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Evaluating the Similarity in Postures Between Forklift Operators in Virtual Reality and the Workplace

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A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science

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EVALUATING THE SIMILARITY IN POSTURES BETWEEN FORKLIFT OPERATORS IN VIRTUAL REALITY AND THE WORKPLACE

(Thesis format: Monograph)

by

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Graduate Program in Kinesiology

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Kinesiology, Biomechanics

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Abstract

Forklift operators must adopt awkward postures in order to gain appropriate lines of sight; these postures are associated with musculoskeletal injuries and disorders such as low back pain and neck pain. The purpose of this thesis was to evaluate the similarity in postures between forklift operators in virtual reality simulation of forklift loading and unloading operations and a corresponding real world workplace. This evaluation will help determine whether the virtual reality system is a useful tool for performing controlled laboratory-based investigations of ergonomics issues in heavy mobile machinery. One certified forklift operator and one uncertified individual performed two cycles of the loading and unloading tasks in the virtual reality environment. Video images of the participant's postures in the virtual reality simulation quantified the neck and trunk postures as neutral, moderate or awkward. Published data from a warehousing operation were used for comparison. The results showed that the participants adopted similar postures in the simulation and the field; however, there were significant differences in the durations that specific postures were adopted. These preliminary findings suggest promise; further development of the system is necessary to use it as a tool for ergonomic analysis of workplace mobile machinery.

Keywords

Biomechanics, Forklift, Posture, Video Recording, Virtual Reality, Simulation

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Chapter 1

1 Introduction

Forklifts are powered industrial trucks that can lift and transport objects short distances. They are an integral part of the manufacturing and warehousing operations around the world. According to Industrial Truck Association, 197,000 forklifts were sold in North America in 2013 (ITA, 2014). Because they are so powerful and widely used, occupational safety is an issue. Every year in US, forklifts are associated with almost 100 deaths and 20,000 injuries (NIOSH, 2001). Forklifts are also associated with musculoskeletal injuries and disorders for the operators; the most common areas that are affected are lower back (Hoy et al., 2005; Viruet, Genaidy, Shell, Salem, & Karwowski, 2008; Waters, Genaidy, Deddens, & Barriera-Viruet, 2005), neck and shoulders (Ariens et al., 2001; Bernard & Putz-Anderson, 1997). Forklift drivers are at more than twice the risk of experiencing lower back pain than non-operators (Waters et al., 2005). Two specific ergonomic risk factors have been identified for forklift operators: whole-body vibration and postural demands (Hoy et al., 2005; Viruet et al., 2008). This thesis will focus on the postural demand aspect of forklift operations.

1.1 Posture Risk

Operating a forklift requires the operator to perform specific tasks, such as driving backwards while carrying a load; these forklift operations require the forklift operator to adopt various postures in order that they can see their environment and driving path (Eger et al., 2010). The four frequently adopted postures in forklift operation were identified by Hoy and colleagues (2005). The first one was the normal driving posture with flexed trunk, and left hand on steering wheel and right hand on truck controls. The second was the aligning forks posture with laterally bent trunk and twisted and neck twisted. The third was the reversing posture with considerably twisted trunk and neck. The last posture was the stowing posture with laterally bent trunk and extremely extended neck.

It is important to identify the relationship between injury risks and awkward postures. By definition, awkward postures increase risk of fatigue, pain or injury when they are maintained for prolonged periods or repetitively (Keyserling, Brouwer, & Silverstein, 1992). An increased risk of low back pain (LBP) was identified with awkward or non-neutral trunk postures (Hoogendoorn et al., 2000; Hoy et al., 2005; Magnusson & Pope, 1998). In particular, maintaining a minimum trunk flexion of 60° for more than 5% of the working time, or 30° of minimum trunk rotation for more than 10% of the working time, increased the risk of LBP (Hoogendoorn et al., 2000). The greatest risk for LBP was associated with twisted and considerably flexed trunk (Hoy et al., 2005). Awkward neck postures were also responsible for an increased risk of musculoskeletal disorders as well (Bernard & Putz-Anderson, 1997; Delleman & Dul, 2007; Magnusson & Pope, 1998). An increased risk of neck pain was associated with minimum neck flexion of 20° for more than 70% of the working time (Ariens et al., 2001). In addition, driving with neck extended was also associated with an increased risk of LBP (Hoy et al., 2005).

1.2 Simulation

Many studies have evaluated forklift operator’s postures and health risks (Hoy et al., 2005; Waters et al., 2005; Viruet et al., 2008; Delgado, 2012). However, the measurements that are required to perform these assessments in the field can be limited because of issues including: difficulty accessing workplaces, limitations with portable instrumentation, dangerous environment, and expense (Trask et al., 2007). Also, it is difficult to isolate specific factors, such as posture, using field studies as they coexist with other factors, such as whole-body vibration. Given these difficulties, some researchers have developed laboratory-based studies including virtual reality simulations. For example, virtual reality simulations have been used for forklift training (Bergamasco et al., 2005) and evaluating specific safety issues such as forklift turnovers during cornering (Lemerle, Hoppner, & Rebelle, 2011). Many virtual reality simulations have only simulated the visual environment (Lemerle et al., 2011), while other studies have modelled the visual and vibration environments for a more complete reflection of workplace ergonomics factors (Donati, Bolder, Whyte, & Stayner, 1984). Conducting research in the laboratory setting also provides more freedom in terms of choice of instrumentation, and access to the actual workplace can present difficult barriers to research (Trask et al., 2007). So, using a forklift simulator in the lab can bring more control of experimental factors and freedom regarding instrumentation in research. This research setting will enable more controlled studies of issues such as posture and vibration for heavy machinery operations and could expand our understanding of health risks for forklift operators. However, if these virtual reality simulations are going to be useful, then they must enable similar workplace factors, such as operator postures, compared to the workplaces.

1.3 Training

Safe work practices and proper training can prevent injuries. The prevention of occupational injuries and musculoskeletal disorder is a priority in workplaces dealing with heavy machinery (ISO, 2006). Following the recommended standards such as ISO 11226 and EN 1005-4, which are set up by International Organization for Standardization (ISO) and European Committee for Standardization (CEN) respectively, can help reduce health risks caused by awkward postures (Delleman & Dul, 2007). Occupational Health and Safety Act (OHSA) and Ontario Ministry of Labour's Regulation 851 highlight that the training in operating procedure is a required component for forklift operator certification (OHSA, 1990). Although operators of real forklifts must be certified, this is not an absolute requirement for research participants operating forklifts in the virtual reality simulation.

1.4 Purpose

The purpose of this study was to evaluate the similarity in postures between forklift operators in an immersive virtual reality simulation and the real world workplace. Comparing posture data from the field and virtual reality will provide evidence about whether the simulator is an appropriate alternate approach for future research.

Additionally, comparing postures between trained and untrained operators will also provide insight on whether it is necessary to test trained forklift operators in the laboratory simulations. There are two research questions for this thesis. The first question is: are the postures adopted in the simulation similar to those in the field? The second question is: are the postures adopted by uncertified individuals similar to those adopted by certified forklift operators?

Chapter 2

2 Methods

The project was approved by the University of Western Ontario Human Subjects Research Ethics Board (Appendix A). The dimensions for the virtual reality warehouse were obtained from the storage warehouse in London, Ontario, Canada where field testing was performed. The simulator was set up in the Joint Biomechanics Lab led by Dr. James Dickey at Western University, London, Ontario, Canada. The consent form and questionnaire were signed by the subjects prior to participating (Appendices B & C). For comparison purposes, the data collected in the virtual reality simulation was related to the field data from the field testing performed by a previous Master's student, Giselle Delgado (Delgado, 2012).

2.1 Simulator Setup

2.1.1 Equipment

The custom designed cart representing the forklift was mounted on the six degree of freedom parallel robot (R-3000 Rotopod, Mikrolar, NH, USA; Figure 1). This cart contained the seat and machine controls (accelerator and brake pedals, steering wheel and joystick mast controls) in an appropriate configuration to match the Toyota 7FGCU25 forklift from the field testing (Delgado, 2012). Six OptiTrack cameras (V100:R2, NaturalPoint; OR, USA) were set up on the ceiling to read the head position via reflective trackable markers (Figure 2). Tracking Tool software (NaturalPoint; OR, USA) was used to interpret the marker positions and calculate the position and orientation of the subject's heads. A head-mounted display (Oculus Rift, Oculus VR; CA, USA) was used to provide visual feedback to the driver (Figure 2).

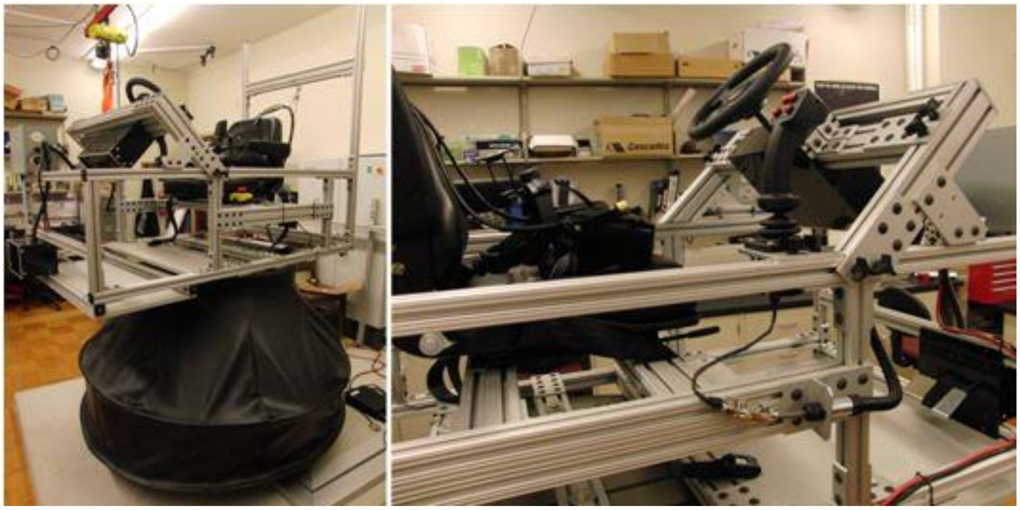

Figure 1: Custom designed cart (aluminum frame) mounted on the parallel robot (under the black skirt at the bottom of the left image). The vehicle controls (steering wheel, joystick, accelerator and brake pedals) are shown in the right image. Reproduced through Open Access from Dickey et al., 2013.

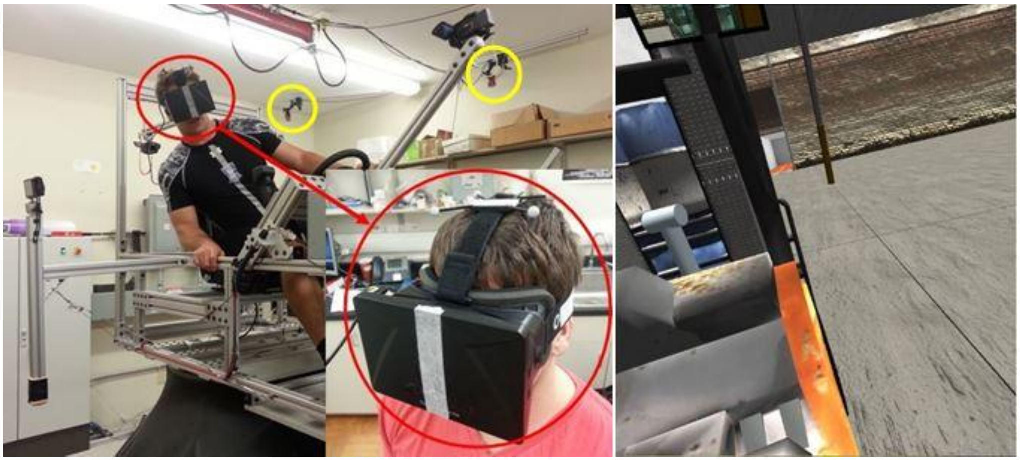

Figure 2: Illustration of a research participant operating the forklift in the virtual reality environment. Two OptiTrack cameras, mounted to the laboratory ceiling, are shown near the top of the left photo (outlined with yellow circles). The inset detail shows the head-mounted display (Oculus Rift, Oculus VR; CA, USA) and the reflective markers on top of the head. Tape strips are apparent on the head-mounted display and the operator’s shirt; these provided cues to help identify the operator’s postures. The right image is the corresponding view from the head-mounted display showing the forklift structures within the field of view.

2.1.2 Virtual Reality

The virtual reality forklift simulation was created within the gaming engine Unity (4.0, Unity; CA, USA), which was also incorporated a physics engine that provided vehicle motion (Wegscheider, 2014). During simulation, the program receives information about the cart controls and uses an embedded physics engine to predict the motion and acceleration of the forklift. These motion and acceleration data are sent to the robot control to provide the participant with the motion feedback. The Unity program receives information about the participant's head position via the OptiTrack system. The relative position of the subject's head with respect to the forklift position is used to update the visual environment and provide the participant with appropriate visual feedback via head-mounted display (Figure 2).

The virtual reality environment was modeled after a real storage warehouse in London, Ontario, Canada where field testing was previously performed (Delgado, 2012). This environment consisted of a warehouse and a transport truck (Figure 3). The warehouse had two aisles, and pallets of barrels for lifting at the end of each aisle. The warehouse and the transport truck were connected by a ramp so the operators can drive the forklift in and out of the truck.

2.2 Protocol

The participants were oriented about the purpose of the experiment, operation of the cart controls and safety procedures. After performing informed consent, the subjects were introduced to the birds-eye view of the virtual warehouse on the computer monitor (Figure 3) before getting into the cart. Once seated in the cart, the participants were required to wear the seat-belt at all times. The locations of the steering wheel, fork gear, transmission gear, emergency stop, gas and brake pedals were indicated to the subject before putting on the head-mounted display. This was necessary since the subjects cannot see their own hands and feet inside the virtual reality simulation; it is necessary that the subjects learn the location of all the control features to operate the forklift. Since the position of the head in the virtual reality determines the participant's view, it was adjusted before the operation of the forklift. The orientation of the side-view mirrors were also adjusted so that the participants had appropriate views. Then the participants were given 15-20 minutes of practice time driving around the virtual warehouse to become accustomed to the virtual reality simulation and the vehicle controls. Once the participants were confident they started performing the experimental tasks. The tasks consisted of two parts: loading the barrels from the aisle into the transport truck and unloading the barrels from the transport truck into the aisle. The participants performed two trials of the loading and unloading tasks. Both tasks started at the front of the transport truck with the forklift facing the entrance to the truck. For the loading task, the participant would drive in reverse to the first aisle, and then drive forward into the aisle to pick up barrels. Then the participant would drive in reverse out of the aisle and drive forwards over the ramp and into the truck to unload the barrels. The participant would back out of the truck to complete one cycle of the loading task. For the unloading task, the participant would drive forward into the transport truck and pick up the barrels. Then the participant would drive in reverse out of the truck and to the first aisle, and drive forward down the aisle to unload the barrels. The participant would drive in reverse out from the aisle and drive forward to the entrance to the truck to complete one cycle of unloading task.

Figure 3: Birds-eye view of the virtual warehouse (left). The workplace tasks involved loading pallets of barrels from the stacks (bottom right) into and out of the transport truck (top left). The right image is showing the perspective view of the virtual warehouse.

2.3 Posture Measurements

Three video cameras (side, front and rear views) were mounted to the cart on outrigger arms to record the participant’s posture while they were operating the forklift in the virtual reality environment (Figure 4). This camera arrangement replicated the arrangement from the field testing (Delgado, 2012). A side-view camera (HDR-XR550V, Sony; Tokyo, Japan) was equipped with wide-angle lens to provide larger field of view; the entire torso and head of the driver were captured in the frame. The front camera (GZ-MG555U, JVC; Yokohama, Japan) captured the head, shoulder, and upper part of the torso from the front of the cart. The back camera (GZ-MG555U, JVC; Yokohama, Japan) captured the head, shoulder, and posterior view of the torso above the seat of the participant. The control computer had two monitors; one displayed the birds-eye view of the virtual warehouse, and the other one displayed the participant’s view inside the head-mounted display (inset in Figure 4); an additional video camera (ST550, Samsung; Seoul, South Korea) captured the view of the warehouse off the monitor (inset in Figure 4). This fourth video image was used for identifying the tasks at the analysis stage.

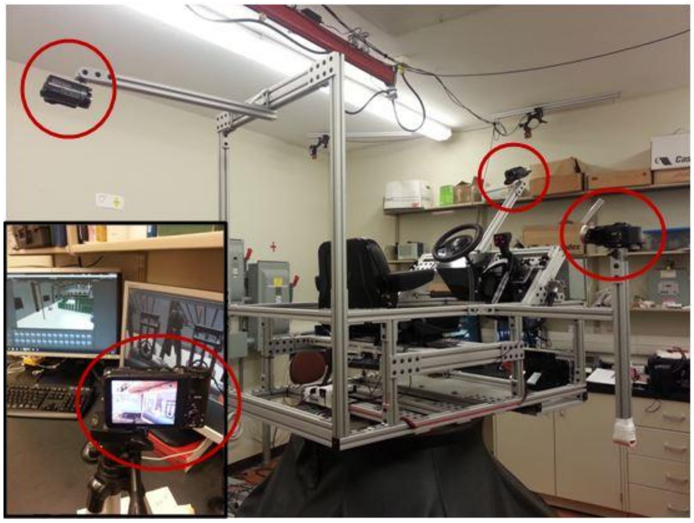

Figure 4: Positions of three cameras for the posture measurement (side, front and rear views). A fourth camera (circled in red in the inset; bottom left corner) captured the computer screens to show the location of the forklift within the warehouse and the tasks that the forklift was performing.

2.4 Posture Analysis

Strips of white tape were attached to the front, back, and side of the torso, and on the shoulders of participant, to aid identifying postures from the video images (Figure 2). White tape was also attached to the head-mounted display to help identify the head and neck postures (Figure 2 and 5). The participants wore dark clothing to make the tape more visible. Before every trial, a LED bulb was turned on within the field of view of all of the cameras (next to the participant's right shoulder) for the purpose of syncing the videos; the camera at the control computer was also turned to face the bulb for this synchronization.

Figure 5: Images showing the strips of tape attached on the body of participant, and on the head-mounted display, for providing cues to help identify the operator's postures during the video analysis.

2.4.1 Video Preparation

The video files were edited by Dartfish software (Dartfish TeamPro 5.5; GA, USA). All files were converted to AVI as this format was optimal for Dartfish editing. Videos from the back camera were rotated as the camera was mounted upside down at the back of the cart (Figure 4). Then the four video files were synchronized based on the moment that the LED light turned on. Four different views were then assembled into one video with a 2x2 arrangement (Figure 6). This composite video file was down sampled to 6 frames per second (fps) from 30 fps for posture coding (v1.10.4, VirtualDub, www.virtualdub.org). Six fps was an acceptable frequency to capture trunk and neck postures during forklift operations based on residual analysis (Delgado, 2012). This video decimation approach has been used by other researchers (5 Hz, Forde et al., 2011; 3 Hz, Seaman et al., 2010) since the postures change relatively slowly and they are appropriately quantified at slower video rates.

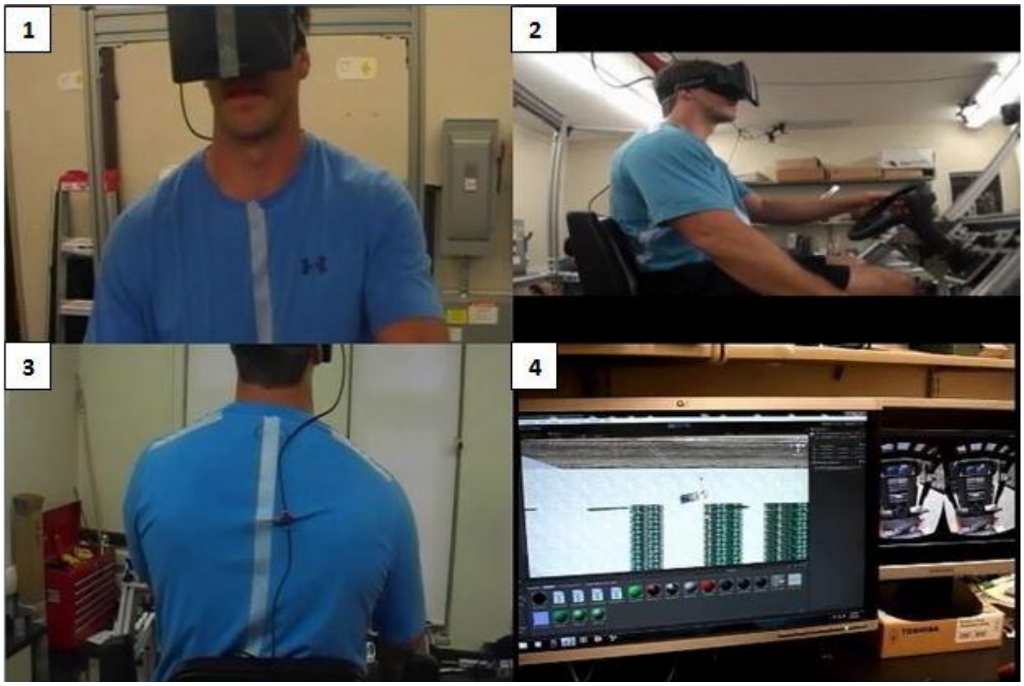

Figure 6: Sample image from the synchronized videos in 2x2 arrangement (1 – from the front camera; 2 – from the side camera; 3 – from the back camera; 4 – from the monitor camera). The fourth sub-image shows the position of the forklift in simulation (left screen) and the participant's view in the head-mounted display (right screen).

2.4.2 Task Identification

Nine tasks were identified which matched the field data, following a convention that was established in earlier work (Delgado, 2012). The tasks included driving forward or backward, and driving in the warehouse or in the truck, and were performed with the forks loaded or unloaded (Table 1). Other tasks, such as adjusting the head-mounted display or calibrating the equipment, were edited out during video preparation process. Then video segments corresponding to each of these tasks were identified while reviewing the synchronized 6 fps videos.

Table 1: The abbreviations and the descriptions of the 9 tasks developed by Delgado (2012) are listed with corresponding task numbers.

Task #	Abbreviations	Description
1	E	Engaging forks
2	LFW	Driving loaded forward in warehouse
3	LFT	Driving loaded forward in truck
4	LBW	Driving loaded backward in warehouse
5	LBT	Driving loaded backward in truck
6	UFW	Driving unloaded forward in warehouse
7	UFT	Driving unloaded forward in truck
8	UBW	Driving unloaded backward in warehouse
9	UBT	Driving unloaded backward in truck

2.4.3 Posture Coding

3DMatch (v5.03, Callaghan; ON, Canada) software was used to extract the trunk and neck postures from the synchronized 6 fps videos. The videos were analyzed frame by frame while categorizing postures for each section of the body into different bins shown in Appendix D. The neck and trunk postures in flexion/extension, lateral bend, and rotation angles were categorized into three bins (neutral, moderate, and awkward; Table 2). The thresholds to define categories for the neck and trunk postures were supported by Rehn et al. (2005) and Punnett et al. (1991). These posture bins were also similar to those used by other researchers (Hermanns et al., 2008; Raffler et al., 2010). The posture data was then saved as text files. A customized LabVIEW program (Version 2010, National Instruments; Austin, TX, USA) was created to categorize the posture data into three different posture bins for each of the nine different tasks (Table 1).

Table 2: The boundary angles defining the trunk and neck postures for the neutral, moderate and awkward categories. Refer to Appendix D for additional detail.

Joint and Plane	Neutral	Moderate	Awkward
Trunk Flexion/Extension	-15° – 15°	15° – 45°	< -15° or >45°
Trunk Lateral Bending	0° – 15°	15° – 30°	>30°
Trunk Axial Rotation	0° – 15°	15° – 25°	>25°
Neck Flexion/Extension	-10° – 10°	10° – 30°	< -10° or >30°
Neck Lateral Bending	0° – 20°	>20°	-
Neck Axial Rotation	0° – 10°	10° – 40°	>40°

2.5 Statistical Analysis

Chi-square tests were performed in SPSS (Version 20, IBM; NY, USA) to determine whether there were significant differences between the expected and observed frequencies of different postures from the field and certified operators, and from the certified and uncertified operators in the virtual reality simulation. If the Chi-square test was significant, then the standardized residuals for each of the cells were examined to determine which cells were observed more frequently than expected based on the distribution of the data. Standardized residuals with magnitudes greater than 1.96 indicate differences that are larger than you would expect by chance for a p value of 0.05. The overall frame count was used for chi-square test, and the raw data are presented in Appendix E. However, these data are expressed as percentages in the thesis to make trends more apparent.

Chapter 3

3 Results

3.1 Participants Demographics

Two subjects were recruited to participate in the virtual reality tasks (Table 3). One subject was a certified forklift operator. The participant from the archived field data (Delgado, 2012) was a 55 year old male (188 cm, 107 kg) certified forklift operator.

Table 3: Participants information

Subject	Sex	Age	Height (cm)	Weight (kg)	Certification
1	Male	25	185	102	Yes
2	Female	21	178	90	No

3.2 Posture Comparison

Six cycles of tasks were performed in the field while two cycles were performed in the virtual reality simulation. Even though the overall duration was longer in the field, the average time per cycle was much shorter (approximately 226 s in the field versus approximately 440 s in the virtual reality simulation; Table 4). The difference in overall duration between the certified and uncertified operators in the simulation was only 6 seconds.

The overall distributions of neck and trunk postures adopted by each operator are presented in Figure 7. The percentages of time that the specific trunk postures were adopted in all three operators were more similar than the neck postures. However, the percentages of neck postures between the certified and uncertified in the simulation were similar.

Table 4: Duration in seconds for each operator to finish the specified tasks (VRC - Virtual Reality Certified; VRU - Virtual Reality Uncertified)

Task	E	LFW	LFT	LBW	LBT	UFW	UFT	UBW	UBT	Overall
Field[1]	277	165	131	188	117	165	57	180	78	1358[1]
VRC[2]	200	120	65	132	80	83	50	93	58	881[2]
VRU[2]	128	134	38	115	64	165	47	141	43	875[2]

[1] The field operator performed six cycles of tasks within this time

[2] The virtual reality operators performed two cycles of tasks within this time

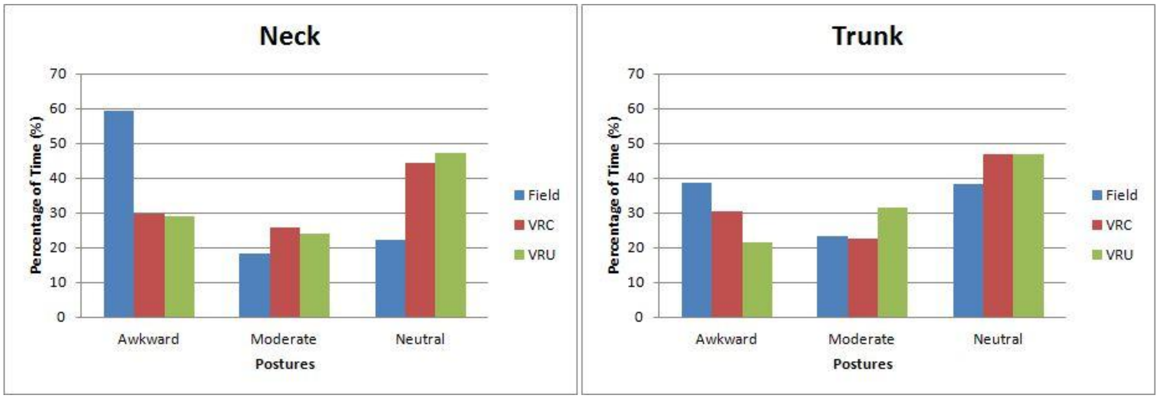

Figure 7: The overall percentages of time that the specific neck (left) and trunk (right) postures being adopted for each operator in the field and simulation (VRC–Virtual Reality Certified; VRU–Virtual Reality Uncertified).

3.2.1 Field vs. Virtual Reality

The posture data from the certified operator in the laboratory simulation (Subject 1) was compared to the previously collected data from the certified operator in the field (Delgado, 2012). The overall postures adopted during various tasks in the simulation (Virtual Reality Certified – VRC) were similar to those from the warehouse (Field). For example, in the forward and backward driving, both operators in the real and virtual workplaces adopted matching neck and trunk postures (Figure 7). Although the types of postures adopted were similar, the durations spent on specific postures were different (Figure 8). The differences in the neck postures from both operators were larger in the forward driving (LFW, LFT, UFW, and UFT) than in the backward driving tasks (LBW, LBT, UBW, and UBT). For example, in the loaded forward driving in the warehouse (LFW) and the truck (LFT) tasks, awkward postures in the neck were adopted 70% and 57% of the time respectively. On the other hand, awkward postures were only adopted 3% and 2% for these tasks in the simulation. The chi-square test demonstrated that the proportions of awkward postures in the simulation were significantly lower than the expected for both the loaded forward driving in the warehouse and the truck tasks ($\text{Chi}^2(2) = 811.529$ (LFW), 362.374 (LFT); Std. Residual = -16.3 (LFW), -11.6 (LFT); $p < 0.05$).

Figure 8: Illustration of the postures adopted by certified forklift operators in the field (1 & 3) and laboratory (2 & 4) for driving forward in the warehouse with a load (1 & 2) and driving backward in the warehouse unloaded (3 & 4).

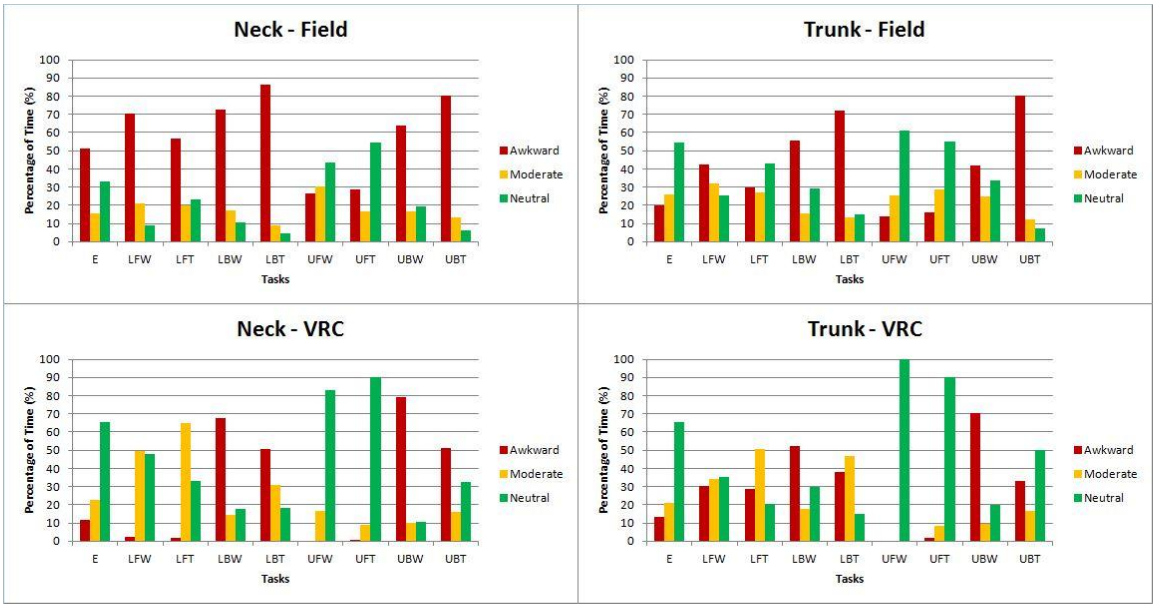

Figure 9: Percentage of time that the certified operators (Field and virtual reality-VRC) adopted particular neck and trunk postures (neutral, moderate, and awkward) for each of the different tasks (refer to Table 1 for the description of the different tasks).

3.2.2 Certified vs. Uncertified Participants

The postures that both the certified and uncertified operators adopted in the simulation were similar to the postures from the field. The posture data from the certified operator and uncertified operator in the laboratory simulation were compared to evaluate whether the training experiences of certified forklift operators impact their postures compared to non-certified operators. The differences in the trends of posture proportions between the certified and uncertified operators (Figure 9) were less than those between the field and the simulation (Figure 8). However, the proportions of awkward postures for both the neck and trunk of loaded backward truck (LBT) in virtual reality for the uncertified operator (VRU) were much higher than that of the certified operator in virtual reality (VRC). The percentages of awkward postures in LBT for neck and trunk were 82% and 80% respectively in VRU, while they were 51% and 38% respectively for the VRC. The chi-square test evaluating the duration of awkward postures in both the neck and trunk in LBT for VRU demonstrated that the proportions were significantly higher than expected

(Chi^2 (2) = 91.934 (neck), 173.805 (trunk); Std. Residual = 4.2 (neck), 6.1 (trunk); $p < 0.05$).

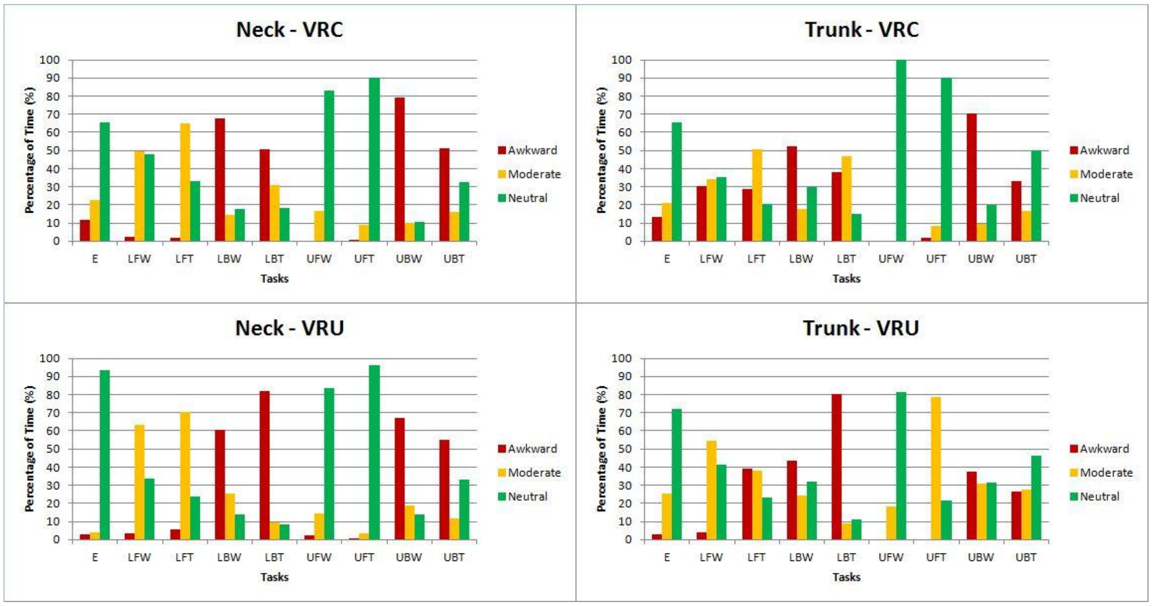

Figure 10: Percentage of time that the certified (VRC) and uncertified (VRU) operators in virtual reality adopted particular neck and trunk postures (neutral, moderate, and awkward) for each of the different tasks (refer to Table 1 for the description of the different tasks).

Chapter 4

4 Discussion

The purpose of this study was to evaluate the similarity in postures between forklift operators in virtual reality and the workplace. I hypothesized that the postures adopted by the operators in virtual reality would be similar to those of the operator in the field. Examination of the video footage illustrated that the simulation operator adopted similar postures as the field operator while performing the same tasks. The range of movements and postures adopted were very close to what was being used on the actual forklift in the workplace.

However, I observed significant differences in the durations that particular postures (neutral, moderate, and awkward) were adopted in each task. In the field versus simulation comparison, the differences in the proportion of time that postures were adopted in the neck from both operators were larger in the forward driving than in the backward driving tasks. For example, the proportions that awkward neck postures were adopted in the both loaded forward driving in the warehouse and the truck in the simulation were significantly smaller than that of the field. The differences in percentage of time spent in specific postures for each task between the certified versus uncertified operators in the simulation were less than the differences between the certified operators in the field versus simulation. This similarity between the operators in the virtual reality environment may reflect the peculiarities of the simulation since both the certified and uncertified operators adopted similar postures. Although the postures were similar in the field and virtual reality simulation, it is important to note that there were significant differences in the duration of specific neck and trunk postures adopted between the certified and uncertified operators in specific tasks, such as the loaded backward driving in the truck.

4.1 Field vs. Virtual Reality

The range and type of neck and trunk postures that the participants adopted during the simulation were similar to that of the field. Limited line-of-sight in forklifts has been identified by previous researchers as one of the factors that is responsible for workers' postures (Choi, Park, Kim, Susan Hallbeck, & Jung, 2009; Bostelman, Teizer, Ray, Agronin, & Albanese, 2014). I observed that specific postures were necessary in order to secure the line-of-sight while operating the virtual reality forklift, just like in the field. Similar line-of-sight issues have been identified in other industrial vehicles such as load-haul-dump trucks used in mining (Godwin, Eger, Salmoni, & Dunn, 2008; Eger, Salmoni, & Whissell, 2004). However, the significant discrepancies in the durations that the operators adopted particular postures (neutral, moderate, and awkward) while performing specific tasks require further consideration. There are two possible contributing factors: the environment and the visual feedback.

4.1.1 Environment

The actual warehouse contained a number of obstacles within the aisles and pathways (Figure 10.A). For example, in the field environment, there were boxes lying on the floor obstructing free motion of the forklift. In addition, in the real world, a co-worker could be standing just around the corner in the warehouse. Accordingly forklift operators must always be mindful of what's near the vehicle given the relatively high frequency and severity of injuries due to interactions between forklifts and pedestrians (Larsson et al., 1994). However, in the virtual warehouse there were no obstacles other than the barrels assigned for the tasks (Figure 10B). It is likely that the participants were aware of this difference in the environment, and they may not have been as focused on attending to the environment around the forklift compared to the field operator. This may explain why awkward postures were adopted less frequently in the simulation compared to the field.

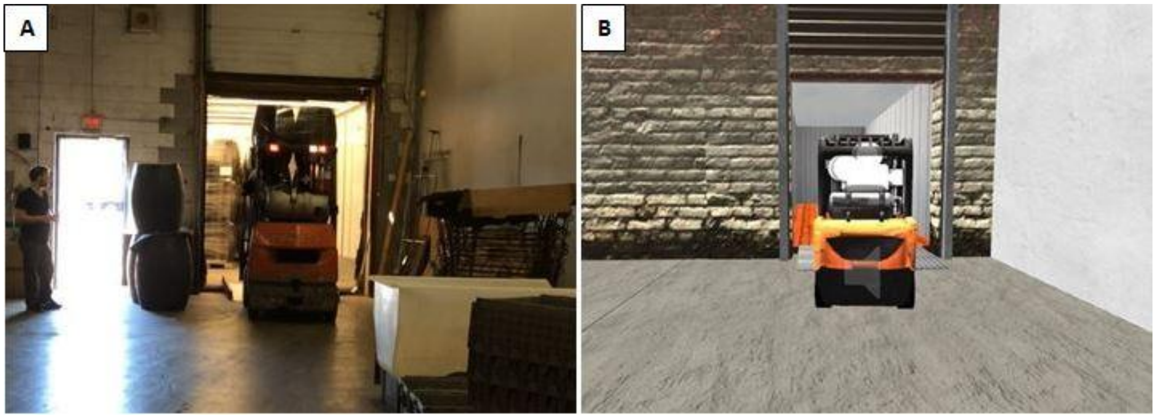

Figure 11: A – The picture of actual warehouse illustrating various obstacles, such as the material on the floor behind the forklift, and a bystander on the left. B – These obstacles were not represented in the virtual warehouse and may have contributed to some of the differences between operator postures in the field and virtual environments.

4.1.2 Visual feedback

Differences in the operator's view between the field and simulation may have led to the observed differences in postures. In order to evaluate this possibility, the operator's view from the warehouse testing that was captured by an eye-gaze monitor was obtained from the archived field data (Delgado, 2012). The real forklift had a four stage QLV mast and the mast in the simulation was modified to attempt to match the geometry (Wegscheider, 2014). However, the actual mast in the field appears larger than the mast in the simulation (Figure 11). This allows for greater visibility for the virtual reality simulation, and may have led to fewer instances of awkward postures. In addition, a second factor in the simulation may have produced differences in operator postures in the simulation: the position of the operator's head was adjusted in the simulation according to the operator's wishes, and most operators preferred their heads to be positioned a little further back compared to the real position. We believe that this was because the slight lag in the virtual feedback through the head-mounted display can induce motion sickness (Classen, Bewernitz, & Shechtman, 2011); it may have been less nauseating to be positioned further back in the forklift, and therefore have a greater amount of fixed information in the field of view, as shown in Figure 11. This offset position causes the mast to appear smaller in the simulation, which gives the participant less visual obstructions when driving forward. This is a possible explanation for why I observed that awkward postures were adopted less frequently in the forward driving in the simulation compared to the field.

Figure 12: The snapshots of operator's view from the field (left - obtained from the eye-gaze monitor) and the virtual reality (right).

4.2 Operator Training

The postures that both operators in the simulation adopted were similar to the postures from the field. The differences in proportions of time spent on particular postures between two conditions in the simulation were much smaller than that of between the field and the simulation. However, for the task of the backward driving in the truck, the proportions of awkward postures in both neck and trunk from the uncertified operator were much higher than the certified operator. I observed that the certified operator in the simulation was using visual cues, such as the line on the floor of the truck or the distance between the wheel and the wall of the truck, to drive the forklift out of the truck in reverse. This operator observed these cues while maintaining a forward gaze and adopting more neutral postures. On the other hand, the uncertified operator relied heavily on axial rotation of the neck and trunk to directly secure the line-of-sight behind the forklift, which required an extremely awkward posture. Although the proportion of awkward posture adopted by the uncertified operator was significantly higher than the certified operator in this task, it took less time for the uncertified operator to back out of the truck. This trade-off between the proportion and the actual duration of the adopted awkward posture can be looked into in the future to determine its association to the risk of injuries.

4.3 Limitations

Limited numbers of subjects were analyzed due to a number of factors. Although a total of nine subjects were recruited to participate, four subsequently withdrew from the testing due to nausea. Of the five subjects that were able to finish the required tasks, three either didn’t have adequate driving skills or couldn’t reach to the level to proficiently carry out the tasks after the practice. The two remaining subjects each completed all of the training and performed two cycles of loading and unloading. Although it would be interesting to evaluate whether forklift driving experience, in virtual reality or in workplaces, influences participants’ postures, it was impossible to evaluate in the current project due to the small number of subjects. The similarities in the adopted postures between these two participants may indicate that there would have been diminishing returns with testing a large number of subjects. A final limitation of this study is that we did not directly assess the intra-observer reliability for the posture coding. Although studies have described the strong inter-observer reliability of the 3DMatch posture assessment approach (Cann et al, 2008; Sutherland et al, 2007), we did not assess the intra-observer reliability of either individual that performed the posture coding.

4.3.1 Simulator Sickness

Motion sickness or simulator sickness happens when there’s a disagreement between visual perception and vestibular system’s perception of the movement (Classen et al., 2011). Previous research has shown that most participants in similar simulations using a head-mounted display cannot tolerate one hour long training sessions (Bergamasco et al., 2005). Due to the enormous amount of data that needs to be processed and transferred within the simulation (virtual reality, physics engine, robot, cart, tracking system, and visual feedback), and the limitations of the hardware, we observed a slight mismatch in the timing of the visual and motion feedback. This lag caused simulator sickness (Classen et al., 2011) and eventually nausea to four of the nine participants. This represents a relatively large proportion of subjects and likely reflects that our simulation was not optimized. Although other researchers have noted that actuated platforms, such as the one used in this thesis, prevent motion sickness (Lemerle et al., 2011), apparently the benefits from motion cues in our study were not enough to offset the challenges due to the head-mounted display.

4.3.2 Digitizing

Posture coding process via 3DMatch (v5.03, Callaghan; ON, Canada) took about 30 hours per subject. Each subject in the current study was analyzed by different person. One may raise a concern in terms of inconsistency because each subject's data was digitized by two different people. However, research evaluating the inter-rater reliability has demonstrated that the 3DMatch software is a reliable ergonomic tool when more than one rater was involved (Cann et al., 2008). Given the common concern about quantifying worker postures and the relatively few available tools, other studies also frequently use a variety of raters (Eger et al., 2008)

Chapter 5

5 Conclusions

The results showed that the participants in the simulation and the field adopted similar postures; however, there were significant differences in the durations that specific postures were adopted. The postures that both operators in the simulation adopted were also similar to the postures from the field and to each other. The differences in proportions of time spent on particular postures between the two operators in the simulation were much smaller than that of between the field and the simulation. These preliminary findings suggest that further development of the system is necessary to use it as a tool for ergonomic analysis of workplace mobile machinery and its associated health risk.

5.1 Future Direction

Further development of the simulation system will be required for this to be a useful tool for the posture research. The slight mismatch in visual and motion feedback can be reduced as the hardware and software involved in the system develops; this will reduce the simulator sickness, which will enable testing of a larger number of subjects. Testing a larger number of trained and untrained subjects will also provide the better understanding of the effectiveness of the forklift training in reducing the occupational injuries. Future research may involve other instrumentation such as electromyographic sensors in the back and neck muscles to identify the mechanism of musculoskeletal injuries from awkward postures.

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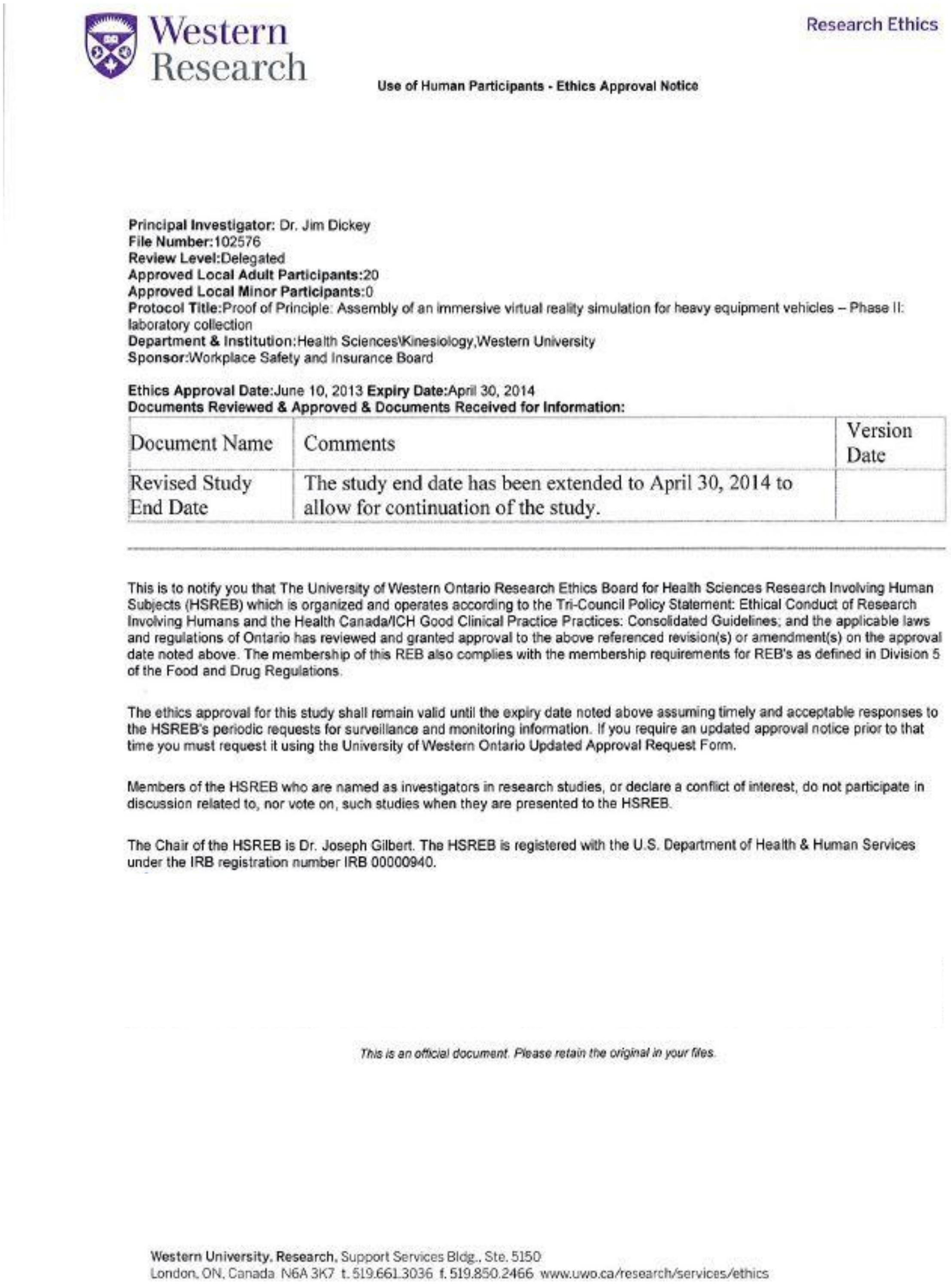
Appendices

Appendix A - Ethics Approval



Western Research

Research Ethics

Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Jim Dickey
File Number:102576
Review Level: Delegated
Approved Local Adult Participants:20
Approved Local Minor Participants:0
Protocol Title: Proof of Principle: Assembly of an immersive virtual reality simulation for heavy equipment vehicles – Phase II: laboratory collection
Department & Institution: Health Sciences\Kinesiology,Western University
Sponsor: Workplace Safety and Insurance Board

Ethics Approval Date: June 10, 2013 **Expiry Date:**April 30, 2014
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Revised Study End Date	The study end date has been extended to April 30, 2014 to allow for continuation of the study.	

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the University of Western Ontario Updated Approval Request Form.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

This is an official document. Please retain the original in your files.

Western University, Research, Support Services Bldg., Ste. 5150
London, ON, Canada N6A 3K7 t. 519.661.3036 f. 519.850.2466 www.uwo.ca/research/services/ethics

Appendix B – Letter of Information and Consent Form

You are being invited to participate in a study on the response of human subjects to multi-axis vibrations since you have indicated your interest in this project. We will be testing 20 participants. Long-term exposure to whole-body vibration is associated with low-back pain and injury, and is a major industrial and societal concern. This research project is the second phase of a project that will study whole-body vibration in a laboratory setting using a virtual reality simulation. This study is conducted under the supervision of Dr Jim Dickey, and is sponsored by the Ontario Workplace Safety and Insurance Board (WSIB).

If you agree to participate, you will operate a simulated fork lift vehicle within a virtual reality environment. You will sit in a simulated vehicle mounted to the top of a motion platform. The vibration and motion of the fork lift will be simulated by the motion platform. The visual and auditory environment will be presented using a head-mounted display. You will be trained to operate vehicle controls including steering wheel, accelerator pedal, brake pedal and fork height controls. When you are comfortable with the vehicle controls then you will be asked to perform a series of occupational tasks such as driving, loading and unloading pallets and stacking pallets. We will measure the vehicle and seat pan vibration using small devices to measure acceleration mounted under the seat and on the seat pan. We will use video cameras to record your posture while you perform these tasks in the virtual environment. We will also record the direction of your eye gaze using a small camera within the head-mounted display.

Your participation is strictly voluntary. You are free to withdraw from the study at any time, you may refuse to answer any questions, or refuse to participate without any penalty. We hope to learn more about how vibration affects spines, but you will not get any benefit from participating in this research.

The experiment will take one hour. You will be compensated $20 for your participation. If you choose to withdraw from the experiment then you will be paid $10 for each 1/2 hour (or part of 1/2 hour) that you participate.

Data will remain strictly confidential. Individual results will not be reported. Completed study documentation will be stored in a secure cabinet within the principal investigator's office. Vibration data will be stored on an external hard drive and will be stored in a locked file cabinet the Joint Biomechanics Laboratory at Western University. The video data will be transferred from the cameras to the external hard drive and will be stored in a locked file cabinet the Joint Biomechanics Laboratory at Western University. These data will be retained indefinitely so that we can use it for future analyses as well as for illustrations in scientific meetings, scientific manuscripts and potential teaching opportunities. We will obscure your face in these images in order to protect your confidentiality.

Representatives of The University of Western Ontario Health Sciences Research Ethics Board may contact you or require access to your study-related records to monitor the conduct of the research. There are two copies of this consent form; one which the researcher keeps and one that you keep.

If you have any questions or concerns about the study or about being a subject, you should contact the principal investigator, Dr Jim Dickey, Assistant Professor, School of Kinesiology, The University of Western Ontario, [redacted] [redacted]. If you have any questions about your rights as a research participant or the conduct of the study you may contact the Office of Research Ethics [redacted] [redacted].

I have read the letter of information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Participant's Signature:

__________________________ _________________________ Date: _________________

Printed name Signature

Person Obtaining Informed Consent:

__________________________ _________________________ Date: _________________

Printed name Signature

Do you consent to using your data for <u>future research projects</u>?

☐ No ☐ Yes

<u>If Yes</u>, you may change your mind and withdraw your data at a future time by contacting Dr Jim Dickey at the above address.

Do you consent to us using <u>images from the video for scientific presentations, scientific manuscripts or for purposes of teaching.</u>

☐ No ☐ Yes

<u>If Yes</u>, you may change your mind and withdraw your data at a future time by contacting Dr Jim Dickey at the address in the information form and the footer.

Appendix C – Questionnaire

Proof of Principle: Assembly of an Immersive Virtual Reality Simulation for Heavy Equipment Vehicles

Dr. Jim Dickey	Principle Investigator	[redacted]
Xiaoxu Ji	Student Investigator	[redacted]
Youngmin Jun	Student Investigator	[redacted]
Peter Wegsheider	Student Investigator	[redacted]

Screening and Information Questionnaire:

Note: the vibration in this experiment may aggravate neck or back problems – do not participate if you have experienced significant back or neck trouble in the last three years.

Have you experienced any **BACK** trouble (**ache, pain, numbness or discomfort**):

☐ No

☐ Yes - Please indicate the last episode.

☐ Over 3 years ago ☐ 1 year ago ☐ within the last year

Please describe the nature and intensity of this back trouble:

____

Have you experienced any **NECK** trouble (**ache, pain, numbness or discomfort**):

☐ No

☐ Yes - Please indicate the last episode.

☐ Over 1 year ago ☐ 6- 12 months ago ☐ 1- 6 months ago

☐ 2- 4 weeks ago ☐ 1- 2 weeks ago ☐ within the last week ☐ today

Please describe the nature and intensity of this back trouble:

____

Information:

Male ☐ Female ☐

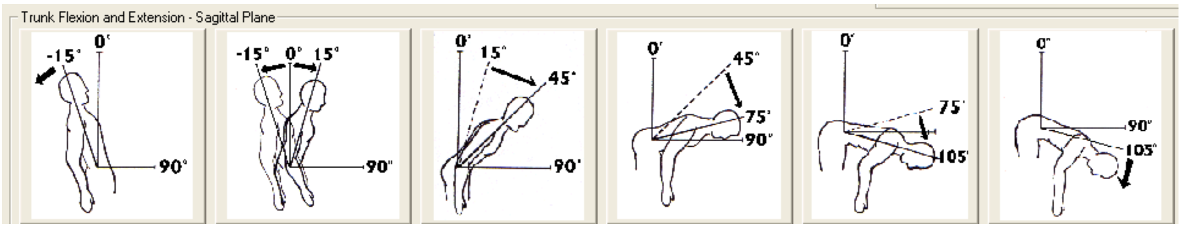
Age in Years: ______

Height: _______cm Weight: ________kg

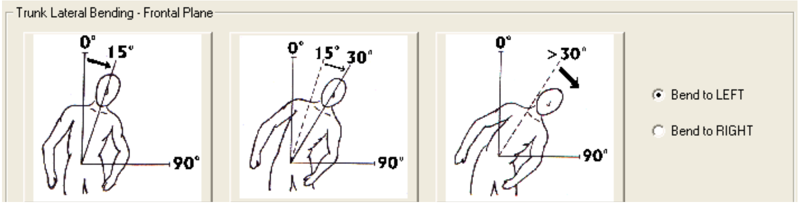
Corrective glasses or contact lenses? (If so, which)________________

Appendix D - Posture categories and bins from 3DMatch

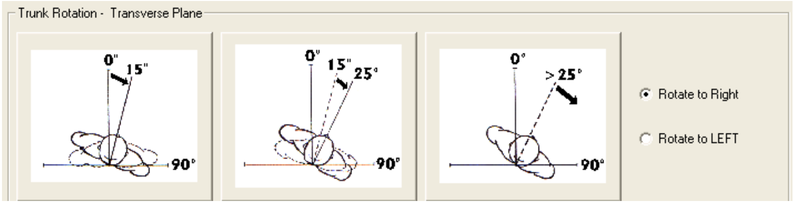
Trunk Posture Bin – Flexion/Extension



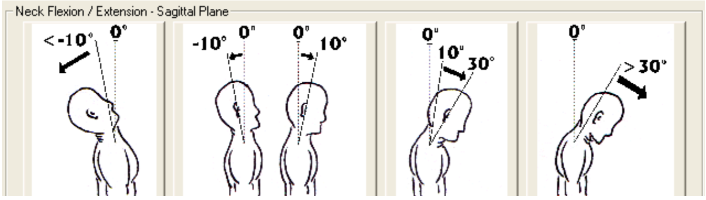
Trunk Posture Bin – Lateral Bending



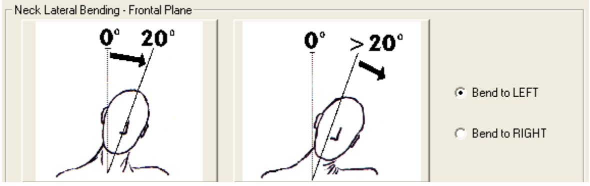
Trunk Posture Bin – Axial Rotation



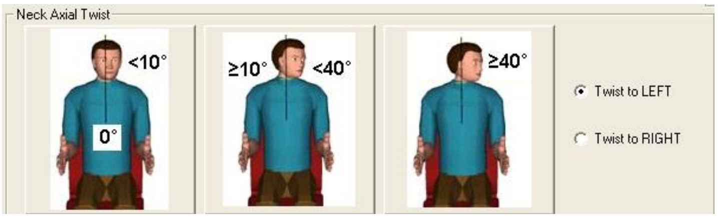
Neck Posture Bin – Flexion/Extension



Neck Posture Bin – Lateral Bending



Neck Posture Bin – Axial Rotation



Appendix E - Frame count of posture data collected at 6 frames per second (refer to Table 1 for the task abbreviations).

Neck	Neutral									Total
Task	**E**	**LFW**	**LFT**	**LBW**	**LBT**	**UFW**	**UFT**	**UBW**	**UBT**	
Field	547	87.6	183.6	118.2	33.8	430.4	185.6	209	30	1825.2
VRC	788	347	129	139	88	413	270	60	112	2346
VRU	715	269	54	98	33	826	270	119	84	2468
	Moderate									
Task	**E**	**LFW**	**LFT**	**LBW**	**LBT**	**UFW**	**UFT**	**UBW**	**UBT**	
Field	262.4	205.6	156.8	193.8	63	298.4	57	181.8	62.2	1481
VRC	272	356	254	115	149	84	27	57	56	1370
VRU	31	507	159	176	37	144	9	159	30	1252
	Awkward									
Task	**E**	**LFW**	**LFT**	**LBW**	**LBT**	**UFW**	**UFT**	**UBW**	**UBT**	
Field	850.2	694.4	445.4	817.6	606.6	259.6	98.4	694.2	375.8	4842.2
VRC	140	19	8	538	245	0	3	440	177	1570
VRU	21	27	13	418	316	21	2	568	141	1527
										18681.4

Trunk	Neutral									Total
Task	**E**	**LFW**	**LFT**	**LBW**	**LBT**	**UFW**	**UFT**	**UBW**	**UBT**	
Field	904	249	338.6	328.2	103.6	603.2	188.6	363.8	35	3114
VRC	785	255	80	237	71	497	270	112	173	2480
VRU	551	334	52	221	42	808	60	267	118	2453
	Moderate									
Task	**E**	**LFW**	**LFT**	**LBW**	**LBT**	**UFW**	**UFT**	**UBW**	**UBT**	
Field	427	318	211.6	172.6	93	250	98.4	267.8	56.2	1894.6
VRC	254	246	198	142	227	0	25	52	58	1202
VRU	195	437	86	170	34	183	221	263	70	1659
	Awkward									
Task	**E**	**LFW**	**LFT**	**LBW**	**LBT**	**UFW**	**UFT**	**UBW**	**UBT**	
Field	328.6	420.6	235.6	628.8	506.8	135.2	54	453.4	376.8	3139.8
VRC	161	221	113	413	184	0	5	393	114	1604
VRU	21	32	88	301	310	0	0	316	67	1135
										18681.4

Curriculum Vitae

Name:	Youngmin Jun
Post-secondary Education and Degrees:	University of Guelph Guelph, Ontario, Canada 2005-2008 BSc. Honours in Molecular Biology and Genetics Western University London, Ontario, Canada 2012-2014 MSc. Biomechanics Candidate
Honours and Awards:	Western Graduate Research Scholarship 2012-2014
Related Work Experience	Teaching Assistant Western University 2012-2014