012). Health concerns of the U.S. fire service: perspectives from the firehouse. *Am J Health Promot, 27*(2), 111-118.

Jang, R., Karwowski, W., Quesada, P. M., Rodrick, D., Sherehiy, B., Cronin, S. N., & Layer, J. K. (2007). Biomechanical evaluation of nursing tasks in a hospital setting. *Ergonomics, 50*(11), 1835-1855.

Julien, T. U. S., & Shaw, C. D. (2002). *Firefighter training virtual environment*. Paper presented at the ACM SIGGRAPH 2002 conference abstracts and applications, San Antonio, Texas.

Kamper, D., Connelly, L., Jia, Y., Toro, M., Stoykov, M., & Kenyon, R. (2010). A Pneumatic Glove and Immersive Virtual Reality Environment for Hand Rehabilitative Training after Stroke. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*. doi: 10.1109/tnsre.2010.2047588

Koes, B. W., van Tulder, M. W., van der Windt, W. M., & Bouter, L. M. (1994). The efficacy of back schools: a review of randomized clinical trials. *Journal of Clinical Epidemiology, 47*(8), 851-862.

Korhonen, T., Hostikka, S., Heliövaara, S., Ehtamo, H., & Matikainen, K. (2007). *Integration of an agent based evacuation simulation and the state-of-the-art fire simulation.* Paper presented at the Proceedings of the 7th Asia-Oceania Symposium on Fire Science & Technology.

Kron, F., Gjerde, C., Sen, A., & Fetters, M. (2010). Medical student attitudes toward video games and related new media technologies in medical education. *BMC Medical Education, 10*(1), 50.

Kuligowski, E. (2013). Predicting human behavior during fires. *Fire Technology, 49*(1), 101-120.

Lagacé, C., Perruccio, A., DesMeules, M., & Badley, E. (2003). *The impact of arthritis on Canadians. Arthritis in Canada. An ongoing challenge.* Ottawa: Health Canada.

Lange, B. S., Requejo, P., Flynn, S. M., Rizzo, A. A., Valero-Cuevas, F. J., Baker, L., & Winstein, C. (2010). The potential of virtual reality and gaming to assist successful aging with disability. *Physical Medicine and Rehabilitation Clinics of North America, 21*(2), 339-356. doi: 10.1016/j.pmr.2009.12.007

Leamon, T. B. (1994). Research to reality: a critical review of the validity of various criteria for the prevention of occupationally induced low back pain disability. *Ergonomics, 37*(12), 1959-1974.

Lebram, M., Backlund, P., Engström, H., & Johannesson, M. (2009). Design and Architecture of Sidh–a Cave Based Firefighter Training Game. *Design and Use of Serious Games*, 19-31.

Li, W., Jin, Y., Li, J., Guo, G., Peng, G., & Chen, C. (2004). *Collaborative forest fire fighting simulation*.

Liu, Z., Kashef, A., Lougheed, G., & Benichou, N. (2002). *Review Of Three Dimensional Water Fog Techniques For Firefighting*: National Research Council Canada, Institute for Research in Construction.

Lusa, S., Louhevaara, V., & Kinnunen, K. (1994). Are the job demands on physical work capacity equal for young and aging firefighters? *Journal of Occupational Medicine, 36*(1), 70-74.

Marsh, R., Hao, X., Xu, D., Wang, Z., Duan, Y., Liu, J., . . . Tau, G. (2010). A Virtual Reality-Based FMRI Study of Reward-Based Spatial Learning. *Neuropsychologia*.

Mayer, J. M., & Nuzzo, J. L. (2014). Worksite back and core exercise in firefighters: effect on development of lumbar multifidus muscle size. *Work, Jan 21 [Epub ahead of print]*.

McDonough, S. L., Phillips, J., & Twilbeck, T. (2015). Determining best practices to reduce occupational health risks in firefighters. *J Strength Cond Res, Jan 6 [Epub ahead of print]*.

McGrattan, K. B., Klein, B., Hostikka, S., & Floyd, J. (2008). Fire Dynamics Simulator (Version 5), User's Guide. *NIST special publication, 1019*(5), 1-186.

McLellan, T. M., & Selkirk, G. A. (2006). The management of heat stress for the firefighter: a review of work conducted on behalf of the Toronto Fire Service. *Industrial Health, 44*(3), 414-426.

McNeill, D. (1996). *Hand and mind: What gestures reveal about thought*: University of Chicago Press.

Morgan, D. L., & Krueger, R. A. (1998). Focus Group Kit. In D. Morgan (Ed.), *The focus group guidebook*

Thousand Oaks, CA: Sage

Morley, J., Beauchamp, G., Suyama, J., Guyette, F. X., Reis, S. E., Callaway, C. W., & Hostler, D. (2012). Cognitive function following treadmill exercise in thermal protective clothing. *European Journal of Applied Physiology, 112*(5), 1733-1740.

NIOSH. (1981). *Work practices guide for manual lifting*: US Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Biomedical and Behavioral Science.

Norman, D. (2001). The future of education: Lessons learned from video games and museum exhibits. *16*(2004), 2004.

Norman, G., Dore, K., & Grierson, L. (2012). The minimal relationship between simulation fidelity and transfer of learning. *Medical Education, 46*(7), 636-647.

Nybo, L., Møller, K., Volianitis, S., Nielsen, B., & Secher, N. H. (2002). Effects of hyperthermia on cerebral blood flow and metabolism during prolonged exercise in humans. *Journal of Applied Physiology, 93*(1), 58-64.

Nybo, L., & Nielsen, B. (2001). Middle cerebral artery blood velocity is reduced with hyperthermia during prolonged exercise in humans. *Journal of Physiology-London, 534*(1), 279-286. doi: DOI 10.1111/j.1469-7793.2001.t01-1-00279.x

Peacock, R. D., Jones, W. W., & Forney, G. P. (2005). *CFAST: Consolidated Model of Fire Growth and Smoke Transport (version 6): User's Guide*: US Department of Commerce, Technology Administration, National Institute of Standards and Technology.

Péruch, P., & Gaunet, F. (1998). Virtual environments as a promising tool for investigating human spatial cognition. *Cahiers de Psychologie Cognitive/Current Psychology of Cognition*.

Pietrzak, L., & Johanson, G. (1986). Directions for improving manual fire suppression using a physically based computer simulation. *Fire Technology, 22*(3), 184-209.

Poplin, G. S., Harris, R. B., Pollack, K. M., Peate, W. F., & Burgess, J. L. (2012). Beyond the fireground: injuries in the fire service. *Inj Prev, 18*(4), 228-233.

Poston, W. S., Haddock, C. K., Jahnke, S. A., Jitnarin, N., & Day, R. S. (2013). An examination of the benefits of health promotion programs for the national fire service. *BMC Public Health, 13*, 805.

Potvin, J. (1997). Use of NIOSH equation inputs to calculate lumbosacral compression forces. *Ergonomics, 40*(7), 691-707.

Prensky, M. (2003). Digital game-based learning. *Computers in Entertainment (CIE), 1*(1), 21.

Qian, S., Jiang, Q., Liu, K., Li, B., Li, M., Li, L., . . . Sun, G. (2014). Effects of short-term environmental hyperthermia on patterns of cerebral blood flow. *Physiology and Behavior, 128*, 99-107.

Querrec, R., Buche, C., Maffre, E., & Chevaillier, P. *SécuRéVi: virtual environments for fire-fighting training*.

Querrec, R., Buche, C., Maffre, E., & Chevaillier, P. (2004). Multiagents systems for virtual environment for training. application to fire-fighting. *International Journal of Computers and Applications (IJCA), 1*(1), 25-34.

Rand, D., Weiss, P. L., & Katz, N. (2009). Training multitasking in a virtual supermarket: a novel intervention after stroke. *American Journal of Occupational Therapy, 63*(5), 535-542.
Rayson, M. P., Wilkinson, D. M., Carter, J. M., Richmond, V. L., Blacker, S. D., Bullock, N., . . . Jones, D. A. (2005). Physiological assessment of firefighting in the built up environment: Fire Research Technical Report 2 *Fire Research Technical Report 2* (pp. 13-37). Wetherby, UK: Office of the Deputy Prime Minister.
Ren, A., Chen, C., & Luo, Y. (2008). Simulation of Emergency Evacuation in Virtual Reality*. *Tsinghua Science & Technology, 13*(5), 674-680.
Richardson, A. E., Montello, D. R., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory and Cognition, 27*(4), 741-750.
Robinson, S. J., Leach, J., Owen-Lynch, P. J., & Sunram-Lea, S. I. (2013). Stress Reactivity and Cognitive Performance in a Simulated Firefighting Emergency. *Aviation, space, and environmental medicine, 84*(6), 592-599.
Robison, R. A., Liu, C. Y., & Apuzzo, M. L. (2011). Man, mind, and machine: the past and future of virtual reality simulation in neurologic surgery. *World Neurosurgery, 76*(5), 419-430.
Rothermel, R. C. (1972). A mathematical model for predicting fire spread in wildland fuels. *USDA Forests Service Research Paper, Intermountain Forest and Range Experiment Station*(INT-115).
Rothermel, R. C. (1991). Predicting behavior and size of crown fires in the Northern Rocky Mountains.
Sandelowski, M. (2000). Focus on Research Methods-Whatever Happened to Qualitative Description? *Research in Nursing and Health, 23*(4), 334-340.
Scheffey, J. P., Siegmann III, C. W., Toomey, T. A., Williams, F. W., & Farley, J. P. (1997). 1994 Attack Team Workshop: Phase II-Full-Scale Offensive Fog Attack Tests: DTIC Document.
Schlader, Z. J., Gagnon, D., Adams, A., Rivas, E., Cullum, C. M., & Crandall, C. G. (2015). Cognitive and perceptual responses during passive heat stress in younger and older adults. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology, 308*(10), R847-854. doi: 10.1152/ajpregu.00010.2015
Selkirk, G., McLellan, T. M., & Wong, J. (2004). Active versus passive cooling during work in warm environments while wearing firefighting protective clothing. *Journal of Occupational and Environmental Hygiene, 1*(8), 521-531.
Selkirk, G. A., & McLellan, T. M. (2004). Physical work limits for Toronto firefighters in warm environments. *Journal of Occupational and Environmental Hygiene, 1*(4), 199-212. doi: 10.1080/15459620490432114
Shute, V. J., Ventura, M., Bauer, M., & Zapata-Rivera, D. (2009). Melding the power of serious games and embedded assessment to monitor and foster learning. *Serious games: Mechanisms and effects*, 295-321.
Simpson, K. M., Porter, K., McConnell, E. S., Colon-Emeric, C., Daily, K. A., Stalzer, A., & Anderson, R. A. (2013). Tool for evaluating research implementation challenges: a sense-making protocol for addressing implementation challenges in complex research settings. *Implement Sci, 8*, 2. doi: 10.1186/1748-5908-8-2
Smith, D. L., & Petruzzello, S. J. (1998). Selected physiological and psychological responses to live-fire drills in different configurations of firefighting gear. *Ergonomics, 41*(8), 1141-1154.
Smith, S. P., & Trenholme, D. (2009). Rapid prototyping a virtual fire drill environment using computer game technology. *Fire safety journal, 44*(4), 559-569.
Sowndararajan, A., Wang, R., & Bowman, D. A. (2008). *Quantifying the benefits of immersion for procedural training*. Paper presented at the Proceedings of the 2008 workshop on Immersive projection technologies/Emerging display technologiges, Los Angeles, California.
St.Julien, T. U., & Shaw, C. D. (2003). *Firefighter command training virtual environment*. Paper presented at the Proceedings of the 2003 conference on Diversity in computing, Atlanta, Georgia, USA.

Staal, J., Rainville, J., Fritz, J., Van Mechelen, W., & Pransky, G. (2005). Physical exercise interventions to improve disability and return to work in low back pain: current insights and opportunities for improvement. *Journal of Occupational Rehabilitation, 15*(4), 491-505.

Stapleton, A. (2004). Serious games: Serious opportunities.

Stokes, J., Desjardins, S., & Perruccio, A. (2003). *Economic Burden. Arthritis in Canada. An ongoing challenge*. Ottawa: Health Canada.

Susi, T., Johannesson, M., & Backlund, P. (2007). Serious games–An overview. *Skövde: University of Skövde (Technical Report HS-IKI-TR-07-001)*.

Tashiro, J. S., & Dunlap, D. (2007). *The impact of realism on learning engagement in educational games*.

Tate, D. (1997). *Virtual environments for shipboard firefighting training*.

Tate, D. L., Sibert, L., & King, T. (1997). Using virtual environments to train firefighters. *Computer Graphics and Applications, IEEE, 17*(6), 23-29.

Tawadrous, M., Kevan, S. D., Kapralos, B., & Hogue, A. (2013). A serious game for incidence response education and training. *The International journal of technology, knowledge, and society, 8*(4), 177-184.

Toups, Z. O., & Kerne, A. (2007). *Implicit coordination in firefighting practice: design implications for teaching fire emergency responders*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems, San Jose, California, USA.

Toups, Z. O., & Kerne, A. (2007). Location-Aware Augmented Reality Gaming for Emergency Response Education: Concepts and Development.

Toups, Z. O., Kerne, A., Hamilton, W., & Blevins, A. (2009). *Emergent team coordination: from fire emergency response practice to a non-mimetic simulation game*. Paper presented at the Proceedings of the ACM 2009 international conference on Supporting group work, Sanibel Island, Florida, USA.

Toups, Z. O., Kerne, A., Hamilton, W. A., & Shahzad, N. (2011). *Zero-fidelity simulation of fire emergency response: improving team coordination learning.* Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.

Verhoef, M. J., Mulkins, A., & Boon, H. (2005). Integrative health care: how can we determine whether patients benefit? *Journal of Alternative and Complementary Medicine, 11*(supplement 1).

Walker, B. L., Beck, K., Walker, A. L., & Shemanski, S. (1992). The short-term effects of a fire safety education program for the elderly. *Fire Technology, 28*(2), 134-162.

Waller, D., Hunt, E., & Knapp, D. (1998). The transfer of spatial knowledge in virtual environment training. *Presence, 7*(2), 129-143.

Waller, D. A. (1999). *An assessment of individual differences in spatial knowledge of real and virtual environments.* Citeseer.

Walton, S. M., Conrad, K. M., Furner, S. E., & Samo, D. G. (2003). Cause, type, and workers' compensation costs of injury to fire fighters. *American Journal of Industrial Medicine, 43*(4), 454-458.

Waters, T. R., Putz-Anderson, V., Garg, A., & Fine, L. J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics, 36*(7), 749-776.

Williams-Bell, F. M., Boisseau, G., McGill, J., Kostiuk, A., & Hughson, R. L. (2010). Air management and physiological responses during simulated firefighting tasks in a high-rise structure. *Applied Ergonomics, 41*(2), 251-259. doi: 10.1016/j.apergo.2009.07.009

Williams-Bell, F. M., Boisseau, G., McGill, J., Kostiuk, A., & Hughson, R. L. (2010). Physiological responses and air consumption during simulated firefighting tasks in a subway system. *Applied Physiology, Nutrition, and Metabolism, 35*(5), 671-678.

Williams-Bell, F. M., Villar, R., Sharratt, M. T., & Hughson, R. L. (2009). Physiological demands of the firefighter Candidate Physical Ability Test. *Medicine and Science in Sports and Exercise, 41*(3), 653-662. doi: 10.1249/MSS.0b013e31818ad117

Wilson, P. N., Foreman, N., & Tlauka, M. (1997). Transfer of spatial information from a virtual to a real environment. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 39*(4), 526-531.

Witmer, B. G., Bailey, J. H., Knerr, B. W., & Parsons, K. C. (1996). Virtual spaces and real world places: Transfer of route knowledge. *International journal of human computer studies, 45*(4), 413-428.

Witmer, B. G., & Sadowski Jr, W. J. (1998). Nonvisually guided locomotion to a previously viewed target in real and virtual environments. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 40*(3), 478-488.

Wright, H. E., McLellan, T. M., Friesen, B. J., Casa, D. J., & Kenny, G. P. (2012). Influence of circulating cytokines on prolactin during slow vs. fast exertional heat stress followed by active or passive recovery. *Journal of Applied Physiology, 113*(4), 574-583.

WS, M., & W, K. (2006). *The Occupational Ergonomics Handbook: Fundamentals and Assessment Tools for Occupational Ergonomics, 2nd ed.* Boca Raton, FL: Taylor & Francis.

Figure Legends

Figure 1 Physiological data for ΔT_{core} (A; normalized to percent of protocol completed) and ΔT_{core} (B) during each of the cognitive assessment trials (normalized from 0 – 100% of trial completed).

*indicates different from 30°C ($p \leq 0.05$)

**indicates main effect of condition ($p \leq 0.05$).

Figure 2 Data from the simple reaction time (RTI) test (A), spatial working memory (SWM) test (B), rapid visual information processing (RVP) test (C and D), PAL test (E), and SSP test (F) for the 30°C (closed circles) and 35°C (open circles) conditions.

*indicates main effect of cognitive trial ($p \leq 0.05$) with planned contrasts revealing different from PRE or Cog 1 ($p \leq 0.05$).

¥indicates main effect of cognitive trial ($p \leq 0.05$)

**indicates planned contrasts different from Cog 2 ($p \leq 0.05$)

Objective 3. Using serious games and virtual simulation for training in the fire service: a review **– published in *Fire Technology*.**

Running title: Virtual simulations, serious games, firefighting, firefighter training

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ABSTRACT: Fire fighting is an extremely physically and physiologically demanding occupation, requiring tremendous resources for training personnel as well as incurring significant workplace safety and insurance board (WSIB) costs. Approximately 33% of fire fighter injuries result from exposure to fire leading to the possibility of reducing these injuries through training fire fighters to make better decisions, particularly when under stress. Simulation (and virtual simulation in particular) offers a safe and cost-effective alternative to practice with real fire, offering entry level training to aid fire fighters to reach a specific competency level. With the ubiquity of video-game play and advent of new consumer-level physical interfaces for video-games (e.g., the Nintendo Wii Fit balance-board and the Microsoft Kinect), serious games (games whose primary purpose is education and training), are able to provide users with innovative interactive techniques that are highly engaging and immersive. This paper reviews the development of serious games and virtual simulation applications that may be utilized for training in the fire service. Current technology allows for the simulation of fire spread and smoke movement along with training certain fire fighting skills and incident command co-ordination. To date, gaming technology is not capable of providing a real world scenario that is completely and faithfully accurate in a dynamic virtual environment. Although additional work remains to overcome current issues associated with serious games and virtual simulations, future work should focus on utilizing the benefits of gaming environments and virtual simulations to recreate the decision making processes and physical task requirements that individual fire fighters encounter in an emergency situation and incorporate them into a simulation environment where the physical and psychological stresses are analogous to live fire fighting situations.

1.0 Introduction

Fire fighting is a rigorous and physically demanding occupation involving heavy lifting, bending, twisting, and awkward postures, with only a small amount of time actually spent fighting fires (Austin, Dussault, & Ecobichon, 2001; Baker, Grice, Roby, & Matthews, 2000; Duncan, Gardner, & Barnard, 1979; Lusa, Louhevaara, & Kinnunen, 1994). However, while fighting fires, fire fighters must make many decisions in potentially life-threatening situations, most of which involve protecting the safety of civilians and the fire fighters themselves. Outside of fighting fire, the majority of work-related time involves responding to medical emergencies, motor vehicle collisions, and industrial accidents in addition to maintaining and storing equipment in the fire hall (Baker et al., 2000; G. A. Selkirk & McLellan, 2004). Nearly one-third of fire fighter injuries result from exposure to fire (including smoke inhalation), with many of these injuries thought to be preventable through better decision making under conditions of increased physiological strain (P. Hancock & Vasmatzidis, 2003). According to data from the International Association of Fire fighters (IAFF), the incidence of injury in the fire service is four times greater than in private industry, with one in every three fire fighters being injured in the line of duty (Walton, Conrad, Furner, & Samo, 2003). Due to the combined physiological and psychological demands of fighting fires, then, fire fighters go through extensive training which typically takes place in the "classroom" with the implementation of the standard operating guidelines taking place during live fire training scenarios. These scenarios require tremendous resources including training personnel, specialized training facilities and carefully planned live fire evolutions, as well as new training models for each subsequent training activity (P. Backlund, H. Engstrom, C. Hammar, M. Johannesson, & M. Lebram, 2007).

Simulation (and virtual simulation in particular) offers a safe, ethical, and cost-effective alternative to practice in certain real fire scenarios, offering trainees the opportunity to train until they reach a specific competency level. Using simulations of virtual buildings with virtual fire environments, trainees can interact with a changing environment simulate various work-related procedures and/or judge whether a building design is reasonable from a fire safety point of view. Virtual simulation permits trainees to make and correct mistakes while allowing them to experience situations that may not easily be recreated in the real-world due to ethical, cost, and time concerns. The rising popularity of video games has seen a recent push towards the application of video game-based technologies to teaching and learning. Serious games (games that are used for training, advertising, simulation, or education (Susi, Johannesson, & Backlund, 2007)), provide a high level of interactivity and engagement not easily captured in traditional teaching and learning environments. In contrast to traditional teaching environments where the teacher controls the learning (e.g., teacher-centered), serious games and virtual simulations present a learner-centered approach to education, so that the player controls the learning through interaction with the situation using an active, critical approach (Stapleton, 2004).

Serious games and virtual reality-based simulations (or virtual simulations) have grown as a form of teaching in many occupational settings, including medicine (Deutsch, 2009; Fairhurst et al., 2010; Kron et al., 2010; Marsh et al., 2010), rehabilitation (Cox et al., 2010; Kamper et al., 2010; Lange et al., 2010; Rand et al., 2009), baseball (Fink et al., 2009), and fire fighting (Boulet, 2009; Sowndararajan et al., 2008; St.Julien & Shaw, 2003; Zachary O. Toups et al., 2009). Current gaming technologies implemented in the fire service focus on training those involved at the strategic and tactical levels of fire fighting and not at the task or individual level. While there may be some debate over definitions, the strategy is generally comprised of elements of what needs to be done, what is to be done and who is to do it, whereas the tactical plan relates to how it will be done given the particular strategy that is adopted and situation in which it is being applied (Clark, 1991; Coleman, 2002). Fire fighter education at the task level (e.g., selection and use of tools, ventilation, hose line selection and operation, right or left hand room search), typically occurs at the fire academy, through early recruit training programs and learning on the job while working with senior fire fighters. With the advancement in the use of computer games for educational purposes, appropriate fire fighter training at the task level can be implemented, particularly as related to reduction of injuries from musculoskeletal disorders, as well as to improvement of decision making under stress.

Educators, researchers, and game developers have recognized that console-based video and computer games are capable of providing enhanced learning experiences (Gee, 2003; D. Norman, 2001; Prensky, 2003; Stapleton, 2004). Current literature on the use of games and virtual reality for fire fighting has primarily focused on improving team communication and incident command decision making (Boulet, 2009; Sowndararajan et al., 2008; St.Julien & Shaw, 2003; Zachary O. Toups et al., 2009), but has generally ignored skills training, such as in appropriate materials-handling techniques, or training with respect to cognitive decision making. Involving fire fighters in problem solving and training exercises related to materials handling, for example, requires an appreciation of the conditions and specific attributes that may contribute to or maintain musculoskeletal disorders in their work environment. One study reported 40% of injuries were caused by physical training, followed by on-duty emergency and fire hall activities at 25% and 14%, respectively (Staal, Rainville, Fritz, Van Mechelen, & Pransky, 2005).

With the advent of new physical interfaces for video-games, (e.g., the Nintendo Wii Fit balance-board and the Microsoft Kinect), video games are able to provide users with innovative interaction techniques that are highly engaging and immersive. Furthermore, such technologies allow video games to easily monitor the user's physical activity with minimal barriers to entry, enabling a host of new applications to be developed at reasonable cost. For example, the Microsoft Kinect camera-based sensor enables accurate measurement of up to twenty locations on the human body, can track the pose of the user's joint structure, recognize trained gestures, and perform all of this processing in real-time for multiple users simultaneously. It does not require the user to wear special tracking markers, allowing for fast and reliable setup. Thus, this platform provides serious games developers and educators the opportunity to develop highly engaging, interactive, and entertaining physical training programs at relatively low cost.

Given the potential afforded by the use of game-based technologies for fire fighter training, here we present a thorough overview of the existing literature pertaining to serious gaming and virtual simulation as it might be applied for training purposes in the fire service. In the process of doing so, we outline existing serious games and virtual simulations that have been applied to fire fighter training and discuss their benefits and limitations. We also discuss what we believe are some open problems that must be addressed in order to capitalize on these technologies for advanced fire fighter training applications.

To guide the discussion, Table 1 provides a complete summary of all the video games, serious games, and other relevant computer-based software reviewed in this article. For each game or software reviewed, the specific focus is categorized into the following classes: i) Entertainment, ii) Education, and iii) Training. Within the training category, the primary focus of the game or software has been further divided into whether it relates to training in: i) incident response, ii) decision making, iii) team coordination, or iv) task level skills. Those items which relate to multiple categories or foci have been identified and are illustrated with an "X" to represent the various aspects of their applicability. Items in each category are reviewed in further detail in the following sections. Furthermore, Table 2 represents which major aspects of fire safety were addressed by each gaming or simulation technology, based on whether it primarily dealt with: i) fire dynamics, ii) people dynamics, iii) fire fighting skills, iv) building evacuation, or v) fire safety education.

2.0 Fire fighting Video Games

Given the rising popularity of video games in addition to their many benefits when used for educational purposes, there have been numerous attempts to create fun, fire fighting-themed games for entertainment purposes. In 1982, one of the first fire fighting themed video games, *Fire Fighter* (Fig. 1), was released for the Atari 2600 gaming console. In *Fire Fighter*, players take on the role of a fire fighter attempting to save a panicked man from a burning warehouse. The player's goal is rather simple: rescue the panicked man in the minimum amount of time. Since the release of *Fire Fighter*, there have been additional attempts to create entertaining fire fighting games: *Fire fighter FD* (Konami, 2004) for the Sony PlayStation 2, *Fire fighter Command: Raging Inferno* (Kudosoft Interactive, 2005) for the PC, *Real Heroes: Fire fighter* (Conspiracy Entertainment Corp., 2006) for the Nintendo Wii (Fig. 1), and the *Emergency* series of six games (Sixteen Tons Entertainment, 1998-2013) for the PC (Fig. 1). These games were developed explicitly for the purpose of entertainment using home entertainment systems and generally lack the appropriate instructional design and clear learning objectives that are required for effective fire fighter training and educational purposes. Their content and game play is not necessarily accurate to standard operating guidelines of structural fire fighting services nor will they require the user to have the same experience or expertise for decision making or incident command organization as would be essential for an actual fire fighter.

3.0 Serious Games, Virtual Simulations and Fire fighting

With the emergence of serious games, researchers and training personnel involved in fire fighter educational development have attempted to employ gaming methods to train recruit and incumbent fire fighters (Backlund et al., 2009; P Backlund, H Engstrom, C Hammar, M Johannesson, & M Lebram, 2007; Houtkamp & Bos, 2007; Lebram, Backlund, Engström, & Johannesson, 2009). Many of the fire fighting simulations and serious games currently employed focus primarily on training for breathing apparatus entry, systematic search of a smoke filled building, or fire suppression (Backlund et al., 2009; P Backlund et al., 2007; Lebram et al., 2009; Pietrzak & Johanson, 1986), communication and leadership on the fire ground (Houtkamp & Bos, 2007; Julien & Shaw, 2002; R Querrec, Buche, Maffre, & Chevaillier; St.Julien & Shaw, 2003), and fire safety education (DeChamplain et al., 2012; Tawadrous, Kevan, Kapralos, & Hogue, 2013; Walker, Beck, Walker, & Shemanski, 1992), while other simulation platforms have also been developed for visualization of structural fires for applications related to fire safety engineering and design. Though these latter simulations and serious games were not developed with any objective related to fire fighter training, the underlying software that predicts fire behaviour in buildings forms one key element necessary in any integrated gaming platform for advanced fire training applications.

One of the initial applications of simulating fire behaviour in structures was developed by Bukowski and Sequin (1997) for just such an engineering application (see Fig. 2 revealing how a pool fire scenario could be previewed and destructive experiments performed to evaluate fire safety studies). They coupled the real-time, interactive, Walkthru visualization system to the CFAST (Consolidated Model of Fire and Smoke Transport) model for fire behaviour developed at the National Institute of Standards and Technology (NIST) (Peacock, Jones, & Forney, 2005). The CFAST model was used to simulate the gas concentrations, temperatures, and the height of the smoke layer that developed during a fire in a dwelling with multiple rooms (Peacock et al., 2005). The predicted data were passed to the Walkthru visualization system which was configured to present the information to the user in various modes depending on the intent of the exercise. The calculation speed of CFAST is relatively fast which makes the software amenable to this kind of application; however, speed comes at the expense of significant simplification of the fire physics, as well as limitations in the complexity of compartment geometries that can be modelled. Nonetheless, the Walkthru-CFAST model was deemed useful to provide fire safety engineers with a simulation based design environment in which to assess building fire hazards and safety systems, as well as to evaluate the fire performance of different building designs. While the CFAST zone modeling software is still widely used by the engineering community for computer based prediction of fire behaviour, the visualization and graphic technology that was utilized has become outdated.

Research to evaluate the use of serious games directly for rescue services training has recently been undertaken in Sweden (Backlund et al., 2009; P. Backlund et al., 2007; Lebram et al., 2009). This led to the development of Sidh (see Fig. 3 depicting the users point of view in the simulation model while in a standing position) , a game-based fire fighter training system which employs a CAVE (Cave Automatic Virtual Environment) immersive virtual reality environment (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992) to simulate thirteen realistic situational environments for training students in search and rescue while wearing breathing apparatus. In the CAVE, the fire fighter trainee is surrounded by four fixed position screens that deliver stereoscopic 3D visualization of the scenario while they move around, pointing their fire fighting nozzle as they search for victims. The ‘hot, stressful’ interactive audio-visual environment is intended to simulate the physical and psychological demands of the search and rescue task in a smoke-filled environment. As such, the health of the fire fighter is adapted during the game depending on time taken to fulfil a task and whether the player is in an upright or crouched position, etc. After the game was developed, thirty-one fire fighting students were recruited to play. The participants were divided into two groups, with the first group (experimental group) being given two, thirty minute sessions playing Sidh, followed by a search mission at a training centre. The other group (control group) started with the search mission followed by a single session playing Sidh. Student performance was monitored during the game by a camera hung from the ceiling, as well as data automatically collected by the software. Student self-reflections were also collected after each session. Comparison of data from the experimental versus the control group revealed that the simulation provided an enjoyable experience and successfully complemented traditional learning as shown by a decrease in the times a victim was missed and through student responses to the self-reported learning questionnaires (P Backlund et al., 2007; P. Backlund et al., 2007).

Another study by Tate et al. (D. Tate, 1997), examined the effects of using a virtual environment to train shipboard fire fighters compared to traditional mission preparation. A full-scale virtual model of the USS Shadwell was created with Corypheus' Designers Workbench and trainees interacted with their environment using a Virtual Research VR4 head-mounted display (HMD) and joystick interactive controls. The fire was simulated using video images of a real fire capturing the dynamic nature of the fire growth and smoke movement through each compartment. A selection of navy fire fighters was tasked to perform a familiarization exercise in the smoke filled ship with no fire, in addition to a full fire fighting and suppression operation. Although the sample size was statistically limited, it was found that those fire fighters who trained using the virtual environment completed a two minute long real-life fire fighting mission, on average, thirty seconds faster than the control group. Clearly both of the above studies point to the potential to develop new fire fighting training methods using game-based immersive virtual environments.

In the area of training for incident command, St. Julien and Shaw (2002) developed the Fire fighter Command Training Virtual Environment (FCTVE) to train commanding officers how to conduct and lead a fire team on the fire ground (see Fig. 4 depicting the characters and single family home in the virtual environment). Visuals of fire trucks and fire hydrants are added to the fire ground as appropriate. A database of animated characters allows simulation of the team of fire fighters as they engage in various walking, crawling, climbing, cutting, chopping, rescue, carrying and fire fighting/suppression operations. The house fire scenarios themselves are modelled offline using the Fire Dynamics Simulator (FDS) computational fluid dynamics software developed at NIST (McGrattan, Klein, Hostikka, & Floyd, 2008). FDS is a large eddy fire simulation model that numerically solves the Navier Stokes equations for low speed, buoyancy driven flows to predict time and spatially resolved temperatures, concentrations and smoke distributions throughout an entire burning structure[1]. Each house fire situation is pre-computed in FDS with data output at one second intervals. Different related scenarios must be run to model the impacts of each fire fighter action on the base fire scenario. The spatial and temporally resolved data is rendered onto volumes to visualize smoke distribution throughout the space, and coupled with decision trees to pass appropriate information to the virtual environment in order to visualize and animate the fire and smoke movement in the single family house fire of interest. Based on the evolution of the fire, the fire fighter command training virtual environment (FCTVE) system then allows commanding officer trainees to instruct the virtual fire fighters (avatars) to perform various tasks to extinguish the fire. During the training exercise, the trainee navigates within and around the environment, viewing the fire scene from any angle, and commands and instructs the fire fighter avatars to perform specific duties. Through incorporation of the precomputed FDS data, users experience dynamic fire situations with changing fire and smoke behaviour based on changes to the environment brought about by fire fighter actions. This system has been classified as the first to incorporate data from a three-dimensional computational fluid dynamics (CFD) model into a fire training simulator (Cha, Han, Lee, & Choi, 2012).

Again using the FDS software to predict fire development and smoke movement, Ren et al. (2008) created a virtual reality system intended for training of personnel in fire and emergency evacuation drills (Fig. 5). As in the FCTVE simulator discussed above, a three-dimensional building model is created and FDS is used to precompute detailed time and spatially resolved data from a variety of plausible fire and evacuation scenarios. The FDS output data is stored and instead of being volume rendered, it is instead reprocessed using a multi-grid, multi-base state amendment model so that fire and smoke movement information can be passed in compressed form and thus in real time to the Vega visualization system. This system employs video images of real fire plumes and smoke to create textured images which are mapped to particle systems to provide very fast and realistic animations of fire and smoke movement. The trainee interacts with

[1] "Smokeview is a software tool designed to visualize numerical calculations generated by fire models such as the Fire Dynamics Simulator (FDS), a computational fluid dynamics (CFD) model of fire-driven fluid flow or CFAST, a zone fire model. Smokeview visualizes smoke and other attributes of the fire using traditional scientific models such as displaying tracer particle flow, 2D or 3D shaded contours of gas flow data such as temperature and flow vectors showing flow direction and magnitude" (Glenn P Forney & McGrattan, 2008).

the fire scenario via a head-mounted display and mouse with functions that allow the use to navigate through the scenario and pick up and use fire fighting tools. Evacuation paths and human animations can also be added to simulate evacuation during the fire. Once developed, the system was tested for evacuation training using a simulated scenario that involved a fire in a below-grade subway station. It was determined that the system could be used to safely and effectively simulate and evaluate emergency evacuation procedures as well as to conduct fire response and evacuation drills in a virtual environment.

Cha et al. (2012) further developed a virtual reality based fire simulator that was intended to allow members of the general public to experience 'real' fire situations, to allow firefighters to train at an entry level, and to aid firefighting commanders in the assessment of different fire scenarios and in making appropriate fire ground plans and safe command decisions (see Fig. 8 of the fire development and smoke spread of an automobile accident in a tunnel). To accomplish this, FDS was again employed to precompute detailed time and spatially resolved smoke, gas concentration and temperature data related to the fire and evacuation scenarios of interest. The large quantities of FDS output data were then reprocessed using Octree space partitioning (Foley, Dam, Feiner, Hughes, & Carter, 1997) and multiple-resolution based, level of detail selection methods (Foley et al., 1997) to optimize data transfer and facilitate real time simulation of changing environment. In this simulation, normalized soot density data was used for visualization of general smoke propagation, while other output variables such as temperature, heat release rates, CO, CO_2, and O_2 concentrations were normalized based on threshold values representing safe versus hazardous exposure conditions. Since these variables are not generally related to optical signatures, an appropriate colour-based transfer function was developed to incorporate their hazard information (red for most noxious gas; blue for less noxious gas, for example) into the virtual scene as well. Based on the combined information, multiple measures of safety could be included in an operational simulation. The system was tested using the scenario of a vehicle fire in the Jukryeong Tunnel in Korea. While the basic fire situation and individual hazards were represented in their simulation, extension is required to further optimize data transfer so that multiple hazards can be visualized and more complex environments can be simulated. In addition, interaction between the simulation and the trainee can be improved through inclusion of multi-sensory interfaces and through precomputed or real-time adaptation of the simulated environment as avatars or trainees undertake fire fighting tasks.

The Environmental Tectonics Corporation developed the Advanced Disaster Management Simulator (ADMS) (see Fig. 7 depicting the visualization of fire fighters suppressing a fire on a city block) as a virtual reality training solution to train emergency response commanders how to properly respond to terrorism, fire threats and other emergencies (Environmental Tectonics Corportation, 2012). ADMS is commercially available and allows emergency coordination center staff, incident commanders and crews to setup appropriate protocols and chain of command, make important fire ground decisions, allocate fire fighting resources, such as equipment and personnel, and apply response tactics for various emergency and fire incidents. Despite the apparent breadth of this system over other existing simulators, it does not provide trainees with very realistic experience in fighting fires due to the simple, planar graphics technology that it employs, thus limiting visualization of fire progression and precluding realistic immersion of the user into the scenario at hand (Cha et al., 2012).

The concept of faithfully representing real life situations via virtual interaction with an environment can present interesting issues when considering training via virtual reality simulation. Although the situation is improving, given recent technological advances and the availability of innovative consumer level hardware such as the Microsoft Kinect, mapping real-world interactions to the virtual world can still be challenging (2004). Dugdale and Pavard (2002) developed a serious game intended to train incident commanders to properly supervise a rescue operation by coordinating their unit's actions including the safety of the crew and civilians, and appropriately establishing the chain of command to report information back to the control centre and request reinforcements or further information as necessary. Due to the objective of the game, they attempted to include real-world interactions between characters in the virtual training environment. Furthermore, since human communication relies heavily on gestures, this included determination of appropriate gestures for the virtual characters. In order to collect the necessary background data, they utilized observational field studies with on-site video capture of real fire scenarios, including an analysis of operating procedures and other formal documents related to each situation. In addition, they conducted interviews with fire fighters and training personnel and participated in debriefing sessions with the trainees (Dugdale & Pavard, 2002). The on-site field data was then analyzed to determine the appropriate design for realistic interactions amongst various members of the teams, including gestures (Cassell, McNeill, & McCullough, 1999; McNeill, 1996). An analysis of the data revealed that there was a series of generic gestures that individuals perform during conversations a finding that led to the development of a set of rules outlining when and how each gestures is commonly executed. As a result, the virtual characters developed in the simulation were generally considered to be realistic; except in some aspects of their facial appearance. This, as suggested by the authors, can be overcome by employing texture-based photographs and mapping them to the face of each avatar. Furthermore, due to the real-life situational data used in the game design, the virtual training environment appeared to initiate similar decision making processes for the trainees as they would encounter in real world situations.

Another interesting approach in fire fighting simulation was employed by Querrec et al. (2004) in their SecureVi (Security and Virtual Reality) system which allows developers to create various training environments and offers mechanisms by which these environments can also be improved as they are run (see Fig. 9 depicting a gas leaking scenario at a factory site and the development of a gas cloud in the simulation). Using the MASCARET concept (Multi Agents Systems to simulate Collaborative Adaptive and Realistic Environments for Training), they incorporated non-player controlled 'agents' into a physical simulation of a real scenario and programmed these 'agents' with human characteristics to act realistically in terms of transfer of information amongst, for example, members of a response team. Through the use of artificial intelligence techniques, these programmed agents reacted to the actions of a user and adapted their actions based on the evolving situation so that users became immersed in specific operational situations or environments that were too dangerous to conduct, or were inaccessible, in the real world. The simulation system included an organizational model with interacting physical and social environments and appropriate rules, behaviour and constraints configured to train incident commanders in operational management and control of larger emergency scenarios, such as a major toxic gas leak at a factory site. The main incident in this example dealt with development and propagation of a gas cloud due to the leak and was dependent on the environmental conditions, as well as the behaviour of team members. It was of interest to assess the impacts of the leaked gas on fire fighters and civilians so that the objective of the scenario was to efficiently secure the civilians, to reduce the spread of the gas leak and minimize its effect on emergency responders, and to protect any additional gas tanks on the site by minimizing the possibility of ignition of the gas cloud. A series of source and target agents were established through which information related to the situation was passed (from source to target) with a recruiter whose role it was to track the source-target interactions at the organizational level. In the course of the simulation, three different networks interacted, including i) a mobility network in which the wind (source and recruiter) acted on toxic gas particles (target) to predict dispersion, ii) a toxicity network where effects of the gas cloud and leak were determined so that here humans play the role of both recruiter and target, and iii) a collision network where the water walls which were being used to slow down the progression of the gas cloud acted as source and recruiter. The use of the autonomous multi-agents allowed the characters in the scenario to adapt to their dynamic environment and to calculate implicit plans to carry out specific actions that may not have been instructed by the user to that point in the exercise. If these autonomous characters were not able to fulfill a particular action, they could deem the action to be a failure and the agent would then ask the user for supplementary orders. This model required three roles (expert, trainer, and learner) based on four phases within the teaching use of SecureVi: i) design of elements, ii) describing scenarios and assigning roles to agents, iii) simulation, and iv) debriefing. The intended use of this model requires an expert or group of experts with expertise in MASCARET to program the specific physical characteristics of the simulation. Once the simulation is performed, the model is capable of recording all actions and messages entered by the users that can be used by fire fighter training personnel during the debriefing stage. However, the effectiveness of the model to efficiently train incumbent or recruit fire fighters was not reported using quantitative measures.

Toups and Kerne (Zachary O. Toups & Andruid Kerne, 2007) sought to develop principles for design of games that promoted collaboration and team work amongst users based on examination of practices and information transfer processes experienced by fire fighter trainees during the actual process of communicating, processing, and integrating emergency information at an incident scene (in the workplace). Based on the results, the authors note that fire fighters make use of their cognitive resources more efficiently through implicit coordination, which is typically learned from live fire training exercises and/or responding to actual emergencies. They concluded, then, that interactive simulations could aid in the training process by allowing development and implementation of particular attributes that are based on the proper information acquisition and communication needed to work together to build the 'information picture'.

Following up on their analysis of the potential for implicit coordination training in fire fighter trainees, Toups and Kerne (Zachary O Toups & Andruid Kerne, 2007) developed an augmented reality game, called *Rogue Signals*, with the purpose to enhance training of team coordination skills. As such, a user must coordinate their actions effectively to be successful in the game. Utilizing head-mounted displays, global positioning receivers (GPS), speakers, radio, and a backpack-mounted computer the player is provided with differential information, mixed communication modes and audible cues related to the training scenario while immersed in the game environment. Fire fighter trainees (*seekers)* work together with an external viewer (*coordinator)* to find hidden artifacts in the real world while attempting to avoid computer-controlled enemies in the virtual world. The *coordinator* has access to the virtual world view and must guide the *seekers* around virtual obstacles toward their intended goals. In a later evolution of the game, work practices of fire emergency personnel were also incorporated to teach response coordination skills (Zachary O. Toups et al., 2009) without the fire and smoke inherent in an actual incident. The game creates a distributed cognition environment where team members need to rely on each other to communicate rapidly-changing information, while also being subjected to a realistic level of stress that might be encountered during performance in a real emergency response.

Most recently, Zachary O Toups, Kerne, Hamilton, and Shahzad (2011) developed a zero-fidelity simulation (defined as a simulation "in which human- and information-centric elements of a target environment are abstracted"), called *Teaching Team Coordination Game (*T^2*eC)*, to supplement the preparation of fire emergency response students for live burn training. According to the authors, the zero-fidelity approach reduces the cost of the simulation whilst increasing the focus on the desired elements of education. In order to test whether the game improved coordination, twenty-eight fire students played the game over four sessions, separated by one-week intervals. In each session, team members played the game under two conditions, with all the seekers co-located in one room and the *coordinator* in a separate room or with all seekers and coordinator distributed in separate rooms. It was concluded that the team coordination amongst students had improved through a shift to implicit coordination and that this also enhanced their ability to connect the game play to real practice during live fire burn training. As such, this study provided further evidence that zero-fidelity simulation is an effective approach to fire fighter education.

Many urban fire departments are currently using serious games and virtual simulations to aid in training incident commanders how to respond in various emergency scenarios. A large metropolitan fire department in Canada has used two of the available training products, *Fire Studio* (Digital Combustion, California) and *VECTOR Tactical Command Trainer* (VectorCommand Ltd, United Kingdom) to develop educational programs for their personnel. Custom digital photographs are imported into *Fire Studio* and used to create relevant emergency scenarios for a given training exercise. This, coupled to a flexible incident command trainer, allows fire departments to create their own custom scenarios and to train fire fighters and incident commanders on appropriate coordination and management of emergency situations according to their own departmental guidelines.

VECTOR, launched in 1997 in the United Kingdom, is a flexible command trainer that combines artificial intelligence, virtual reality, and 3D training methods into a training tool for incident commanders in the fire service. Fire departments can again customize emergency scenarios by changing multiple variables (type and location of fire, different building skins, time of day, and wind direction), in an attempt to challenge the trainees' incident command knowledge and decision-making skills. The trainee has the capacity to use the visual information for their initial observations of the scene after which they provide radio or face-to-face communication with a system facilitator to issue orders or to call in additional support. All participants within the training system have their own virtual characters (avatars) so that the command trainee is able to view where all team members are located within the scenario.

In addition to workplace coordination and command skills, one of the other major skills required in the fire service is the ability to safely and effective drive a fire truck. Texas A & M Engineering Extension Service developed the MPRI FireSim driving simulator to augment on board training of vehicle operation across Texas. The simulator utilizes computers, various driving scenarios, and three high definition (HD) display screens to enhance the decision-making power and driving behaviour of vehicle operators over a broad spectrum of maneuvers.

Another relevant serious game that has been implemented for training purposes within the fire service was originally designed for use by the Fire Department of New York (FDNY). This game was developed under the project name: HazMat Hotzone (Carnegie Mellon University, 2002). It was created to assist fire fighters in training for hazardous and chemical emergencies using video gaming technology. For the fire fighters participating in the simulation, the main objective is to teach communication, observation, and critical decision making to the first responders. One of the key benefits of this particular serious game over many of the others are that the training instructor has full reign over what aspects of the simulation are involved for a particular scenario (i.e., location of the hazard, the specific effects, weather conditions, and where the victims are located in addition to their particular symptoms). The training instructor can also implement any secondary scenarios within the game at any time to further incorporate new elements into the original emergency situation while fire fighters are participating in the game.

The serious games and virtual simulations discussed here have implemented various models to simulate the physical characteristics of a fire situation to provide a training environment for fire fighters. Many of these models have focused primarily on the development and programming of a set of realistic characteristics for the fire scenario, whereas others were more concerned with the interaction of the users and their ability to accurately co-ordinate a team of fire fighters. The difficult yet important integration of these two facets onto a single platform will provide advancement in the use of serious games and virtual simulations for training in the fire service.

3.1 Fire Education Using Serious Games and Virtual Simulations

It is clear from the above discussion that many of the elements required for simulation of different training scenarios for fire fighters are currently in use or under development. Despite this, it is important to step back and ask whether games are a most appropriate platform for the conduct of this training. Along these lines, virtual reality has gained considerable interest, since its inception, as an application under which to study various features of spatial cognition (Péruch & Gaunet, 1998; D. A. Waller, 1999; Wilson, Foreman, & Tlauka, 1997), memory (Gamberini, 2000), and learning (Wilson et al., 1997), based on the conclusion that the cognitive mechanisms that exist within real environments and virtual environments appear to be analogous (Richardson, Montello, & Hegarty, 1999).

One of the initial studies in this area was conducted by Witmer et al. (1996) in 1996 where they concluded that virtual environments were able to effectively train users to determine a navigational route through a situation without the need to receive verbal directions and photographs. They also showed that learning a specific route within a real building can be accomplished using a virtual environment where the users are able to interact with the environment possibly through a head-mounted display. Furthermore, Witmer and Sadowski, Jr. (1998) found that virtual environments can be configured to depict real world complexities and, as such, can be employed to effectively train users how to undertake cognitive spatial tasks. Conversely, some of the literature reveals that a virtual environment may not be as effective for the acquisition of spatial knowledge so that learning a specific spatial layout by use of a virtual simulation may take individuals significantly longer (Arthur & Hancock, 2001) or equal time (D. Waller, Hunt, & Knapp, 1998) when compared to obtaining the same knowledge by way of a map, in a static or dynamic virtual environment. Impediments to these studies revolve around the limitations of the software technology employed (Arthur & Hancock, 2001) or the expertise of the participants' in using a virtual environment system (D. Waller et al., 1998). Based on this earlier work, Gamberini et al. (2003) developed a virtual environment through which to study participants' responses to the appearance of a fire and to the resulting emergency within a library structure. Eighty-four participants were provided the opportunity to explore the library environment without any hazards present to orient themselves with the environment. Following this, participants were asked to reach a pre-determined point in the virtual environment where a fire emergency would be enacted via one of two possible situations, a fire closer to the participant and the other further away from the participant. Participants themselves were subjected to three different surrounding environments based on the intensity of the situation. In all cases, they were asked to act as naturally as possible to find their way to the exit. Results indicated that individuals recognized and responded to complex situations within a virtual environment in a manner similar to how they react in a real environment. The authors concluded that their data supports the use of virtual environments to simulate emergency scenarios for training based on the fact that participants in these tests produced adaptive responses to their virtual environment, again in an analogous fashion to what would be expected in a real world situation.

Smith and Trenholme (S. P. Smith & Trenholme, 2009) note that conducting live fire evacuation drills in buildings with realistic conditions is difficult and, no matter how well planned, they cannot feature dynamically changing environments such as smoked filled corridors, blocked exits, and fires in unexpected locations; just those situations that require immediate decisions and action by fire fighting personnel . To overcome these limitations, they developed a 3D gaming environment to aid in virtual fire drill evaluations. By re-using existing gaming technologies and assets, over a three week period, a single developer was able to create a virtual real-world environment to aid in fire drill evaluations. The authors conclude that users perceive the virtual environment to be realistic, but performance during the evaluations is also correlated with the previous gaming experience of each trainee.

Chittaro and Ranon (Chittaro & Ranon, 2009) also developed a serious game to educate individuals on the proper evacuation procedures during a building fire scenario. The game allows the user to gain navigational knowledge of the building and to learn appropriate techniques to properly evacuate the building under various fire conditions and scenarios. The authors conclude that the initial prototype of the game has advantages in that it is capable of acquiring actions of the players and determining behaviors of the users. Furthermore, analysis of the players' actions may lead to revealing deficiencies in the architecture or layout of the real building. However, future work is needed to increase the realism of the fire and fire room environment, to implement more robust physiological feedback to the user, and to create a multi-user environment that can more realistically simulate multiple person evacuation from larger structures.

Not all simulations and serious games have been created specifically for the fire service; some have been produced to train and educate the general public in fire safety. *Blaze* (DeChamplain et al., 2012), a serious game developed to improve and educate on household (kitchen) fire safety, allows the user to experience and deal with dangerous and potentially life-threatening fire-based events in a safe, fun, and engaging manner (see Fig. 10a revealing a stove top fire in the kitchen of a home). The game was developed to educate a participant on how a fire should properly be extinguished, and to recognize that, depending on how big the fire is, they should either call the fire department or evacuate their home. As the game starts the user's avatar body is not visible in the scenario, so the game participant begins by seeing a stove top cooking fire in the kitchen. The goal is to choose the appropriate instrument or method by which to respond to the fire and to extinguish the fire should that be a viable option. When the appropriate response is to extinguish the fire, the user must recognize the type of fire and choose whether to use baking soda, water, or a fire extinguisher to extinguish the fire. For example, choosing to pour water over a grease fire will cause the fire to continue to burn. If a user continually makes incorrect choices and decisions, their progress in the game ceases and their avatar will come into view, passed out due to smoke inhalation or prolonged exposure to the fire. This approach allows players to gain knowledge in the potential positive and negative effects of using products in a house on a stove top fire without the use of an actual fire. The use of feedback following a decision or action being made along with the simulation training model appears to provide a strong platform for the training of civilians during kitchen fires.

More recently a serious game was developed by Tawadrous et al. (Tawadrous et al., 2013) to train individuals (employees of a large institution such as a university) to react appropriately to a given type of threat (bomb threat, gas leak, or explosion and fire, amongst others) (see Fig. 10b depicting a chemistry lab in a university environment within the serious game). The authors describe a gaming platform in which the trainee is faced with a toxic fire scenario within a typical university biology laboratory. Based on the sequence of events that ensue, the user must make correct responses and decisions in order to handle the emergency scenario present and proceed through the game. A specific fire extinguisher technique known as the Pull, Aim, Squeeze, and Sweep method is implemented and must be used to put out a fire (Fig. 11). Thus, if the user does not employ this method or if they make an incorrect decision, they will not be able to proceed and instead will be given on-screen information as to why the proper response was not achieved. Again the combination of scenario based training and active feedback included in the game is thought to provide an effective platform upon which to train employees with a wide variety of skill sets on appropriate decision making, safety precautions and fire extinguishing methods to employ should a fire actually occur in their institution.

3.2 Forest Fire fighting Simulations

The work by Li et al. (2004) developed a virtual reality simulator suitable for training fire fighters on how to battle forest fires. Their system employed a virtual reality and Distributed Interactive Simulation (DIS) technique to render and model a virtual forest fire environment such that participants could be asked to establish the organizational flow required in collaborative forest fire fighting using ground and air fire fighting units to efficiently fight the fire. To represent the many complexities associated with forest fires (wind, nature of the wood, slope of the forest area, slope direction, vegetation, climate, and terrain), the authors based the physical fire simulation on the Rothermel (1972) models for behaviour of surface fires and the improved model (Rothermel, 1991) for crown fires. The original model proposed by Rothermel in 1972 was very suitable for this purpose as it required no prior knowledge of the burning characteristics of a particular fuel source. The only variables that were required were the physical and chemical composition of the fuel source and the environment where it would burn (Rothermel, 1972). The spreading rate and the boundary of the forest fire were determined using the FARSITE (Finney, 1994) fire spread model (based on Huygen's principle to describe the movement of a wavefront (Born & Wolf, 1999)), allowing wind speed, slope, and additional aspects to influence how the fire spreads during the simulation. Based on the overall functionality of the models for smoke and spread of the forest fire, as well as the demonstrated effectiveness of the air and ground fire fighting units to co-ordinate fighting the fire, the authors concluded that the simulation system met the need in terms of training wildland fire fighters for forest fire fighting. However, the authors did not report any quantitative data on how this particular simulation was determined to be a useful aid in the training process.

4.0 Open Problems

The fire fighting occupation has been well established as a physically and psychologically demanding job which can put the fire fighter in extremely hazardous situations that include thermal stress, exposure to chemical substances, and impact by numerous psychological factors (Gledhill & Jamnik, 1992; G. A. Selkirk & McLellan, 2004; F. M. Williams-Bell, G. Boisseau, J. McGill, A. Kostiuk, & R. L. Hughson, 2010; F Michael Williams-Bell, Geoff Boisseau, John McGill, Andrew Kostiuk, & Richard L Hughson, 2010; Williams-Bell, Villar, Sharratt, & Hughson, 2009). Due to the nature of the job, performing live training simulations places the fire fighter at risk even if all safety precautions are taken. Additionally, real-life simulations of realistic fire situations are expensive and take long times to set-up and run. With the continuing development of new technology and methods, substantial benefit may accrue to the fire service with increasing the use of serious games to aid in the education and training of fire fighters. Such technology may be used to minimize exposure of fire fighter trainees to hazardous fire conditions during training and to supplement the ever waning live fire fighting experience that they obtain in the course of their daily jobs. With the current ubiquity of video game play, particularly with the current generation of learners, and the inherent engagement, interaction, and motivation of video games, the use of video game-based technologies for educational purposes (i.e., serious games), are being applied in a variety of applications including fire fighter training. Serious games applied to fire fighter education and training minimize the hazardous conditions that fire fighters are often subjected during training simulations. Although serious games cannot completely replace hands-on training sessions, their incorporation into a comprehensive training package can mediate the high costs of running certain training scenarios and can provide a more convenient training environment for particular tasks and critical decision making that is required of the job.

Serious games can also be used as a precursor to live simulations offering trainees the opportunity to train until they reach a specific competency level, thereby ensuring they optimize their time and learning potential when exposed to live simulation training exercises that are resource intensive and expensive to run.

In this paper, we presented a thorough review of the use of serious gaming and virtual simulation for the education and training of fire fighters. The majority of these serious games and virtual simulations have focused primarily on decision making and strategic command of fire fighting crews on the fire ground required by incident commanders (St.Julien & Shaw, 2003; D. L. Tate, Sibert, & King, 1997). Although the decisions and actions of incident commanders at a fire scene are critical to the tactics used in fire suppression and for the safety of the fire fighter and civilians, there appears to be a void in the development of serious games for task level job activities of the individual fire fighter. These task level activities can range from task specific movements based on safe biomechanical techniques to accurate decisions being made by the fire fighter within the fire scenario itself. Typically, the average fire fighter will not have the same experience or expertise as a captain or incident commander, therefore serious games and simulations provide an optimal opportunity for fire fighters to gain experience that would otherwise take years to achieve through virtual simulations of potential fire ground incidents and benefit from their development. Further research into the development of serious games and simulations to be utilized for the fire service should focus on the physical tasks (e.g., fire suppression, victim search and rescue) and the decision making that the individual fire fighter entering the fire will undergo. None of the previous work presented here has focused on a game or simulation that both educates on proper procedure of fire fighting tasks while accurately monitoring certain physiological variables (i.e., decision making, body position, technique). This may in part be due to the lack, until very recently, of consumer-level (cost-effective) sensors that could be used to monitor physiological progress of the trainee. With the advent of new sensing technologies and strategies initially developed for gaming purposes, it is now possible to accurately monitor physical attributes of motion using a variety of hardware mechanisms while allowing for novel interaction techniques that increase engagement and lead to a better overall educational experience. For instance, the main sensing modality of the Nintendo Wii (the Wii Remote), contains accelerometers and gyroscopes (Wii Motion Plus), that provide enough sensing capability to track the orientation of a single joint in a kinematic chain; the Nintendo Wii Fit balance board provides estimation of the center of gravity and leg lifts; Microsoft's Kinect tracks an entire skeletal model of the player's body by measuring 20 of the player's joints to estimate full-body motion as well as body-type characteristics. The Kinect allows users to interact with their application using a natural user interface that employs gestures thus eliminating the game controller and the typically non-natural and potentially limiting interaction it affords. In surgical training for example, using the Kinect within a virtual operating room, surgery trainees are able to perform their required tasks in a more intuitive manner that is better representative of the real world (Robison, Liu, & Apuzzo, 2011).

That being said, although the popularity of serious games is growing and they are becoming more widely used, before their use becomes more widespread, a number of open problems must be addressed. Tashiro and Dunlap (Tashiro & Dunlap, 2007) developed a typology of serious games for healthcare education and identified seven areas that require research and improvements for the effective development of serious games: i) disposition to engage in learning, ii) impact of realism/fidelity on learning, iii) threshold for learning, iv) process of cognitive development during knowledge gain, v) stability of knowledge gain (retention), vi) capacity for knowledge transfer to related problems, and viii) disposition toward sensible action within clinical settings. Although they focused on serious games for healthcare education, the problems they outline are universally applicable. Of particular importance is the question regarding the impact of realism/fidelity (i.e., the extent to which the appearance and/or the behavior of the simulation matches the appearance and behavior of the real system (Farmer, Van Rooij, Riemersma, Jorna, & Moraal, 1999)) on learning. Despite the great computing hardware and computational advances we have experienced, real-time high fidelity rendering of complex environments across all modalities is still not feasible (Hulusic et al., 2012). Designers and developers of serious games, and virtual simulations in general, typically strive for high fidelity environments, particularly with respect to the visual (graphical) scene. However, evidence suggests high fidelity simulation does not always lead to greater learning (G. Norman, Dore, & Grierson, 2012), and striving for high fidelity can burden our computational resources (particularly when the simulation is intended to be used on portable computing devices), increase the probability of lag and subsequent discomfort and simulator sickness (Blascovich & Bailenson, 2011), and lead to increased development costs. Greater work that examines the relationship between fidelity and learning still remains.

A further issue revolves around the effectiveness of serious games. In other words, for serious games to be considered a viable educational tool, they must provide some means of testing and progress tracking and the testing must be recognizable within the context of the education or training they are attempting to impart (Chen & Michael, 2005). Although various methods and techniques have been used to assess learning via serious games and simulations in general, assessment is commonly accomplished with the use of pre- and post-testing, a common approach in educational research which itself is not perfect (Becker & Parker, 2011). However, serious games (and games in general) generally do contain in-game tests of effectiveness where, as players progress through the game, they accumulate points and experience which make the next stages and levels of the game easier and thus the user should score higher if any learning has been imparted. Recently there has been plenty of effort placed on the use of such in-game assessments for evaluation of user learning, moving assessments away from the predominant, classic form comprised of questionnaires, questions and answers, etc. and providing the opportunity to take advantage of the medium itself to employ alternative, less intrusive, and less obvious forms of assessment which could (and should) become a game element itself (Bente & Breuer, 2009). Integrating the assessment such that the player is unaware of it forms the basis of what Shute et al (Shute, Ventura, Bauer, & Zapata-Rivera, 2009) describe as stealth assessment (see Bellotti et al. (Bellotti, Kapralos, Lee, Moreno-Ger, & Berta, 2013) for a thorough discussion on serious games assessment).

Realistically representing the complexity of a developing fire and faithfully simulating the impact of numerous fire fighter response procedures on that fire also currently represents a limitation in application of serious games and virtual simulations to impart ‘real-life experience’ for the fire fighter. As previously mentioned, one of the limitations of serious games and virtual simulations is the lack of providing real-life experience of actual fire situations for fire fighters. In a non-traditional sense, the inside of a burning structure can be considered the fire fighter's workplace. Thus any fire development and response simulation in a serious game must not only be credible but also sufficiently realistic to afford the necessary level of training, a requirement that becomes increasingly difficult to meet as fire fighting techniques become more sophisticated. Simulating fire suppression, for example, involves not only representation of fire development, already shown to be a limitation in work discussed above (Cha et al., 2012; Julien & Shaw, 2002; Ren et al., 2008), but also involves simulating the complex physics involved in initial attack of the fire, allowing the fire fighters to advance into the structure. For a realistic simulation to proceed, the nozzle stream would have to be altered at the appropriate point in the simulation with the physics modified to model interactions of the hose stream with the seat of the fire. To properly train such complicated techniques in a virtual environment requires not only accurate prediction of complex physical interactions that lead to fire development under multiple possible actions of the fire fighter, but also necessitates an accurate feedback system be in place for assessing and monitoring those actions as well. The level of complexity can be understood by looking at two examples. In the first instance, spraying an insufficient amount of water on the fire will lead to an increase in radiation, temperature, and eventually a flashover scenario (Liu, Kashef, Lougheed, & Benichou, 2002), yet the physics involved with transition to flashover is very much an active area of research in fire science so appropriate models of this phenomena would need to be developed. Alternately, if too much water is applied to the fire clouds of steam can be produced, posing significant hazards to both the fire fighter and any potential victim being rescued (Liu et al., 2002). Again, this situation would somehow have to be incorporated into a comprehensive tool for fire fighter education. In order for serious games and virtual simulations to complement real-life experiences, then more sophisticated models and techniques must be incorporated and properly assessed and feedback provided so the fire fighter can understand and learn from the scenario that they are immersed in.

Whilst incorporating the full complexity of a fire situation into a serious game or virtual simulation may currently be out of reach, incorporation of specific key elements of fire fighting training might well be a viable proposition. Based on current training problems and needs in the fire service, for example, it is recognized that increasing the experience of the fire fighter in hose stream application and the ability to maneuver in a

very low body position within the lower cool gas layer to advance into a structure are critical training procedures that can mean the difference between suppressing a fire or creating a situation of immediate danger to life and health (Grimwood, 2000; Liu et al., 2002; Scheffey, Siegmann III, Toomey, Williams, & Farley, 1997). These two methods are extremely important in the safe and appropriate training of air management, which has previously been reported in being of central importance in the fire service (F. M. Williams-Bell et al., 2010; F Michael Williams-Bell et al., 2010). At the same time, it has been shown to be possible to simulate some aspects of these in a virtual environment (Backlund et al., 2009; P Backlund et al., 2007; Lebram et al., 2009). Therefore, if game developers and researchers are able to develop simulations and serious games that can effectively address even these elements, it may be possible to increase the experience of fire fighters in these critical operational techniques in a safe and cost-effective manner.

5.0 Discussion

The application of virtual simulations and serious games is becoming more widespread within fire fighter education and training. In addition to their inherent interaction, motivation, and engagement, the application of virtual simulations and serious games to fire fighter education and training can provide a safer and cost effective training environment. The majority of these tools that have been developed to date focus on fire education (Bukowski & Sequin, 1997; Chittaro & Ranon, 2009; DeChamplain et al., 2012; G.P. Forney, 2007; Gamberini et al., 2003; Ren et al., 2008; S. P. Smith & Trenholme, 2009; Tawadrous et al., 2013; Zachary O Toups & Andruid Kerne, 2007; Zachary O Toups et al., 2011) incident command level decision making and team coordination (Cha et al., 2012; Dugdale et al., 2004; Environmental Tectonics Corportation, 2012; R. Querrec et al., 2004; St.Julien & Shaw, 2003; D. Tate, 1997), building evacuations (Korhonen, Hostikka, Heliövaara, Ehtamo, & Matikainen, 2007; Kuligowski, 2013), and very few at the individual task level duties of the fire fighter (Backlund et al., 2009). One of the major limitations of virtual simulations and serious games has been the limited use and reporting of quantitative measures to accurately assess the effectiveness and efficacy of the simulation along with the ecological validity. For serious games to be accepted as a viable educational tool, they must provide some means of testing and progress-tracking and the testing must be recognizable within the context of the education or training they are attempting to impart

(Chen & Michael, 2005). A number of studies have employed various methods and techniques to assess the effectiveness of serious games and various comprehensive reviews have been conducted to examine the overall validity of game-based learning in general. Results of these studies and reviews seem to suggest that game-based learning is effective for motivating and for achieving learning goals at the lower levels in the Bloom's taxonomy (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). The assessment of user learning within a serious game is not a trivial matter and greater work is required. However, with the advent of recent technological advancements, it is now possible to extend and enhance assessment by recording game-play sessions, and keeping track of players' in-game performance. In-game assessment is particularly useful given that it is integrated into the game logic without breaking the player's game experience and it enables immediate provision of feedback and implementation of adaptability (Bellotti et al., 2013).

Another major criticism of virtual simulations and serious games has been their ability to provide a realistic educational and training environment. Fully recreating a complex interactive, and dynamic real-world fire environment across all of the senses is still beyond our computational reach (Hulusic et al., 2012). That being said, recent hardware and computational advancements are providing designers and developers of serious games the opportunity to develop applications that employ high levels of fidelity/realism and novel interaction techniques using off-the-shelf consumer level hardware and devices; as technology continues to improve, even higher fidelity/realism will follow. However, despite striving for high fidelity, recent work has suggested that high fidelity does not always lead to greater learning (G. Norman et al., 2012) and therefore, greater work remains to examine the intricate relationship between the level of fidelity and effectiveness of learning.

With respect to fire fighting, one of the most important factors for health and safety in the fire service that has received limited attention in the scientific literature is cognitive function, and primarily how it relates to thermal stress. Similarly, it has been incorporated at only a cursory level, with no consideration of the impact of thermal stress, into the serious games and virtual simulations discussed above. To date, the few studies which have examined cognitive function during exertional heat stress in fire fighters have utilized simple mental performance tasks, such as reaction time, to determine any changes in cognition with increasing core temperature. These tests have been reported as being capable of withstanding the effects of thermal strain due to their simple nature (P. Hancock & Vasmatzidis, 1998), and therefore as not being practical to the fire fighting occupation (Barr et al., 2010), nor ecologically valid. On the other hand, cognitive performance tests that involve dual-tasks (either motor and/or cognitive tasks) or those involving central executive function are more susceptible to decrements from exposure to thermal strain (Cian, Barraud, Melin, & Raphel, 2001; Cian et al., 2000; P. Hancock & Vasmatzidis, 1998). In a review study by Barr et al. (2010), the authors concluded that future work should focus on performing simulated fire fighting tasks, at the intensities and durations that reflect similar energy expenditures as those encountered by fire fighters, while in a climatic chamber using computer-based cognitive function tests that are more realistic to the mental tasks encountered at emergency scenarios. This idea points to yet another open opportunity for the use of serious games and virtual simulation in an application with direct impact to the fire service.

6.0 Conclusion

In this paper we have reviewed the use of virtual simulation and serious games for the education and training of fire fighting. The advances in technology have allowed for game developers to depict emergency scenarios in a semi-realistic fashion that can greatly benefit fire fighter education; however, the ability to completely recreate real world dynamic fire simulations that are precisely accurate are still beyond the technological capacities currently available. Although greater work remains to overcome the open problems associated with use of serious games and virtual simulations in universal fire training applications, the next step in the process will be to utilize the benefits of the gaming environments in recreating the decision making processes that fire fighters must encounter in an emergency situation and incorporate and monitor them in an environment where the physical and psychological stresses are analogous to a live situation.

Table 1: Overview of the nature of the video games, serious games, and virtual simulations reviewed

Fire fighter Games and Virtual Simulations						
Authors	**Entertainment**	**Education**	**Training**			
			Incident Response	*Decision Making*	*Team Coordination*	*Task Level Skills*
Fire fighter by Atari	X					
Fire fighter FD by Konami	X					
Fire fighter Command: Raging Inferno by Kudosoft Interactive	X					
Real Heroes: Fire fighter by Conspiracy Entertainment Corp.	X					
Emergency by Sixteen Tons Entertainment	X					
Bukowski and Sequin (1997)		X				
Backlund et al.						X
D. Tate (1997)			X			
St. St.Julien and Shaw (2003)			X			
Ren et al. (2008)		X				
Li et al. (Li et al., 2004)				X	X	
Environmental Tectonics Corportation (2012)			X	X	X	
Cha et al. (2012)			X	X	X	
Dugdale et al. (2004)			X	X	X	

R. Querrec et al. (2004)			X	X	X	
Digital Combustion			X	X	X	
Zachary O Toups and Andruid Kerne (2007)		X			X	
Zachary O Toups et al. (2011)		X			X	
VectorCommand Ltd.			X	X		
TEEX Emergency Services Training Institute				X		
Carnegie Mellon University			X	X		
Gamberini et al. (2003)		X				
S. P. Smith and Trenholme (2009)		X				
Chittaro and Ranon (2009)		X				
DeChamplain et al. (2012)		X				
Tawadrous et al. (2013)		X				

Table 2: Overview of the main characteristics of the serious games and virtual simulations reviewed in this paper based on the goals of the developed model

Authors	**Fire Dynamics**		**People Dynamics**		**Fire fighter Skills Training**	**Building Evacuation**	**Fire Safety Education**
	Fire Development	*Smoke Movement*	*User Co-ordination*	*Virtual Agent Co-ordination*			

Bukowski and Sequin (1997)	X	X					
Backlund et al.					X		
D. Tate (1997)					X		
St. St.Julien and Shaw (2003)	X	X		X			
Ren et al. (2008)	X	X			X		
Li et al. (Li et al., 2004)							
Environmental Tectonics Corportation (2012)			X				
Cha et al. (2012)	X	X	X		X		
Dugdale et al. (2004)			X	X			
R. Querrec et al. (2004)		X		X			
Digital Combustion			X				
Zachary O Toups and Andruid Kerne (2007)			X				
Zachary O Toups et al. (2011)			X				
VectorCommand Ltd.			X				
TEEX Emergency Services Training Institute					X		
Carnegie Mellon University			X				
Gamberini et al. (2003)						X	
S. P. Smith and Trenholme (2009)						X	
Chittaro and Ranon (2009)						X	

DeChamplain et al. (2012)							X
Tawadrous et al. (2013)							X

Figure 1: Screenshot of *Emergency: 2013* developed by Deep Silver in 2012 for PC. Reprinted with permission.

Figure 2: **An intense pool fire in a student office; 100 seconds after ignition, the room is nearly filled with smoke. Reprinted with permission.**

Fig. 3 In-game visual of the Sidh fire fighter training simulation with the fire fighter in a standing position dealing with a smoke filled room. (Backlund et al., 2009; P. Backlund et al., 2007; Lebram et al., 2009). Reprinted with permission.

Fig. 4 **Snapshot of the single family home used in St. Julien and Shaw's (Julien & Shaw, 2002) virtual environment fire fighter training simulation. Reprinted with permission.**

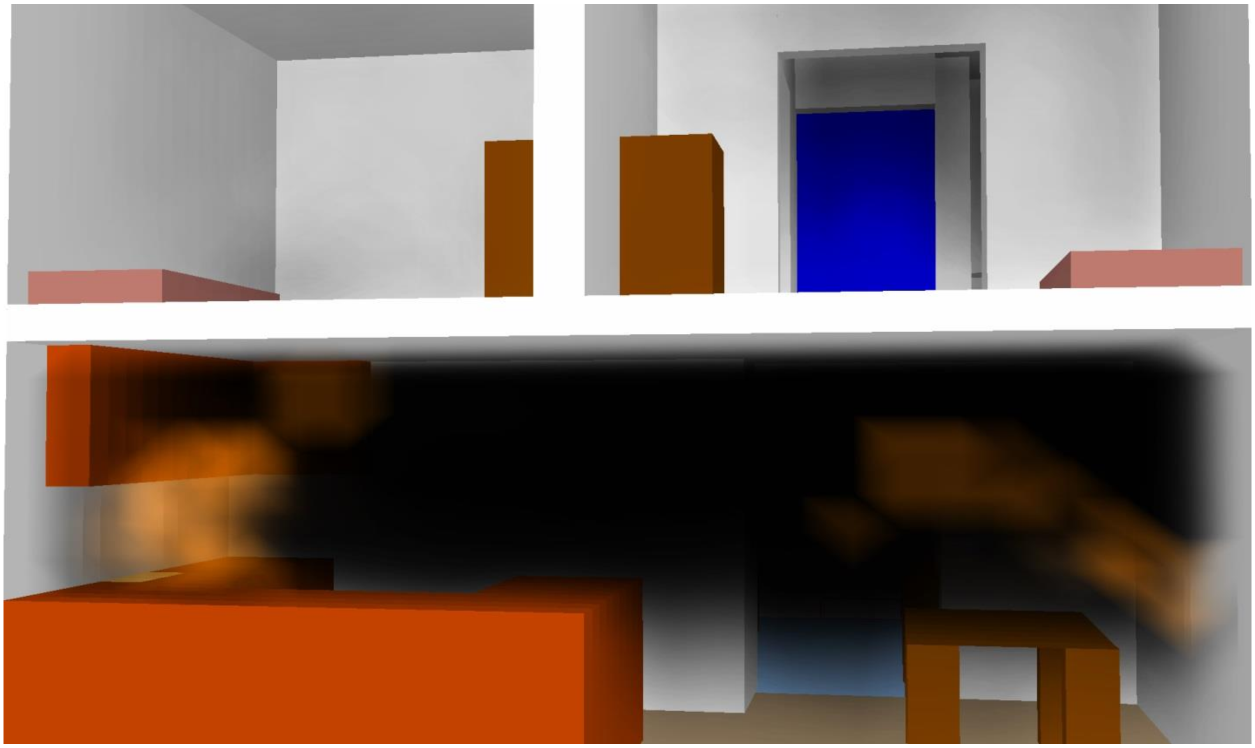


Figure 5: **A depiction of fire development and smoke spread using Smokeview for visualizing Fire Dynamics Simulation data from (Glenn P Forney & McGrattan, 2008). Reprinted with permission.**

Figure 6: **Fire training scenario of an automobile accident and fire in a tunnel using the virtual reality based fire training simulator developed by Cha et al. (Cha et al., 2012). Reprinted with permission.**

Figure 7: **Firefighters performing fire suppression within the Advanced Disaster Management Simulator (Environmental Tectonics Corportation, 2012). Reprinted with permission.**

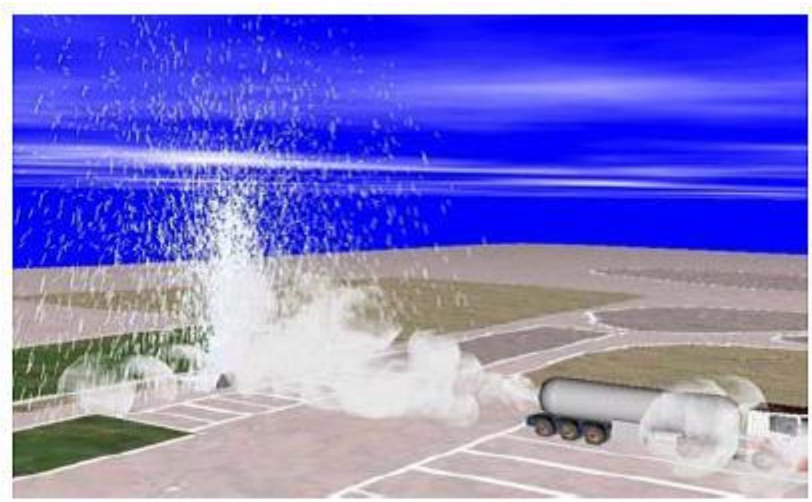


Figure 8: **Example of the 3D environment from the SecureVi virtual environment fire fighter training simulation from Querrec et al (R. Querrec et al., 2004). Reprinted with permission.**

Figure 9: a) screenshot depicting a stove top fire that has started to spread out of control. Reprinted with permission from DeChamplain et al. (2012), b) sample screenshot illustrating the area of the chemistry laboratory where the simulation is based. Reprinted with permission from Tawadrous et al. (2013).

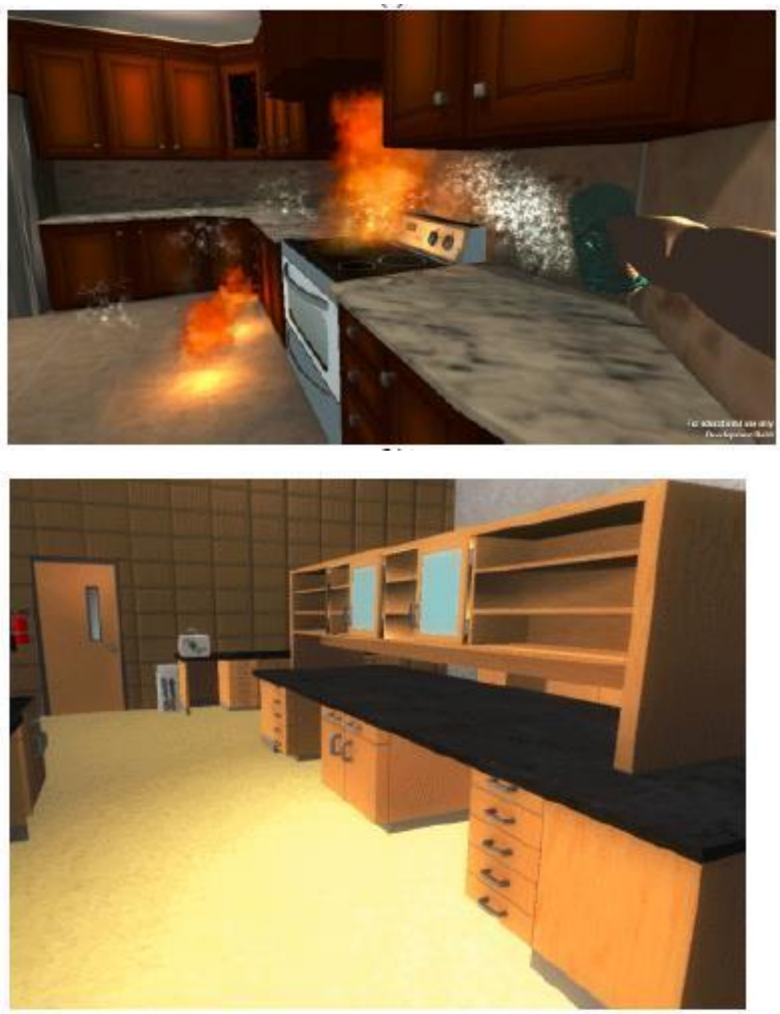
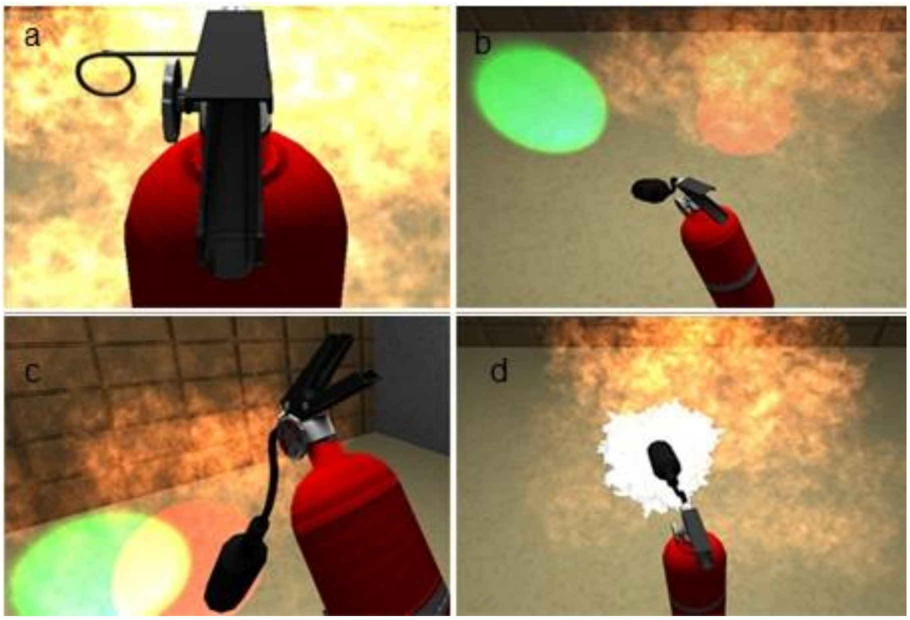
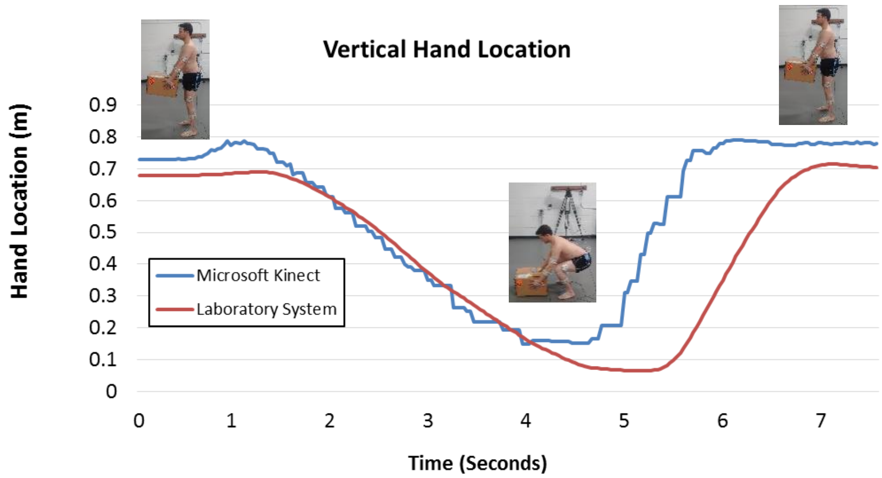


Figure 10: Screenshot from the Tawadrous et al. (2013) game depicting the Pull, Aim, Squeeze, and Sweep (P.A.S.S.) method. a) prompts user to pull pin, b) prompts user to aim, c) prompts user to squeeze handle, and d) Prompts user to maneuver sweeping motion). Reprinted with permission

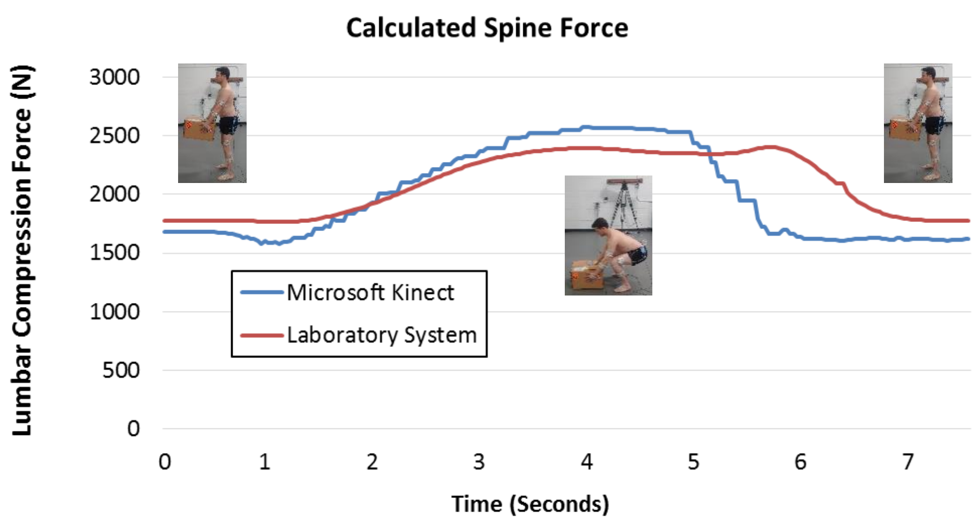


Objective 5: Develop a serious game that will assess the movement patterns of firefighters during various lifting techniques to determine the level of risk associated

Below is some data from one individual performing a simple lifting task. We have indicated on the graph what the person was doing at each time point with an actual image from data collection. The following graph represents a time series of the vertical hand location coordinates as calculated by the Kinect and the 3DInvertigator (the laboratory grade system). There appears to be a slight time shift between the systems, but this is a simple synchronization issue during data collection and can easily be accounted for.



The accuracy of the hand location data clearly translates to our calculated spine forces. Below is an example of the time history calculated spine load for one participant, performing a squat lift.



Given th ... pants (2 Males an ... rigid bodies attached to the hands, feet and trunk of the participant we collected kinematic data for the orientation and position of the hands, feet and trunk during a series of lifting tasks. The rigid bodies tracked the positional data for the laboratory system markers.

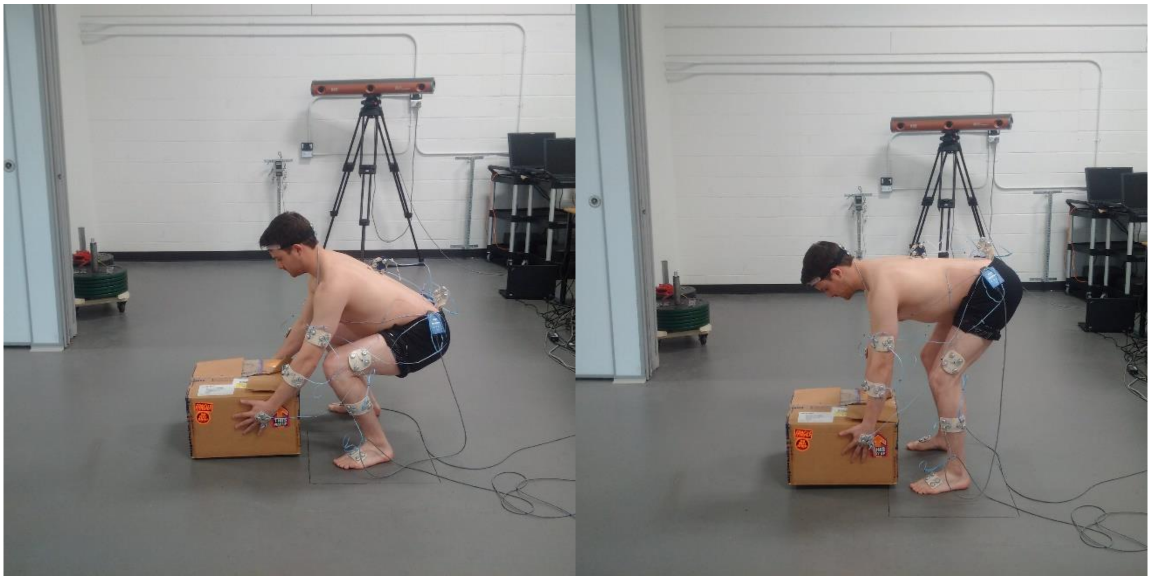


Figure 1: Example data collection session. 3D Investigator camera is visible in the background. Notice markers attached to the participants limb segments. The Kinect camera would be positioned facing the participant. Left, squat lift condition; Right, stoop lift condition.

Using our previously developed approach, participants wore colored items on the hands and feet to allow for improved tracking of the Kinect. The tasks included 3 repetitions each of a squat lift, stoop lift and a lift involving twisting (Figure 1). The load lifted was a box, weighing 1 lbs. A very small load was selected because we were not attempting to determine the effects of object weight on spine loads during lifting. We were only interested in determining accuracy between the Kinect and laboratory systems and the Kinects ability to track the coordinates required to estimate spine load. We captured the kinematic data from both the laboratory system and the Kinect simultaneously. The Potvin (1997) equations provide 2 models for the calculation of spine forces. We used both methods as outputs to the spine compression model. Model 2 performed better and had less error between the two systems (Figure 2). Figure 2 demonstrates the average spine compression difference that was calculated using the Kinect and laboratory systems. As demonstrated in the figure, the spine compression difference between the two systems (Kinect and laboratory system) was reasonable and well within acceptable ranges. During the squat lift, model 2 estimates produced only a 300N difference between the systems.

The stoop lift was only slightly higher. The difference was largest for twisting, and this was to be expected. The Kinect has trouble tracking objects as they fall outside the frontal plane and the participant's hands did just that during our twisting conditions. Twisting was added as a condition to evaluate these potential effects, and when using model 2, a difference of approximately 400N was found. This is still a reasonable finding, considering the biomechanical variability associated with most spine compression models. There is discrepancy in the literature as to what the most appropriate recommended compression level threshold should be for safe lifting guidelines. NIOSH recommends a limit of 3400N, even 6400N for some individuals (NIOSH, 1981). In addition, other researchers have provided limits of 5000N (Leamon, 1994), 5700N and 3900N for males and females respectively (Jager & Luttmann, 1991). Therefore, given that the Kinect and 3D Investigator was separated by only 300N, it appears that the Kinect is a useful tool to continue exploring its potential as an ergonomic lifting tool.

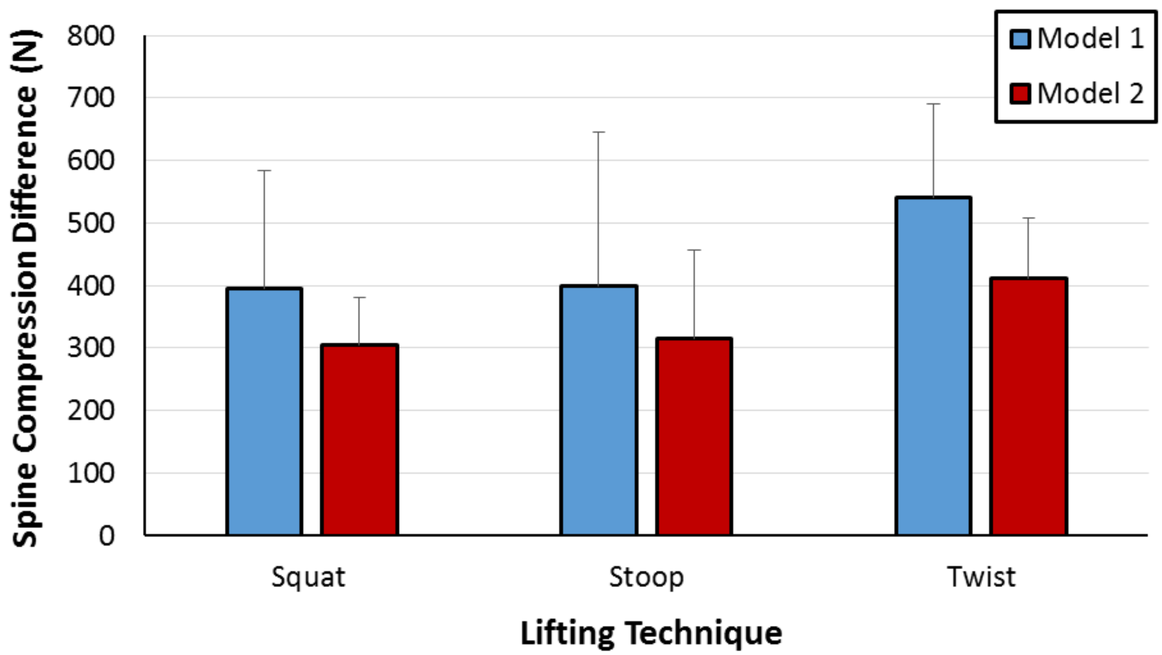


Figure 2: Calculated spine compression difference between the Kinect and Laboratory system for model 1 (blue) and model 2 (red) during the 3 lifting conditions.

Given that model 2 appeared to provide the best estimations between both systems, spine compression values for model 2 are highlighted below. Figure 3 demonstrates the calculated spine compression using model 2 for both the Kinect and laboratory systems during the 3 lifting conditions.

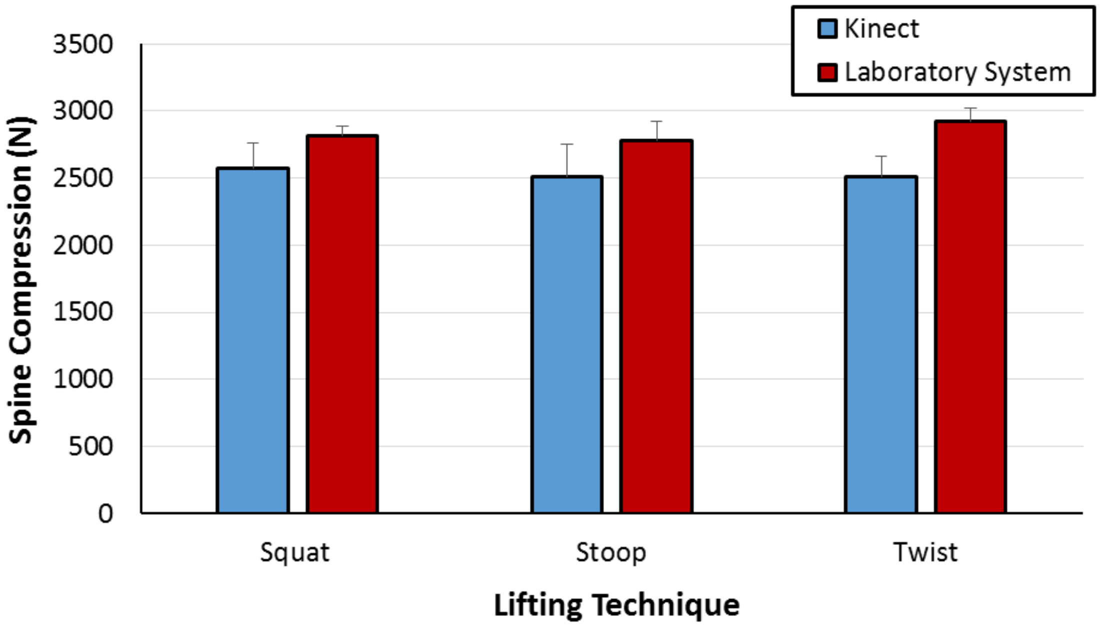


Figure 3: Average spine compression (newton's) for the 3 lifting tasks for the Kinect (blue) and Laboratory (red) systems.

6.0 Appendix C: Copy of Resources Developed from the project

The different levels of difficulty for the decision-making game can be viewed using the following URL: https://www.youtube.com/playlist?list=PLU97-xZpaaYYTvPBerNZCr0TxX8QVSJ13 .

7.0 APPENDIX D: Financial Report (*Please see separate signed file)

University of Ontario Institutue of Technology

STATEMENT OF REVENUE AND EXPENDITURES

Serious Games to Decrease Injury in the Fire Services by Training Safer Movement Patterns and Decision Making Skills: Development and Piloting

Principal Investigator: Dr.Bernadette Murphy

As of December 2015

Budget	**Actual**		**Variance**
Revenue:			
WCB	199,993.00	189,167.00	10,826.00
199,993.00	**189,167.00**		**10,826.00**
Expenditures:			
Salaries & Benefits:			
Focus Group Project Assistant	-		-
Project Manager	20,000.00	20,000.00	-
Ergonomic Graduate Student Stipend	14,445.00	15,000.07	(555.07)
Game developer Master Student Stipend	7,759.00	7,758.80	0.20
Research Assistant	5,000.00	7,523.13	(2,523.13)
Programmers	27,133.78	22,804.76	4,329.02
Materials and Supplies:	4,813.00	4,813.28	(0.28)
Equipment:	-		-
Digital Recorder	450.00	450.00	-
Microsoft Kinech Sensors	-	-	-
MVTA Software, Force Gauge, cameras	5,726.00	5,725.92	0.08
NViv09 License	-	-	-
Cssmed K4b2 Lease	41,000.00	40,487.01	512.99
Environmental chamber rental	33,765.90	33,765.90	-
Core Temperature Data Logger and Temperature Pills	7,303.00	7,302.66	0.34
Lab Facility Fee	-	-	-
Treadmill Lease	10,000.00	9,999.74	0.26
Travel, Accommodation and Meals	2,631.00	4,505.70	(1,874.70)
Communication and Knowledge Transfer Costs	-	-	-
Focus Group Honoiaria	450.00	450.00	-
Transcriber	-	-	-
Firefighters' Stipdends and Mileage	14,516.32	14,516.32	-
Conference	5,000.00	4,889.71	110.29
Expenditures Funded by WCB	**199,993.00**	**199,993.00**	**(0.00)**
Excess of revenue over expenditures	**-**	**(10,826.00)**	**10,826.00**