DEVELOPMENT OF AN APPROACH FOR ASSESSING THE COMBINED POSTURE AND VIBRATION RISKS FOR FORKLIFT DRIVING TASKS

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Abstract

This study describes a method for combining two known risk factors for musculoskeletal injuries in heavy machine operators: whole-body vibration and posture. Time spent in specific forklift driving tasks in combinations of neck and trunk postures (from video) with the concurrent vibration exposure (r.m.s frequency weighted acceleration at seatpan) is presented in contingency tables; vibration (low, medium and high) in columns/ posture (neutral, moderate and awkward) in rows. Time spent in different combinations differed between tasks and between joints. For example, 30% was associated with low/neutral trunk postures and 18% for the neck in the engaging the forks task. Meanwhile driving backward with a load inside the truck involved 52% in an awkward/low neck combination and 42% in the same task but without a load. Future research should evaluate this method with more subjects and perhaps other machines in addition to the forklift, and aim to evaluate risk of injury.

Keywords

Driving posture, whole-body vibration, forklift operator, driving tasks

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List of Abbreviations and Nomenclature

LBP	Low back pain
ISO	International Standard Organization
LOS	Line of sight
EMG	Electromyography
WBV	Whole - body vibration
r.m.s	Root-mean-square
Hz	Hertz
fps	Frames per second
IMU	Inertial measurement unit
AVI	Audio Video Interleave
VDV	Vibration Dose Value
m/s^2	Meters per second squared
$m/s^{1.75}$	Meters per second to the fourth power
HGCZ	Health Guidance Caution Zones
OWAS	Ovako Working Posture Analysis System
RULA	Rapid Upper Limb Assessment
CUELA	“Computer-assisted recording and long-term analysis of musculoskeletal loads”
DOF	Degree of freedom
w_k	Frequency weighting factor

Chapter 1

1 Literature review

1.1 Workplace hazards involving heavy machinery and forklift trucks

Heavy machinery operators should be trained in safe and proper use of their vehicle and equipment, since the consequences of inadequate training can be deadly to the operator and to those in the surroundings (Horberry et al., 2004). In the United States, nearly 100 workers are killed and 20,000 are seriously injured from forklift use each year (NIOSH, 2001). However, this should not be attributed to poor training on the operator's part alone; other factors can play a role. The forklift truck is a commonly used piece of mobile equipment in the supply and demand chain where the lifting of heavy objects is involved. These powerful, heavy and relatively fast moving vehicles are responsible for deadly and traumatic accidents, and also for musculoskeletal injuries and disorders to the operator (Bovenzi and Hulshof, 1999; Hoy et al., 2005; Viruet et al., 2008).

The areas of the body that are commonly affected by occupational injuries in forklift operators are the lower back (Hoy et al., 2005; Viruet et al., 2008; Waters et al., 2005), neck and shoulders (Ariens et al., 2001; Bernard, 1997). Musculoskeletal problems include pain, fatigue and disorders from inadequate working postures, which may result in performance issues in the workplace (Standardization, 2000). Low back pain (LBP) in forklift operators has been found to be twice as likely to occur than for non-driving workers (Hoy et al., 2005), while the incidence of neck and shoulder problems was 81% in machine operators, including forklift drivers (Tola et al., 1988). The prevention of work-related incidents, injuries, and musculoskeletal disorders is a priority in occupational settings where heavy machinery is used (Standardization, 2000). The Occupational Safety & Health Administration (OSHA) is an example of one of the many agencies that have injury prevention as their main focus. Injury prevention recommendations include having more organized traffic management, incorporating comprehensive worker training, providing a safe work environment, having a safe forklift, and encouraging safe work practices. It is clear that these injury prevention measurements are not geared toward musculoskeletal injuries suffered by the operator from their daily work tasks. Standards such as ISO 11226 and EN 1005-4 have been developed to assess postures in the workplace and to provide recommendations that are intended to reduce health risks (Delleman and Dul, 2007). Both standards agree that postures involving lateral flexion of the neck and trunk, a flexed low back, and high frequency of postures in which the joints are near their maximum range of motion, should be avoided (Delleman and Dul, 2007). The majority of the previously mentioned postures occur in normal forklift driving tasks.

1.2 Risks for forklift operators due to posture

Forklift operators adopt awkward postures to see specific targets around the forklift (Godwin et al., 2010). An awkward posture is one that when maintained for a long period of time, or when used repetitively, can increase the risk of fatigue, pain or injury (Keyserling et al., 1992). The visibility constraints that result from the design of the forklift truck are enhanced when carrying a load by blocking much of the view forcing the forklift operator to adopt extreme neck and trunk postures (Giguere et al., 2006). Visibility of a target around the machine, or line-of-sight (LOS), is a major concern in occupational settings where heavy machinery vehicles are used (Eger et al., 2010; Godwin et al., 2010). Even though reports tend to focus on the outcome of accidents rather than the cause, approximately 80% of accidents involving forklifts causing harm to pedestrians, falling-off ramps, and hitting objects could be reduced by improving LOS (Choi et al., 2009). The ultimate goal of ergonomists and forklift truck designers is to improve LOS while having minimal amounts of twisting and bending of the trunk and neck by the operator, to hopefully reduce the incidence of musculoskeletal injuries and accidents.

The tasks that forklift operators have to do require them to adopt different postures. Hoy and colleagues (2005) isolated four posture combinations for specific tasks: normal driving posture (forward bent trunk, left hand on steering wheel and right hand on truck controls), aligning forks posture (trunk bent sideways and twisted with the neck twisted), reversing posture (considerably twisted trunk and neck), and stowing posture (laterally bent trunk and extremely extended neck). Identifying the tasks that forklift operators are required to do, and the postures that they adopt in order to do them, is beneficial towards the development of ergonomic interventions to avoid dangerous postures.

Working in bent or twisted postures has been linked to neck and shoulder problems (Delleman and Dul, 2007; Tola et al., 1988), and there is strong evidence to suggests that posture in general is a risk factor for musculoskeletal disorders of the neck and shoulder regions (Bernard, 1997). Approximately 86% of machine operators reported pain in the neck area of the body in a previous study (Tola et al., 1988). Meanwhile, trunk rotation has been associated with 60% of back injuries in different occupations (Kumar et al., 2001). It is believed that these awkward postures place the spine at risk of high levels of loading of the spine and trunk (Eger et al., 2008b; Eklund et al., 1994; Griffin, 1996) and thus, may lead to LBP (Toren, 2001). The role that fatigue may play in the development of musculoskeletal injuries has also been investigated by looking at the EMG activity of different trunk muscles during isometric rotation; they have found that there is a statistically significant difference between muscles in initial median frequency and the rate of decrease of the power spectra ($p < 0.01$; Kumar et al., 2001). The amount of time (or the duration) spent in awkward or non-neutral postures has also been investigated in different occupations to find a relationship with the risk of injury; studies have evaluated helicopter pilots (Forde et al., 2011), load-haul dump operators (Eger et al., 2008b), and a variety of people who work in service and industrial branches (Ariens et al., 2001). Eger and colleagues (Eger et al., 2008b) found that load-haul dump operators on average, spent about 89% of the time with their neck rotated more than 40°, 3% with their trunk rotated more than 30°, and 16% of the time with lateral flexion of the trunk between 15 and 30°. In addition to being exposed to these awkward postures, and the risks that accompany them, there are other factors that can increase the risk of musculoskeletal injury to forklift operators.

1.3 Risks for forklift operators due to vibration

Forklift operators are exposed to whole-body vibration (WBV), which is known to have negative health effects in drivers of heavy machinery (Bovenzi and Hulshof, 1999; Eger et al., 2008a; Milosavljevic et al., 2010; Palmer et al., 2003; Viruet et al., 2008). LBP is the most common health problem presented from WBV exposure, followed by digestive, reproductive and vestibular system disorders, visual and other nervous system problems (Griffin, 1996). WBV is caused by mechanical vibration that can be transmitted through the seat, the backrest, and the floor (Mansfield, 2005). WBV can consist of transient or steady state vibration. Steady state vibration for example, can result from the engine of the vehicle causing the vehicle to shake, while transient vibration can result from traveling over uneven terrain, which can cause mechanical shock that is transmitted to the operator (Mansfield, 2005). The methods for measuring WBV can be found in the ISO standards (ISO 2631-1; 1997), and the appropriate standards and calculation methods are to be selected accordingly with concerns of health and comfort, vibration perception and motion sickness. Since the human body responds differently depending on the frequency of the vibration, frequency weightings are applied to the root-mean-square (r.m.s) acceleration to allow comparison (Mansfield, 2005). Health, performance, and comfort are affected by WBV exposures in the frequency range between 1 – 20 Hz (Mansfield, 2005), and there is strong epidemiological evidence linking LBP to WBV (Bernard, 1997; Pope et al., 2002; Pope et al., 1999). LBP has been reported as the main cause of sick leave in the developing world (Pope and Novotny, 1993), it is at least twice as high in forklift operators than in non-driving controls (Hoy et al., 2005), and it is a major health concern that affects millions of people worldwide (Pope et al., 2002). In the findings from a national survey in Great Britain, it was concluded that the most common sources of occupational vibration with significantly higher exposures were found in forklift truck and mechanical truck operators, farm workers, and truck drivers (Palmer et al., 2000). Motmans and colleagues (2012), investigated how factors such as track, load, engine, tires, cab suspension, seat suspension, driving speed, driving behaviour, body weight of the driver, and driving posture affect the amount of WBV to which forklift operators are exposed. From this experiment it was determined that a combination of having a smooth driving surface, reducing the maximum speed limit and the use of air suspension can reduce WBV below the European directive's limits (0.5 m/s2; Motmans, 2012).

Standards for human health and vibration (ISO 2631-1) state that to look at the effects of vibration exposure on health and comfort, the magnitude of vibration in the dominant axis should be observed in relation to the Health Guidance Caution Zones (HGCZ; ISO, 1997). The dominant signal is usually found in the vertical translational axis (a_z), in the direction of the spine. Exposure can be measured using a basicentric co-ordinate system *(Figure 1)* with an origin at a point between the vibrating surface and the body; on the seat pan in the case of forklift operators (Griffin, 1996).

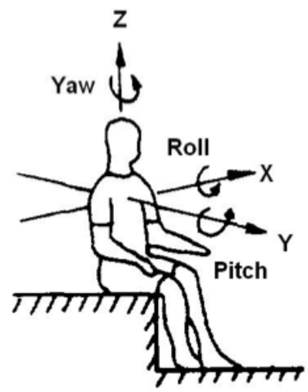

Figure 1 - The basicentric co-ordinate system with its six degrees of freedom.

The risk of musculoskeletal injuries suffered by heavy machinery operators, who are exposed to WBV, can be lowered by making sure that certain working conditions are met; these include: lowering speed limits (e.g., from 15 km/h to 8 km/h; Motmans, 2012), having adequate seat attenuation (e.g., mechanical suspension for heavier drivers and air suspension for lighter drivers; Motmans, 2012), have adequate maintenance of traveled roads to avoid excessive exposure to vibration, and to adopt comfortable postures avoiding excessive twisting, bending or slouching (Griffin, 1996). In the case of forklift operators, among others, it is virtually impossible to avoid twisting, bending and slouching since performing their jobs in a safe manner depend on them. Ergonomic modifications need to be made to the design of forklift trucks to change this. Standards for WBV such as the ISO 2631-1 do not consider the combined effects of vibration with different postures. Currently the majority of the literature regarding the combination of posture and WBV exposure is relatively new; the interest is from researchers in occupational fields that involve driving due to the high incidence of low back pain, and musculoskeletal disorders in general (Eger et al., 2008a; Eger et al., 2008b; Hermanns et al., 2008; Hoy et al., 2005; Morgan, 2011; Okunribido et al., 2007; Punnett et al., 2005; Raffler et al., 2010; Wikstrom, 1993).

1.4. Risks for forklift operators due to combined posture and vibration

There is a biologically plausible relationship between WBV and posture as the cause of LBP in forklift drivers (Viruet et al., 2008). A factor in this relationship is the resonance frequency of the body (Pope et al., 1999). Research has shown that different postures change the way vibration travels through the body, affecting its frequency response (DeShaw and Rahmatalla, 2011). For example, sitting in a slouched position on a seat without a backrest has been found to decrease the principal resonance frequency of the body from 5.2 to 4.4 Hz, (Kitazaki and Griffin, 1998). Simultaneous WBV and posture exposure led to decreases in performance in terms of reaction time and workload demand while doing the NASA task load index workload assessment; performance was affected further while in twisting postures without a backrest (Newell and Mansfield, 2008). Health and safety guidelines for WBV exposure in the workplace state that ergonomic factors such as poor posture (while driving) and poor visibility (that requires twisting and stretching) can cause back pain on their own, and these risks increase further when you combine them with WBV (Griffin et al., 2006).

Hoy and colleagues (2005) are one of the few research teams who have investigated WBV and posture in forklift operators as a risk factor for LBP. They found that forklift drivers were exposed to dangerous levels of vibration in the z-axis, while vibration in the x and y-axes was acceptable, and they identified certain postures as being likely to lead to LBP. However, they comment on the possible increased risk due to these factors individually, and not on the possible effects resulting from both. Standards for musculoskeletal risk prevention due to combined exposures of WBV and postures need to be developed. To develop these standards, more research is needed to establish the relationship and the factors that can lead to injury as a result of both WBV and posture.

1.5 Methods for assessing combined posture and vibration

Methods for assessing posture include questionnaires, observational measurements from video, and field measurements such as goniometers and for video analysis. Hoy and colleagues (2005) assessed the combined exposure of vibration and postures, in forklift operators. From video, evaluators identified four tasks that were performed the most, which were then subjected to further investigation with the Ovako Working Posture Analysis System (OWAS) and the Rapid Upper Limb Assessment (RULA) techniques. The postures adopted by city bus drivers have also been evaluated by using observational measurements; Okunribido and colleagues (2007) observed drivers for a period of time in which notes were taken every minute on the postures that were adopted. Two disadvantages with these methods are that they only evaluate postures at designated times and not consistently throughout the entire driving time, and the latter relies on the evaluator's memory.

An adaptation of the "Computer-assisted recording and long-term analysis of musculoskeletal loads" (CUELA) system has been used (Hermanns et al., 2008; Raffler et al., 2010) on seated operators of many different vehicles (e.g., tram, helicopter, saloon car, van, forklift truck, etc). The CUELA system is capable of displaying simultaneous posture, video and vibration data; however, an unfortunate limitation was the system's inability to measure axial rotations, which are very common postures adopted by forklift operators. Conversely, they classified postures and vibrations into categories and then into a 3 x 3 matrix scheme. This method of displaying the posture and vibration exposure is helpful for understanding their relationship.

3D Match is a video-based posture assessment method that has been used with automobile assembly workers (McClellan et al., 2009; Seaman et al., 2010), load-haul dump operators (Eger et al., 2008b), and helicopter pilots (Forde et al., 2011). One of the advantages of using observational measures is that operators are free to do their job without any pieces of equipment that may affect their normal performance of tasks (Vieira and Kumar, 2004). Another advantage of using software like 3D Match is that it allows the evaluator to assess the operator's posture at each frame of the video by selecting a bin containing the appropriate range of movement (e.g., 0-10°) for a given posture (e.g., neck/trunk flexion/extension, lateral flexion, and axial rotation). The optimal size for posture bins in the 3D Match software have been evaluated and deemed appropriate to avoid misclassification errors by the coder (van Wyk et al., 2009).

The potential health risks resulting from WBV and posture as individual factors have been evaluated; however, the combined effects of these factors need to be addressed further.

Chapter 2

2 Introduction

The forklift is the most commonly used piece of mobile equipment in occupational settings where there is heavy lifting involved, such as in warehouses. These powerful, heavy and relatively fast moving vehicles are involved in deadly and traumatic accidents, and also in musculoskeletal injuries and disorders to the operator (Bovenzi and Hulshof, 1999; Hoy et al., 2005; Viruet et al., 2008). The areas of the body that are commonly affected by occupational injuries in forklift operators are the lower back (Hoy et al., 2005; Viruet et al., 2008; Waters et al., 2005), neck and shoulders (Ariens et al., 2001; Bernard, 1997). Forklift operators are twice as likely to suffer of low-back pain (LBP) than those who do not operate heavy machinery (Hoy et al., 2005). Musculoskeletal problems such as pain, fatigue and disorders from inadequate working postures may result in performance issues in the workplace (Standardization, 2000).

Standards like ISO 11226 and EN 1005-4 are designed to assess postures in the workplace and to provide recommendations to reduce health risks (Delleman and Dul, 2007). It is generally understood that quick and frequent movements of joints nearing the limit of their range of motion, postures involving lateral flexion of the neck and trunk, a flexed low back, and postures in which the joints are near their maximum range of motion, to name a few, should be avoided (Delleman and Dul, 2007). However, the previously mentioned postures all occur in normal forklift driving to improve visibility of targets, or line-of-sight (LOS; Giguere et al., 2006; Godwin et al., 2010; Hella et al., 1991; Hoy et al., 2005; Waters et al., 2005). Even though reports tend to focus on the outcome of accidents rather than the cause, approximately 80% of accidents involving forklifts causing harm to pedestrians, falling-off ramps, and hitting objects could be reduced by improving LOS (Choi et al., 2009). It is well recognized that a major risk factor to musculoskeletal injuries are awkward or extreme postures (bent or twisted postures; Delleman and Dul, 2007); therefore, identifying the postures involved in the tasks performed by forklift operators may be beneficial in the development of ergonomic interventions to avoid potentially harmful postures. In addition to being exposed to an increased risk of injury from awkward postures, there are other factors that can increase the risk of musculoskeletal injury to forklift operators.

Whole body vibration (WBV) is another factor that affects forklift operators (Blood et al., 2010; Costa and Arezes, 2009; Motmans, 2012; Rashed, 2007). Health, performance, and comfort are affected by WBV exposures in the frequency range between 1 – 20 Hz (Mansfield, 2005), and there is strong epidemiological evidence linking low back pain (LBP) to WBV (Bernard, 1997; Pope et al., 2002; Pope et al., 1999). Standards for health and vibration (ISO 2631-1) provide Health Guidance Caution Zones (HGCZ) for evaluating vibration exposure (ISO, 1997). The vertical translational axis (a_z), along the length of the spine, is commonly the dominant vibration axis; exposure can be measured using a basicentric co-ordinate system with an origin at a point between the vibrating surface and the body (i.e., the seatpan for seated exposure; Griffin, 1996). It is recognized that WBV and posture can lead to musculoskeletal injuries as individual factors, but more research is needed to determine how these factors behave in combination.

There is evidence indicating a biologically plausible relationship between WBV and posture as the cause of LBP in forklift drivers (Viruet et al., 2008); however, the link is not yet fully defined. A possible link is the resonance frequency of the body (Pope et al., 1999) since it has been found to change with different postures; e.g., increases when the spine is rotated (DeShaw and Rahmatalla, 2011). Discomfort increases if the spine is twisted during vibration exposure (Wikstrom, 1993). Lastly, simultaneous WBV and posture exposure decreases performance, especially while in twisted postures without a backrest (Newell and Mansfield, 2008). This is all clear evidence that in order to create workplace modifications that might decrease the occurrence of musculoskeletal injuries, the combined effects of WBV and posture need to be assessed.

The relationship between vibration exposure and overall time spent in extreme postures has been investigated in a variety of ways. Field posture measurements have used the CUELA system or observational methods combined with the Ovako working posture analysis system (OWAS) and the rapid upper limb assessment (RULA) techniques (Hermanns et al., 2008; Hoy et al., 2005; Raffler et al., 2010). These posture assessment techniques separate movements, tasks and body parts and create a code to assess posture, similarly to other studies (Eger et al., 2008b; Hermanns et al., 2008; Raffler et al., 2010). The CUELA system was used (Hermanns et al., 2008; Raffler et al., 2010) to evaluate seated operators of many different vehicles (e.g., tram, helicopter, saloon car, van, forklift truck, etc). Unfortunately this system is not able to measure axial movements, which are very common postures adopted by forklift operators; this is an important limitation. However, they classified postures and vibrations into categories and then into a 3 x 3 matrix scheme. We believe that this is a useful way of displaying the posture and vibration exposure relationship, and may help gain a better understanding of the relationship between posture and vibration. Hoy and colleagues (Hoy et al., 2005) also assessed the combined vibration and posture exposures, specifically in forklift operators. They identified postures in different tasks; however, they only evaluated selected postures in specific periods of time, and their conclusions regarding LBP were drawn from considerations when viewing posture and vibration individually rather than in combination.

The goal of this study was to describe a method to assess the proportion of time spent in various combinations of posture and vibration during different tasks. Since certain postures and vibration levels, when viewed individually, are associated with increased risk of injury, it follows that specific combinations of these posture and vibration parameters may increase the risk of injury further, however, a method to study these factors in combination is needed. When considering ergonomic interventions it may also be useful to study the impact of vibration and posture on the neck and trunk separately as the effects may differ.

Chapter 3

3 Methods

The Board of Ethics at Western University approved this field study that took place at a distribution and storage facility in London, Ontario, Canada *(Appendix A.1)*. Informed consent was obtained from the subject prior to the beginning of data collection *(Appendix A.2)*. The desired measurements were obtained during normal forklift operations of a licensed 55-year-old male (1.88 m, 107 kg) with 20 years of forklift driving experience. The normal forklift operations consisted of combinations of driving forward, driving backward, driving with forks loaded or unloaded, engaging the forks, driving in the warehouse, and driving inside the truck. The data collection process was stopped twice to check that all the data acquisition instrumentation was working properly. Information on the forklift *(Figure 2)* is presented in Appendix B.

Figure 2 - Forklift used during testing

3.1 Test procedure

Data collection began with the setting up of the instrumentation, which was placed in a way that it did not interfere with normal machine operations. The instrumentation included three video cameras, two IMUs (Inertial Measurement Units; MAG^3; MEMsense), and an eye-gaze tracking system (ASL H6 Eyetracking system, Applied Science Laboratories, Bedford, MA) The eye tracker data will be used in future in-lab studies; therefore, it will not be discussed in this paper. .

3.2 Driving Posture Measurements

Figure 3 - View of custom-made cross on top of the forklift attached with c-clamps

A custom-made aluminum cross (made from profile beams) was mounted on top of the forklift to attach the cameras. The cross was firmly secured to the fall-on protection with four large 'C-clamps', and the cameras were secured with six-degree of freedom Manfrotto clamps *(Figure 3)*. The cameras were positioned to capture the entire torso of the operator at all times.

Figure 4 – Camera on lateral side of the forklift

Three video cameras were used to capture the postures of the forklift operator. The camera (HDR-XR550V; Sony) that was mounted at the side of the forklift *(Figure 4)* had a sagittal view of the operator and was equipped with a wide-angle lens to capture a larger field of view; this was necessary since the cameras had to be mounted close to the forklift cab so that they did not interfere with machine operations. The camera (GZ-MG555U; JVC) that was mounted at the front of the forklift *(Figure 5)* had a frontal view of the operator, with his head at the top of the image. The camera (GZ-MG555U; JVC) located at the back of the forklift *(Figure 6)* had a posterior view of the operator along with both side-view mirrors.

Figure 5 - Camera at the front of the forklift.

Figure 6 - Camera at the back of the forklift.

3.3 Vibration measurements

The vibration measurement equipment consisted of two IMUs (±5 G, ±1200°/s; MAG^3; MEMsense). One IMU was magnetically attached to the floor of the forklift chassis, at the base of the seat *(Figure 7)*. The second IMU was located

Figure 7 - IMU magnetically attached to the forklift chassis at the base of the seat

on the seat interface (between the seat and the buttocks of the operator) within a semi-solid rubber mold *(Figure 8)* as defined in ISO 10326-1(Standardization, 1992). Two portable data acquisition units, or data loggers (DataLOG P3X8; Biometrics Ltd.; Newport, UK) were used to sample the data (1000 Hz) from 16 analog channels onto two separate one-gigabyte memory flash cards. A SYNC2 cable (Biometrics Ltd.) was used to start data collection on both data loggers simultaneously. The data loggers were placed behind the operator's seat inside a bag *(Figure 9)* with the cables of the accelerometers secured in order to prevent any tripping, tangling or damage to the equipment.

Figure 5 - View of IMU underneath rubber mold on the seatpan and cables secured to the chassis, leading into bag behind operator's seat

Figure 9 - Bag used to store dataloggers behind operator's seat during testing

3.3.1 Accelerometer and IMU Calibration

The IMUs were calibrated by collecting data (1000 Hz) for each translational and rotational axis with the sensors attached to a 6-DOF (degree of freedom) robotic platform (R3000, Mikrolar Inc., Hampton, NH, USA; Cation et al., 2011). Each translational axis was exposed to 17 different profiles containing sinusoidal waveforms with peak-to-peak accelerations between 1 and 8 m/s^2 at 1, 2 and 5 Hz. Each rotational axis was exposed to 20 different profiles containing sinusoidal waveforms with peak-to-peak angular velocities between 10 and 100 °/s at 1, 2, and 5 Hz. The data was filtered with a bandpass 2nd order Butterworth filter (0.5 – 20 Hz) and the maximum and minimum values for each sinusoidal wave were extracted and fitted with a line. The equation for the line for each translational and rotational axis was used for calibration.

3.4 Driving posture analysis

Before doing posture analysis, the video files were prepared by inverting the images, and synchronizing the views from the different cameras. In order to aid the driving posture analysis, white tape was applied to the front and sides of the trunk to help identify translational and rotational movements of the trunk and head on video *(Figure 10)*. This allowed for easier coding of driving postures in situations when the environment was dark and it was more difficult to identify the postures.

Figure 6 - View of operator with white tape on his shirt to aid in the posture analysis process

3.4.1 Video preparation

The video files from the three cameras and the eye-gaze camera were imported to a laptop. As a result of the interruptions for calibration purposes, there were three blocks for analysis referred to as trial 1, trial 2 and trial 3. Each video was flipped horizontally and vertically, since the cameras were mounted up side down, and the different camera views were synchronized for each trial (Dartfish TeamPro 5.5, 2009; Georgia, USA). There were there different camera views of the forklift operator (frontal, sagittal, and posterior perspective), as well as the operator's perspective captured with the eye-gaze camera. Synchronization of the camera views was done by means of identifying the first frame in which a synchronization light was turned-on in front of all the cameras at the start of each video trial. Once the frame with the light "on" was identified, all the videos were lined-up to it and arranged to play simultaneously in a two-by-two layout *(Figure 11)*. Three final videos with synchronized camera views were saved as AVI (Audio Video Interleave) files to allow for straightforward assessment of postures during the frame-by-frame coding process.

Figure 7 - View of synchronized videos in a 2 by 2 arrangement. The top left view is from the eye gaze camera on the goggles; the top right from the camera at the back; bottom left from the camera at the side; bottom right is from the camera at the front of the forklift.

3.4.2 Task Identification

The investigator identified nine tasks that the forklift operator performed, including those identified in previous research (Hoy et al., 2005), and assigned them a numerical value; this was performed while reviewing the 30 frames per seconds (fps) compilation videos. Any task that was not part of normal forklift driving tasks, such as calibrating, was assigned a dummy task number and was excluded from further analysis. The task categories consisted of the following conditions: forklift loaded or unloaded, driving forward or backward, and driving in the truck or in the warehouse *(Table 1)*.

Table 1: List of tasks

Task #	Task Name
1	Engaging forks
2	Driving loaded forward in warehouse
3	Driving loaded forward in truck/ramp
4	Driving loaded backward in warehouse
5	Driving loaded backward in truck/ramp
6	Driving Unloaded forward in warehouse
7	Driving unloaded forward in truck/ramp
8	Driving unloaded backward in warehouse
9	Driving unloaded backward in truck/ramp
10	Dummy task number

3.4.3 Posture coding

The three AVI video trials with the two-by-two synchronized views were down-sampled to 6 fps (Prism Video File Converter v 1.88; Boston, MA), and then used for posture coding. A short clip of the video data that contained quick neck turning movements determined, with a residual analysis (Winter, 2009), that 6 fps was the lowest acceptable frequency to capture postures with the software used. 3D Match software was used to evaluate the forklift operator's postures (version 5.03, Callaghan, University of Waterloo, Ontario, Canada, 2006). Posture was evaluated on a frame-by-frame process by selecting the appropriate posture category bin from the different posture categories for various joint angles in each frame. The joints for the trunk and the neck were evaluated.

The posture categories varied in flexion, extension, lateral bend, and rotation *(Appendix C)*. There were three bins, out of the total, that were used to describe each joint angle in each frame. The posture data were saved as an output file that contained a series of values for each point in time, for each posture of the neck and the trunk; these were reassigned values between zero and two.

3.5 Analysis of the acceleration data

The data from the IMUs and accelerometer were exported as text files using the Biometrics DataLog PC software (Version 7.50; Ladysmith, VA, USA) for further analyses with LabVIEW (LabVIEW 2010, National Instruments; Austin, TX, USA). A custom-made LabVIEW program converted the data from “counts” into voltages (4000 counts = 3 volts), and applied the calibration factors for linear acceleration and angular velocity units. The appropriate frequency weightings for vibration and health were applied by using the National Instruments ‘Sound and vibration’ toolkit. As indicated by ISO 2631-1 standards, different frequency weightings are needed for each axis; for health concerns, the frequency-weighting factor for the dominant axis (w_k) is used, which was the vertical direction in this study. The lower and upper limits for assessing the frequency weighted r.m.s acceleration were 0.45 and 0.90 m/s^2 respectively. These limits are based on ISO 2631-1 magnitudes for the 8-hour HGCZ. From these limits we assigned a value for each of the three regions; for r.m.s frequency weighted acceleration values less than 0.45 (low), between 0.45 and 0.90 (medium), and greater than 0.90 m/s^2 (high) r.m.s respectively.

The vibration exposure data was summarized in terms of commonly reported measures. The dominant frequency was calculated by using one-third octave analysis to determine acceptable daily exposure durations and compare our values to other seated vibration exposure. The crest factor is a ratio of the peak acceleration and the r.m.s, as a result they are highly influenced by instantaneous shock. Vibration Dose Value (VDV) was calculated by taking the fourth root of the sum of the fourth power of the frequency-weighted r.m.s acceleration.

3.6 Sample Rate Differences

It is important to note that studying posture and vibration in combination poses certain technical difficulties. Since the video cameras had a sampling rate of 30 Hz, the vibration measurements were done at 1000 Hz, and posture was assessed with 3D Match at 6 Hz, we needed to match their frequency content to extract vibration and posture data at each point in time for each task. The acceleration data were frequency weighted with the ISO filters. This effectively reduced the frequency content to less than 16 Hz. The acceleration data were then down-sampled to 30 Hz to match the video data that was obtained at 30 fps. The posture output file from 3D Match containing the new values between zero and two at 6 fps were interpolated to 30 Hz to match the task data.

3.7 Combined Effect of Posture and Vibration

Prior to analyzing the combined effects of posture and vibration, the three blocks of data had to be combined. The final version assessed posture and vibration for the nine tasks. The task with the dummy task number was omitted.

To assess the combined effect of posture and vibration, we created a scoring system that allowed us to distinguish the two factors and to know the resulting combination. A different score was obtained for combinations of low, medium high vibration and neutral, moderate and awkward posture. The amount of time spent in each of these combinations was reported on a 3 by 3 contingency table, separately for the neck and trunk for each task. The columns contain the vibration zones divided into low, medium and high risk of exposure, as suggested by ISO-2631-1 and as used in previous research (Eger et al., 2008a). The rows contain the postural risk regions (neutral, moderate and awkward) as determined by the scoring system used on the 3D Match postural ranges, as described previously in this section.

Chapter 4

4 Results

4.1 Participant Demographics

The operator was a 55-year-old male (107 kg, 1.88 m) who had 20 years of experience operating a forklift. He was self-described as having a mesomorph body type and being of average physical fitness. He was involved in physical activity (cardio and strength) between 30-44 minutes 1-2 times per week. With regards to previous musculoskeletal injuries, the operator had experienced an injury over a year ago affecting his shoulder; however, it was believed to have arisen from improperly lifting scuba tanks. He never had to change duties or jobs or missed work due to this shoulder trouble.

When asked about the task demands and the cab design, the operator indicated that in order to see what he was doing and where he was going while operating the forklift, he had to adjust his posture. The task that he isolated as demanding an adjustment in his posture every time was backing up, and it requires him to turn his neck and back to look backwards. Lastly, he indicated that he did not have to adjust his posture in order to manipulate the machine's controls.

4.2 Vibration Measurements

A summary of vibration data was obtained to quantify the vibration exposure *(Table 2)*. The r.m.s acceleration for the total duration was 0.98 m/s^2 and was as low as 0.56 m/s^2 in one of the tasks; these values are to be expected for vibration experienced on a forklift truck and are in the moderate to high risk of injury due to vibration. The majority of the crest factor values were between 6.5 and 9, except for two tasks that had crest factors of about 12. Most tasks had a dominant frequency between 3.15 and 5 Hz. Task 1 had an unusually high dominant frequency (20 Hz).

Table 2 - Vibration Summary Table for the z-axis (vertical)

	VDV ($m/s^{1.75}$)	r.m.s (m/s^2)	Peak (m/s^2)	Crest Factor	Dominant Frequency (Hz)
Task 1	17.71	0.55	3.63	6.53	20
Task 2	20.89	0.65	5.87	8.99	5
Task 3	50.30	1.37	11.82	8.58	3
Task 4	37.89	0.92	11.39	12.33	5
Task 5	24.81	0.74	5.83	7.80	3
Task 6	36.27	1.11	8.52	7.67	5
Task 7	44.52	1.71	12.00	7.01	4
Task 8	32.73	0.96	7.10	7.37	5
Task 9	57.72	1.42	18.45	12.96	4
Total	72.11	0.98	18.45	18.67	4

VDV (Vibration Dose Value); r.m.s (root-mean-square)

4.3 Combinations of vibration and posture

The purpose of this thesis was to develop a method for evaluating the combination of two known (individual) risk factors for musculoskeletal injuries in heavy machine operators; therefore, the specific findings are less important than the overall process. Nevertheless, the specific findings illustrate the power of this approach for gaining insight into the risks of combined posture and vibration exposures.

There are general similarities in the combinations of posture and vibration for the neck and spine; however, usually the neck had a greater proportion of awkward postures and low vibration compared to the back. The contingency tables *(Figure 12)* show that the time spent in the different posture/vibration combinations is different for each task, and also for the neck and the trunk. For example, the task of driving backward with a load in the truck involved having the neck in an awkward posture combined with a low, medium or high level of vibration for 87% of the duration of the task; the trunk spent 72% of the time in an awkward posture combined with different levels of vibration. However, driving forward without a load in the warehouse is an example of a task that had evenly distributed proportions of time for all the posture/vibration combinations. This pattern is also observed in other tasks such as driving with a load forward in the warehouse, and in the truck.

	NECK (%)			TRUNK (%)		
Posture	Low	Medium	High	Low	Medium	High
Awkward	26%	22%	3%	10%	9%	1%
Moderate	9%	6%	1%	13%	11%	2%
Neutral	18%	13%	2%	30%	21%	3%
	Vibration			Vibration		

Percentage of time spent in the different combinations of vibration and posture while engaging the forks (duration of 277 s)

Posture	Low	Medium	High	Low	Medium	High
Awkward	36%	26%	8%	21%	16%	5%
Moderate	13%	6%	2%	17%	12%	4%
Neutral	4%	3%	2%	15%	8%	3%
	Vibration			Vibration		

Percentage of time spent in the different combinations of vibration and posture while driving loaded forward in the warehouse (duration of 167 s)

Posture	Low	Medium	High	Low	Medium	High
Awkward	26%	22%	9%	14%	13%	4%
Moderate	8%	7%	5%	10%	8%	9%
Neutral	10%	7%	7%	20%	15%	8%
	Vibration			Vibration		

Percentage of time spent in the different combinations of vibration and posture while driving loaded forward in truck/ramp (duration of 131 s)

Posture	Low	Medium	High	Low	Medium	High
Awkward	34%	21%	17%	23%	16%	16%
Moderate	11%	5%	1%	10%	4%	2%
Neutral	7%	3%	1%	18%	9%	2%
	Vibration			Vibration		

Percentage of time spent in the different combinations of vibration and posture while driving loaded backward in the warehouse (duration of 188 s)

Posture	Vibration: Low	Vibration: Medium	Vibration: High	Vibration: Low	Vibration: Medium	Vibration: High
Awkward	52%	24%	11%	41%	21%	10%
Moderate	7%	2%	1%	9%	3%	1%
Neutral	4%	1%	0%	11%	2%	1%

Percentage of time spent in the different combinations of vibration and posture while driving loaded backward in truck/ramp (duration of 117 s)

Posture	Vibration: Low	Vibration: Medium	Vibration: High	Vibration: Low	Vibration: Medium	Vibration: High
Awkward	11%	8%	7%	5%	5%	3%
Moderate	11%	10%	9%	9%	9%	7%
Neutral	16%	15%	13%	24%	19%	19%

Percentage of time spent in the different combinations of vibration and posture while driving unloaded forward in the warehouse (duration of 165 s)

Posture	Vibration: Low	Vibration: Medium	Vibration: High	Vibration: Low	Vibration: Medium	Vibration: High
Awkward	8%	6%	15%	5%	5%	6%
Moderate	6%	5%	5%	7%	7%	15%
Neutral	22%	15%	17%	25%	14%	16%

Percentage of time spent in the different combinations of vibration and posture while driving unloaded forward in the truck/ramp (duration of 57 s)

Posture	Vibration: Low	Vibration: Medium	Vibration: High	Vibration: Low	Vibration: Medium	Vibration: High
Awkward	25%	20%	20%	14%	12%	16%
Moderate	10%	5%	2%	14%	8%	3%
Neutral	12%	6%	2%	19%	10%	5%

Percentage of time spent in the different combinations of vibration and posture while driving unloaded backward in the warehouse (duration of 181 s)

Posture	Vibration: Low	Vibration: Medium	Vibration: High	Vibration: Low	Vibration: Medium	Vibration: High
Awkward	42%	21%	18%	42%	21%	18%
Moderate	7%	5%	1%	8%	3%	1%
Neutral	4%	2%	1%	3%	3%	1%

Percentage of time spent in the different combinations of vibration and posture while driving unloaded backward in the truck/ramp (duration of 78 s)

Figure 12 – Percentage of time during different forklift driving tasks for combinations of posture and vibration.

Chapter 5

5 Discussion

In this study we looked at the amount of time spent in combined postures and vibration during tasks performed by forklift operators to assess the potential risk of injury. We suggest a method for comparing vibration (low, medium and high) and posture (neutral, moderate and awkward), with postures arranged in rows and vibration levels are in columns. These contingency tables *(Figure 12)* show the duration in each combination of posture and vibration for each task and describe the findings for the neck separately than the trunk. Our results show that the posture/vibration risks vary between tasks, and also between the neck and trunk.

Since the purpose of this thesis was to develop a method for evaluating the combination of two known risk factors for musculoskeletal injuries in heavy machine operators, the specific findings are less important than the overall process. Nevertheless, the specific findings illustrate the power of this approach for gaining insight into the risks of combined posture and vibration exposures.

The majority of the time in many of the tasks was always spent in either a neutral or an awkward posture with low risk vibration (column one). Hermanns and colleagues (Hermanns et al., 2008) also investigated the amount of time spent in combined postures and vibration; however their posture measuring methods were different and they tested other vehicles and surfaces. They did not show data for forklifts, but the majority of their tables show the highest time percentages for neutral postures with low, medium or high vibration; this is the equivalent to the bottom row in our study.

An explanation for this discrepancy may be the fact that the, axial rotations were not measured in their study. Axial rotations of the neck and the trunk were adopted frequently during forklift driving; therefore, we believe that our higher percentage of time in awkward postures is likely due to neck and trunk twisting.

In some tasks, such as driving backward in the warehouse without a load (for the trunk), and in driving forward in the warehouse without a load (for the neck), there was a rather even distribution of the time spent in various posture/vibration combinations; however, this was not always the case. The task of driving backward with a load in the truck involved 52% of the time with the neck in an awkward posture with low vibration, 24% in awkward posture with medium vibration, and 11% in awkward posture with high vibration. This adds up to 87% of the time spent with the neck in an awkward posture with low to high vibration; all in the first row. Meanwhile, the findings are similar for the trunk during this task, although to a lesser degree; here there is 72% in row one. The second task with a similar situation is driving backward without a load in the truck. This task involves an awkward neck posture for 81% of the time, and an awkward trunk posture for the same percentage of time.

Driving forward without a load in the truck shows a different pattern; presumably LOS is less restricted at this point so the majority of the time is spent in row three (neutral posture with low, medium and high vibration), and in column three. The posture/vibration combinations in column three (high vibration) account for 37% of the total task time; 15% of the total task is spent in high-risk vibration and awkward neck posture. This pattern is also observed in the equivalent task but driving in the warehouse.

The highest amount of time was spent with the neck in awkward postures combined with low to medium vibration, while the trunk was exposed to low to medium vibration, combined with neutral postures. This suggests that the neck is at more risk of injury during this task than the trunk. Our method for evaluating risk of injury by combining posture and vibration exposures is a powerful tool for identifying trends; this trend can be clearly seen in the contingency tables where the percentage of time spent in specific combinations of vibration and posture are noticeably higher than the rest. For example, in tasks like driving with a load backward in the truck (52% in awkward posture/low vibration combination for the neck, and 41% for the trunk), and driving backward unloaded in the truck (42% for neck and trunk in awkward posture/low vibration combination).

Driving mining haul trucks without a load involved the highest vibration exposure, followed by traveling with a load, loading, and dumping respectively (Kumar, 2004). The vibration data in our study does not show clear patterns in the differences between tasks; they are all similarly high values *(Table 2)*, yet we can see clear trends between tasks when we look at vibration and posture together. For example, driving unloaded in the warehouse forward compared to backward; going backward appears to have more dangerous levels of vibration, than going forward, as well as posture *(Figure 12)*. This is evidence that the risk of injury associated with different tasks should not be analyzed solely in terms of vibration.

The vibration exposure limits for low, medium, and high risk regions used in this study were set to r.m.s accelerations of 0.45 m/s^2 at the low end and 0.9 m/s^2 at the high end, similarly to WBV research in other heavy machinery vehicles (Eger et al., 2008a;

Kumar, 2004). According to ISO 2631-1, these are the r.m.s limits for 8-hour daily exposures (A (8)). By these limits, r.m.s accelerations in the vertical direction suggest that the health risk of the majority of the tasks, and the overall period of time, is likely (as illustrated in Table 2). The highest dominant frequency is found in task 1, which corresponds to engaging the forks. This high frequency can be attributed to the vibration of the vehicle's engine. The other frequencies are consistent with the literature, which indicates a range between 2 – 6 Hz in the vertical direction for seated subjects (Griffin, 1996).

A limitation of our study was the use of one participant to develop our method for comparison of vibration and posture; however, our vibration measurements are in the range of previous forklift vibration measurements (Hoy et al., 2005; Mansfield et al., 2006) and our subject was an experienced forklift operator. Accordingly, we believe that our data is representative of routine forklift operations. Other studies have observed similar magnitudes for forklift vibration. Mansfield and colleagues (Mansfield et al., 2006) reported 25th and 75th percentiles of 0.6 and 1 m/s^2, while Hoy and colleagues (Hoy et al., 2005) reported ranges of r.m.s acceleration between 0.32 and 0.73 m/s^2 in the vertical z-axis (dominant). Our r.m.s acceleration for the total duration was 0.98 m/s^2 and was as low as 0.56 m/s^2 in one of the tasks *(Table 2)*.

Research involving vibration exposure in forwarders (Rehn et al., 2005) found that the magnitude of vibration exposure was different under various circumstances (loaded versus unloaded, with different operators, terrain, and forwarder model). They concluded that more data should be collected for several conditions involving a given operator and forwarder model. Further studies investigating different conditions experienced by forklift operators should also be performed in the future using approaches such as the one used in this study. This would help to evaluate whether the approach that is developed in this thesis is generalizable to other workplaces, and perhaps other vehicles.

The goal of this study was to describe an approach for comparing posture and vibration in combination during different tasks performed by forklift operators. This method suggests that there are certain tasks that produce different levels of exposure for the neck and for the trunk. Once these tasks have been identified, the specific neck and trunk postures within these tasks can be determined, similarly to Raffler and colleagues (2010) to guide appropriate ergonomic modifications. Possible modifications to tasks involved in operating forklift trucks can involve the use of cameras to improve LOS and minimize awkward postures. Some forklift trucks have been modified to carry the load to the side of the operator, rather than in front. The use of seats that are able to rotate might be a useful ergonomic modification to the current forklift truck. Lastly, operating forklifts remotely may be another option for the prevention of injury resulting from the combination of awkward postures and vibration, which place the driver and those in the surrounding at risk.

A future goal of the research program is to bring the obtained measurements (i.e., vibration, eye-gaze, and auditory) to the laboratory where it will be incorporated in an immersive 3D virtual reality simulator for a safe and realistic experience. This would allow for testing of a larger population and for more controlled tasks and trials. The methods outlined in this thesis represent an important step in this line of research.

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Appendix A – Ethics approval, Letter of Information & Consent Form.

Appendix A.1 – Ethics of approval

Research Western

Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Jim Dickey
Review Number: 18709E
Review Level: Delegated
Approved Local Adult Participants: 10
Approved Local Minor Participants: 0
Protocol Title: Proof of Principle: Assembly of an immersive virtual reality simulation for heavy equipment vehicles – Phase I: field collection
Department & Institution: Kinesiology, University of Western Ontario
Sponsor: Workplace Safety and Insurance Board

Ethics Approval Date: January 24, 2012 **Expiry Date:** June 30, 2013
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
UWO Protocol		
Letter of Information & Consent	Version 1.1	

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 UWO 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 UWO HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Appendix A.2 – Letter of Information and Consent

Letter of Information and Consent:

Assessment of the effectiveness of heavy machinery seats for multi-axis vibration environments

You are being invited to participate in a study on the response of human subjects to multi-axis vibrations. We will be testing 10 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 first phase of a project that will study whole-body vibration in a laboratory setting. This study is conducted under the supervision of Dr Jim Dickey, and is sponsored by the Natural Sciences and Engineering Research Council of Canada (NSERC).

If you agree to participate, we will make measurements of the vehicle and seatpan vibration and will record the vehicle environment and your posture while you perform your normal routine job operating the lift truck. We will be using video cameras mounted to the cab structure using magnetic mounts in unobtrusive locations and small devices to measure acceleration mounted under the seat and on the seatpan.

Your participation is strictly voluntary and you are free to withdraw from the study at any time 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.

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 the University of Western Ontario. 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 the University of Western Ontario. 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.

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

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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.

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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 above address.

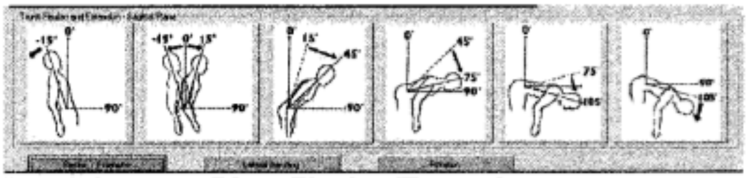
Appendix B- Forklift truck specifications

Toyota forklift truck (Model: 7FGCU25, Serial No: 75034)			
Mast:	QFV	Front Tread:	1 m
Type:	LP	Tire Size:	FR 21 x 7 x 15/ Solid RR 16 x 5 10-1 /2 / Solid
Attach:	Forks	Truck Weight:	4180 kg

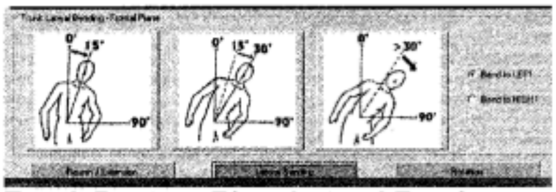
Mast QFV – 4-Stage Full Free View

Type LP – Liquefied Petroleum gas

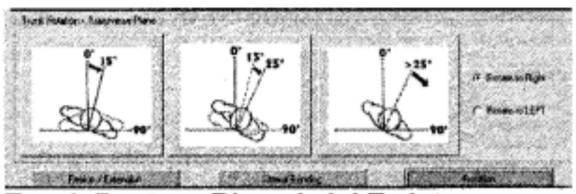
Appendix C – Posture categories and bin sizes from 3D Match



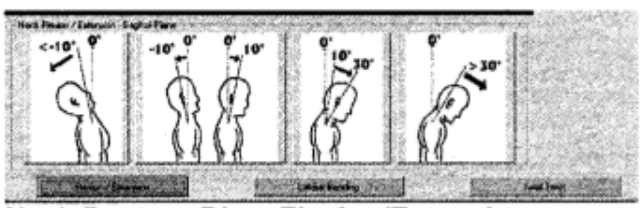
Trunk Posture Bin – Flexion/Extension.



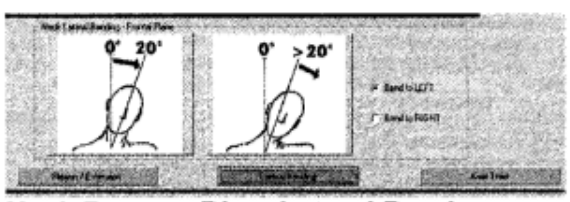
Trunk Posture Bin – Lateral Bend.



Trunk Posture Bin – Axial Twist.



Neck Posture Bin – Flexion/Extension.



Neck Posture Bin – Lateral Bend.

Neck Posture Bin – Rotation.

Appendix D - Curriculum Vitae

Name:	Giselle P. Delgado
Post-secondary Education and Degrees:	The University of Western Ontario London, Ontario, Canada 2006-2010 B.A. Honors Kinesiology Western University London, Ontario, Canada 2010-2012 M.Sc. Candidate in Kinesiology
Related Work Experience	Teaching Assistant: KIN-2241 Introduction to Biomechanics Western University 2010 – 2011

Publications:

Delgado, Giselle; Coghlin, Chelsea; Earle, Katelyn; Holek, Andrea; and O'Hare, Kate (2011) "Trunk Extensor Muscle Fatigue Does Not Affect Postural Control during Upright Static Stance in Young-adults and Middle-aged Adults," *WURJ: Health and Natural Sciences*: Vol. 2: Iss. 1, Article 2. http://ir.lib.uwo.ca/wurjhns/vol2/iss1/2.

Submitted Manuscripts:

Delgado, G., Dickey, J.P., Plewa, K. "Forearm Muscle Activity and Wrist Kinematic Analysis of the Backhand Stroke in Squash as a Risk Factor of Lateral Epicondylitis", *Journal of Applied Biomechanics.*

(Manuscript ID: JAB_2012_0092)- Submitted on April 25th, 2012.

Peer-Reviewed Scientific Presentations

Dickey, J.P., Nield, D.R., Delgado, G., Eger, T., Beauchemin, S., Macpherson, E. Proof of principle: assembly of an immersive virtual reality simulation for lift trucks. 2012 American Conference on Human Vibration, Hartford, Connecticut, June 12-15, 2012.

Non-Peer Reviewed Presentations:

Delgado, G., Dickey, J.P., Plewa, K. Wrist kinematic analysis and forearm muscle activity of the backhand stroke in squash as a risk factor of lateral epicondylitis. 2012 Ontario Biomechanics Conference, Barrie, Ontario, Canada, March 16-18, 2012.