EVALUATING METHODS TO USE THE VIRTUAL CORSET^{TM} INCLINOMETER FOR TRUNK POSTURE MEASUREMENTS

by

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B.Sc. (hons), University of Waterloo 2003

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

The Faculty of Graduate Studies

(Occupational and Environmental Hygiene)

THE UNIVERSITY OF BRITISH COLUMBIA
(Vancouver)

July 2009

ABSTRACT

Non-neutral trunk posture and other related exposures have been linked to low back injuries and the reporting of work-related musculoskeletal disorders. Methods to quantify trunk posture in occupational settings are essential for proper assessment of work tasks and the work environment. There are sophisticated methods that can measure trunk posture and three-dimensional trunk movement; however, these methods are costly, time consuming, have practical field limitations and require extensive data collection. This makes simplified, less accurate methods, such as observation, desirable for field work. Therefore, this work focused on examining a new data-logging inclinometer, the Virtual Corset™ (VC), as a direct reading instrument that can measure trunk posture on par with a complex laboratory based method.

The first study compared posture measurements of trunk motion from a commercially available optoelectronic motion capture system to a method employing the use of a torso mounted and pelvis mounted VC. The results indicated that the double-VC method accurately measured posture with high correlation and excellent agreement with the motion capture system. The second study examined a similar comparison as the first study, except that comparisons were made of posture measurements from a single torso mounted VC. It was found that by including a simple anthropometric measure, lower arm length, measurements using only the torso mounted VC may be used to create a predictive model of trunk posture, though with less accuracy than when using two VCs.

In summary, this work provides a means to utilize the VC as a direct measurement device for characterizing posture without the expense and limitations of more complex systems or the time commitment and subjectivity of observational methods. It is anticipated that this thesis will contribute to future research utilizing the VC as a method of estimating spinal compression. This method will ultimately be applied with previously-collected postural VC data from a study of back injuries in heavy industries completed by the University of British Columbia.

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ACKNOWLEDGEMENTS

First and foremost I would like to thank my advisor and mentor Dr. Kay Teschke. I am most grateful for your continuous encouragement, patience and guidance. You are understanding beyond belief, even when a little someone would blow raspberries during our conference calls. I can never thank you enough for all that you have done.

I would also like to extend my gratitude to:

- My thesis committee members from east to west and north to south: Dr. Jack Callaghan for generously providing your lab time, equipment and research support. It felt good to be home again at BMH. Dr. Mieke Koehoorn for your sincere mentorship and commitment. Dr. Pete Johnson who has always been there with support and patience in pulling this work through the data processing phase. I am very fortunate to have had the opportunity to work with all of you.
- Tyson Beach, Erika Nelson, and Robert Parkinson for all of your help and countless hours in the lab.
- All of the study participants at the University of Waterloo for their patience and cooperation.
- Dr. Catherine Trask for your support, mentorship and most of all friendship throughout my degree.
- Peter Cave, for the late night phone calls and assistance with data cleaning and formatting expertise.
- WorkSafeBC and the Michael Smith Foundation for Health Research for your financial support and continuing efforts to promote population health.

To my husband, my parents, my son, my extended family, and ultimately God. I am truly blessed and could not have done this work without all your love and support.

CO-AUTHORSHIP STATEMENT

Identification and design of research program

The research topic was developed by the candidate. The thesis committee and co-authors assisted with the study design for data collection.

Performing the research

The development of data collection protocols were led by the candidate with the help of research assistants; Tyson Beach, Erika Nelson, and Robert Parkinson at the Callaghan Biomechanics Spine Lab at the University of Waterloo. Recruitment of participants and lab scheduling for data collection was managed and conducted by the candidate, with assistance from Dr. Jack Callaghan.

Data Analyses

Software developed for data processing was developed by Dr. Peter W Johnson at the University of Washington. Data processing and clean-up was carried out by the candidate with the assistance of macro programming by Peter Cave. Data analysis was completed by the candidate in consultation with Dr. Kay Teschke and reviewed by the thesis committee.

Preparation of manuscripts

Manuscript drafts were written by the candidate, the final manuscripts incorporated comments and edits by the thesis committee and co-authors.

1. INTRODUCTION

1.1 The significance of back injuries

The lifetime prevalence of low-back pain (LBP) in the general population has commonly been estimated at nearly 70% for industrialized countries (NIOSH, 1997). Back injuries and low back pain are among the most frequent and disabling conditions among workers in British Columbia (WorkSafeBC, 2007) and in North America at large (Gagnon, Sicard, & Drouin, 1985). Over the ten year period from 1997 to 2006 there were a total of 163,040 accepted workers' compensation claims for back strain in British Columbia, representing 24.5% of all accepted short- and long-term disability claims (excluding those for health care only). Back injuries accounted for 22.4% of the 30.7 million work days lost at a cost of approximately $656 million (WorkSafeBC, 2007). Cost data retrieved from all claims of low back pain initiating in 1986 in the US (N = 98,999) showed the total compensable costs was $11.1 billion (Webster & Snook, 1990). Given the financial and disabling burden, back injuries represent a substantial opportunity for prevention efforts, which requires better understanding the relationship between work-related risk factors and back injury.

The National Institute for Occupational Safety and Health (NIOSH) included a chapter on work-related low-back musculoskeletal disorders in their publication on Musculoskeletal Disorders and Workplace Factors (NIOSH, 1997). This included a review of over 40 articles with evidence regarding positive relationships between low-back disorders and five physical workplace factors: heavy physical work; lifting and forceful movements; awkward postures; whole-body vibration; and static work postures. More recent studies also investigated the association between working exposures and low back pain. They concur with the physical factors described by NIOSH with added emphases on the organizational and social work environments, along with individual psychological, anatomical and genetic traits (Eriksen, Bruusgaard, & Knardahl, 2004; Manek & MacGregor, 2005).

The level of exposure to physical workload can normally be assessed by measuring the magnitude of these factors and their repetitiveness and duration (Li & Buckle, 1999). Posture related risk factors include bending, twisting and static postures. Bending is defined as forward flexion (movement on the sagittal plane) or lateral flexion (movement on the frontal plane). Twisting refers to trunk rotation or torsion in the transverse plane. Awkward posture includes non-neutral trunk postures at or near extreme positions in any plane. The investigations that were reviewed provided evidence that low-back disorders are associated with work-related awkward postures. Punnett *et al.* (1991) found a strong and consistent relationship between occupational exposure to non-neutral trunk postures and musculoskeletal disorders of the back (Punnett, Lawrence, Keyserling, Herrin, & Chaffin, 1991). Despite the fact that studies defined disorders and assessed exposures in different ways, results were consistent in showing increased risk of back disorder with exposure (NIOSH, 1997).

Static work postures are isometric positions with little movement. Cramped or inactive postures can overload tissues causing injury by exceeding their thresholds or tissue tolerance limits (McGill et al., 1996; McGill, Norman, & Cholewicki, 1996; McGill, 1997; NIOSH, 1997; Vieira & Kumar, 2004). Physiologically speaking, static postures for prolonged periods of time compress the veins and capillaries inside the muscles, leading to microlesions which can cause discomfort and pain (Vieira & Kumar, 2004). Thus the NIOSH Work Practices Guide for Manual Lifting (1981) did not consider accelerating lifts but rather frozen static postures in the NIOSH lifting equation. However, upon epidemiologic review inadequate evidence was found that a relationship between back disorders and static postures exists (NIOSH, 1997). Moreover, it was found that the risks of low back disorders are three times more likely during dynamic lifts compared to awkward static postures (Burdorf, 1992). Marras *et al.* (1992) pointed out that three-dimensional dynamic motion components of workplaces must be explored (Marras, Fathallah, Miller, Davis, & Mirka, 1992) in order to reduce the occurance of back injuries. It is essential for researchers and ergonomists to have a better understanding of work exposures that increase the risk of injury (Burdorf, 1992).

1.2 Measuring posture

Measurements are an essential part of estimating risk rates for the development of work-related musculoskeletal disorders (WMSD). In epidemiological studies of WMSD, quantitative and objective methods are needed to establish exposure-response relationships (Burdorf, 1992; Hansson, Asterland, Holmer, & Skerfving, 2001). Various means of measuring trunk posture are often used in the field, labs and rehabilitation clinics. For ergonomists and epidemiologists alike these include observational methods, instrumental or direct methods, and self-reporting. Common measurement methods consist of observation tools, manual goniometers, the lumbar motion monitor, motion capture systems, and inclinometers. All avenues of measurement have their own limitations (Hansson et al., 2001; Marras et al., 1992); however, they maintain their place in epidemiologic studies of musculoskeletal disorders (Li & Buckle, 1999).

1.2.1 Observational methods

Observation methods have frequently been used to estimate work postures and work movements in studies of WMSD. Their techniques are typically based on checklists, diagrams, categories, posture codes, or score tables and are discussed in detail elsewhere (Li & Buckle, 1999). In comparison with direct measurements, observational tools are relatively inexpensive, minimally interfere with work tasks and have acceptable precision to most epidemiologists (Juul-Kristensen, Hansson, Fallentin, Andersen, & Ekdahl, 2001). However, these tools are not suitable for dynamic activities; most focus on sedentary jobs or are too broad to provide accurate posture description, and usually with poor intra- and inter-observer reliability (Li & Buckle, 1999).

1.2.2 Manual goniometers

Manual goniometers are the simplest devices used to measure posture in degrees. A goniometer is made of transparent plastic with two long arms and a protractor in the center that rotates with the moving arm (see Figure 1.1). Each arm is lined up against a body segment with the joint center in the middle of the protractor. These devices are most commonly found in rehabilitation centers being used by occupational and physical therapists. They are inexpensive ($25) (Cupon & Warren, 2003) quick and easy to use for range-of-motion measurements with minimal training required. The biomechanical complexity of the spine makes these types of goniometers less than ideal for spinal measurements due to multiple joints with dynamic axes (Vieira & Kumar, 2004) and would not be suitable for continuous measurements in the workplace.

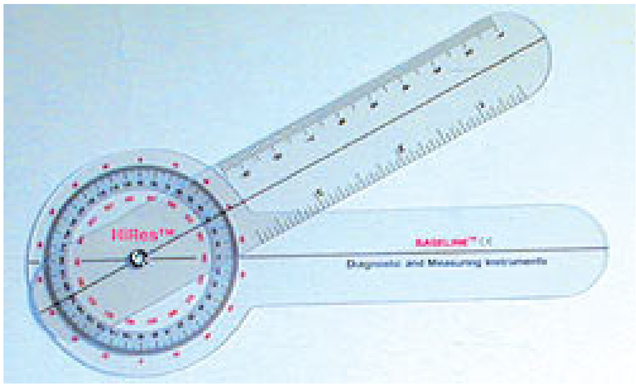

Figure 1.1 Manual goniometer. Original image was taken from NexGen Ergonomics Inc (NexGen Ergonomics Inc., 2007)

1.2.3 Lumbar Motion Monitor (LMM)

The LMM is a triaxial angular measurement system that continuously monitors three-dimensional trunk motion via four potentiometers with an analog-to-digital converter (Li & Buckle, 1999; Marras et al., 1992). It is an exoskeleton that is worn on the worker's back, shown in Figure 1.2, and moves along with them. The wires that run through each section of the exoskeleton are connected to the potentiometers and carry the differential change in voltage readings. Voltage signals are calibrated to correlate with trunk angle and processed to determine position, velocity and acceleration. The LMM is attached at the thorax and pelvis allowing for the difference in spine position to be recorded relative to the pelvis. The LMM is an accurate and a repeatable means to monitor trunk motion in the workplace with relatively easy signal processing compared to video-based motion systems (Marras et al., 1992). This device retails for approximately $25,000 (NexGen Ergonomics Inc., 2009), and requires 8-hours of training time (Marras & Allread, 2004), a considerable investment for consultants, industrial companies, and researchers. The bulkiness of this device and harness may interfere with workers' personal protective equipment or come in contact with other equipment in confined work areas (Marras & Allread, 2004). When worn by larger individuals, the superior portion of the exoskeleton may slip out of the upper plate during positions of extreme flexion.

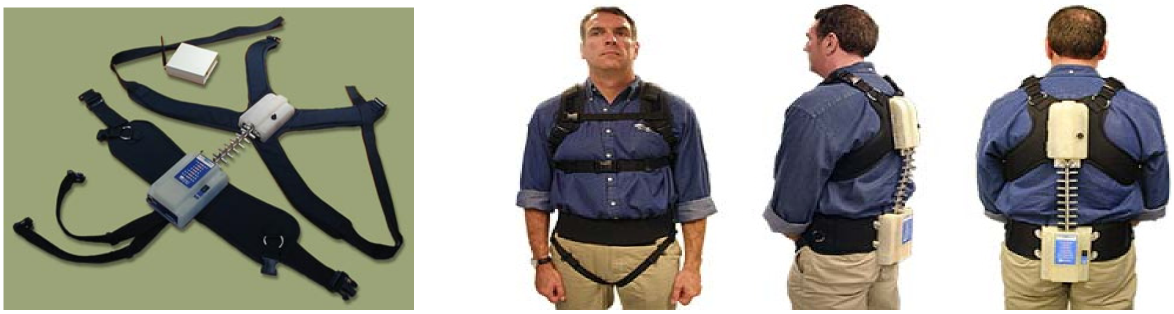

Figure 1.2 LMM components (left), front, lateral and back views of LMM worn on by an individual (right). Original images taken from NexGen Ergonomics Inc (NexGen Ergonomics Inc., 2007).

1.2.4 Motion capture systems

Motion capture systems or video analysis systems track surface markers placed over the skin, shown in Figure 1.3. These systems can record body posture and movement in two- or three-dimensions. The markers are tracked by digitization of the points based on Cartesian coordinates measuring displacement and angles between line segments allow for recordings of angular changes, velocities, and accelerations. These systems provide “gold standard” spatial and temporal accuracy with high precision and the ability to capture extremely fast motion (up to 4600 Hz) (States & Pappas, 2006). However, calibration requirements and image-digitization with these systems can be very time-consuming and may not be suitable in industrial environments, as the rigid-link model on the worker must be viewed by the cameras at all times. Machinery, equipment, assembly lines, personal protective equipment, other workers, mist, poor lighting, etc. may all obstruct the camera’s view (Andrews & Callaghan, 2003; Li & Buckle, 1999; Marras et al., 1992). The geographical range is also limited because cameras are calibrated and remain stationary while workers move around to several workstations. In addition to these limitations, these systems are expensive and can cost over $100,000 (Marras et al., 1992).

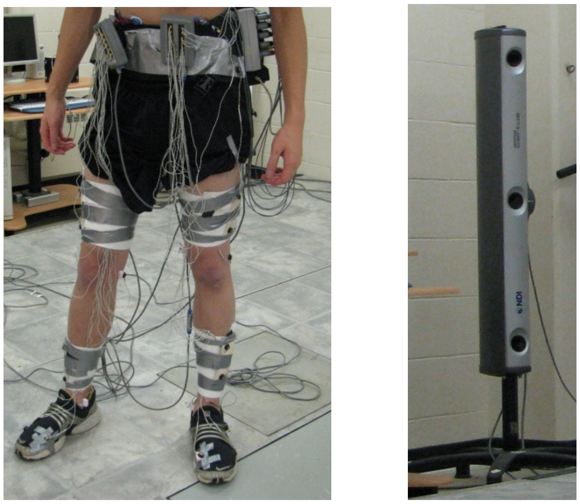

Figure 1.3 Wired rigid-link model (left) Optotrak motion capture camera (right)

1.2.5 Mechanical inclinometers

Inclinometers are devices used to measure body inclination calibrated relative to gravity (Cupon & Warren, 2003; Lea & Gerhardt, 1995). There are many different types of inclinometers categorized as mechanical or electronic instruments. Mechanical inclinometers are hand-held devices that usually have a protractor with a pendulum-weighted needle or fluid level indicators (see Figure 1.4) (Li & Buckle, 1999; Williams, Binkley, Block, Goldsmith, & Minuk, 1993). They are best used for static postures and are most commonly found in clinical settings (Li & Buckle, 1999). They are easy to use, simplify posture measurement and cost less than $125. Most inclinometric devices are clumsy and complicated to mount on the body segment aligned with the selected coordinate system. Studies reporting low reliability are typically due to the lack of training in the use of the inclinometer and problems with stabilizing the instrument on different body contours and the location to position the inclinometer on the body is problematic (Seo, Kakehashi, Tsuru, & Yoshinaga, 1997).

Figure 1.4 Mechanical (bubble) type inclinometer. Image was taken from NexGen Ergonomics Inc. (NexGen Ergonomics Inc., 2007)

1.2.6 The Virtual Corset^{TM}

The Virtual Corset^{TM} (VC) is an electronic inclinometer (Microstrain Inc., Williston, VT, USA) with two orthogonally positioned low pass filtered tri-axial accelerometers measuring angular acceleration. The resulting data can estimate velocity and postural data (in degrees) for the sagittal and frontal planes as well. It is a wireless, battery-powered, pager-sized portable logger, with 2 megabytes of built-in memory (see Figure 1.5). . These accelerometers are designed to calculate angles based on gravitational acceleration. The operator may select a sampling rate of 7.5 or 15 Hz with a reported mean error of 1.8° (± 1.0°) during flexion/extension (Johnson et al., 2002). The VC is easy to use, requires minimal instrumentation and work interruption, capable of full shift analysis, at a lower cost (Trask, 2008) of approximately $1,500 (USD) (Hoskin Scientific Ltd., 2009). It is not required to be in view of the operator. Collected data can be downloaded to a PC via Windows-based Virtual Corset control software (VC-323, Microstrain Inc, Williston, VT, USA) (Johnson et al., 2002). Unfortunately, using gravity as a reference only allows for two-dimensional posture measurement (Hansson et al., 2001). Thus the VC can measure trunk flexion/extension and lateral side-to-side bending but not trunk rotation/twisting.

Figure 1.5 Front (left) and back (center) view of Virtual Corset™ inclinometer, worn by a worker in a trunk harness (right)

This thesis evaluated how well the VC measures sagittal postural movements in comparison to an optoelectronic video analysis system (Optotrak Certus, Northern Digital Inc, Waterloo, Ontario, Canada).

1.3 Posture and spinal compression

Peak and cumulative spinal compression forces within the joint have been shown to result in injury of the spine (Keyserling, 2000; Norman et al., 1998; Schultz & Andersson, 1981; T. Waters, Putz-Anderson, Garg, & Fine, 1993). Waters et al. (2006) found that workers with low back pain were almost twice as likely to have been exposed to higher levels of cumulative spinal loading compared to those without low back pain (odds ratio of 1.66, $p<0.05$) based on their review of relevant studies (T. R. Waters et al., 2006). Although the number of epidemiological studies is limited, evidence from three epidemiological studies suggests a likely association of spinal loading with lower back disorders. In a case-control study of 229 cases and 197 controls, Seidler et al. (2001) found that the risk of having low back disorders as a result of cumulative compression over years of exposure was 8.5 (95% CI: 4.1-17.5) (Seidler et al., 2001). In a cross-sectional study of 161 nursing aids Kumar (1990) found that average daily cumulative compression and shear forces of current jobs were significantly greater in subjects who reported low back pain compared to those without back pain (Kumar, 1990). Lastly, a well known study conducted among 104 cases and 130 controls in the automotive industry by Norman et al. (1998)

reported that the workers in the top 25% of loading exposure were six times more likely to report lower back pain when compared with those in the bottom 25% (Norman et al., 1998).

Interest in how well the VC can measure spinal posture lies in its convenience, affordability, and simplicity. When a direct measurement device can produce valid postural information with those attractive attributes it may become a powerful tool not only for postural measurement but possibly for estimating spinal compression as well. When posture data is available and used along with load moment information a quantitative biomechanical assessment of spinal loads is possible. Literature has shown that a large proportion of spinal compression is directly related to trunk posture (Hoozemans, Kingma, de Vries, & van Dieen, 2006; Potvin, Norman, & McGill, 1996; Schultz & Andersson, 1981). The regression analyses produced by Hoozemans et al. (2006) demonstrated greater regression coefficients for trunk inclination than load weight as a major contributor to spinal load. This suggested that altering the vertical location of the load (origin or destination) would have a greater impact on reducing spinal compression than decreasing the weight. Callaghan et al. (2003) also found the largest contributors to percentage change in spinal compression to be trunk flexion and lateral bend (Callaghan, Jackson, Albert, Andrews, & Potvin, 2003).

With instruments such as the VC available it may become more feasible to collect data on a large number of individuals (Johnson et al., 2002) for evaluation of workplace spinal compression in addition to posture. This can be done by establishing a linear compression calibration equation by using a series of static efforts; for example, with the trunk in an upright standing position, 45°, and 60° of flexion. The calibration will allow posture measures to be expressed as Newtons (N) of spinal compression. A quasi-dynamic link-segment model (Ergowatch 4DWATBAK, University of Waterloo, Canada) can be used to estimate spinal compression under the assumption that posture is linearly related. A similar linear calibration equation has been used for compression normalized EMG (Granata & Marras, 1999; Mientjes, Norman, Wells, & McGill, 1999; Potvin et al., 1996; Trask, 2008; Village et al., 2005). Using the VC in this capacity in the field for epidemiologists is the ultimate goal.

1.4 Objectives and rationale

Methods for estimating posture and compressive spinal loads over the course of a full work shift have traditionally been complex, time-consuming and costly to collect, limiting the ability to identify workplace risk factors and to intervene to prevent back injuries. Epidemiological studies require exposure data on large numbers of individuals in order to observe relationships and to be representative. Therefore, assessing the ability of a novel measurement approach using the VC to estimate posture and spinal compression has the potential to offer a simple and less costly means to quantify work factors associated with back injury, with the ultimate goal of reducing the personal disability and economic burden associated with these disorders.

The proposed method has many benefits over more complex methods:

- it does not require video or direct observation;
- it is portable and suitable for dynamic jobs such as maintenance or construction work;
- it easily allows for the collection and analysis of full-shift data so that cumulative exposures and patterns of exposure can be considered; and
- it is inexpensive to purchase, operate, and analyze compared to other direct measures (Trask et al, 2007).

Before moving towards the application of the VC in estimating spinal compression, researchers first need evidence that the VC has been validated for posture measurement. The purpose of this thesis is to do just that. The objective of Chapter 2 is to compare trunk posture measurements between an Optotrak motion capture system and two VCs simultaneously, one mounted on the torso the other mounted on the pelvis. The objective of Chapter 3 is to make the same comparisons between methods, but with the use of a single VC (torso only). In each chapter an in-depth comparison is made on multiple levels. Researchers will then have the knowledge required to make decisions on whether the VC is the right device to use for their study, and if so, whether using the double- or single-VC method is suitable to meet their objectives.

This is a manuscript based thesis; thus, chapters 2 and 3 were written as articles in preparation for publication. Therefore, there is some replication of information across chapters.

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2. A COMPARISON OF METHODS TO MEASURE TRUNK POSTURE. PART 1: MOTION CAPTURE SYSTEM VS TWO VIRTUAL CORSETS™[1]

2.1 Introduction

Back disorders continue to be of interest among occupational populations. Back injuries and low back pain are among the most frequent and disabling conditions among workers in British Columbia, Canada (WorkSafeBC, 2007). Physical workload is a risk factor that encompasses posture, repetition, force, and duration. Vieira and Kumar (2004) found evidence in the literature that working postures and musculoskeletal health are related; thus, measuring postures in the workplace is worthy of considerable attention. To measure postures in the workplace, observational tools, goniometers, the lumbar motion monitor, inclinometers, and video analysis systems are the most common measurement methods used. The choice of measurement methods will vary based on the tasks being assessed and the evaluation objectives. The ideal measurement method should be able to handle the demands of the work environment and worker tasks with valid and reliable assessments for a reasonable cost (Trask et al., 2007). However, many direct monitoring devices are complex, with extensive data generation, and may influence work tasks when utilized in the workplace. Most alternatives are subjective in nature and rely on self-reporting or trained observers, compromising precision and accuracy while at the same time requiring long periods of analysis (Vieira & Kumar, 2004).

This study investigated a small, portable, data-logging inclinometer device called the Virtual Corset™ (VC) (Microstrain Inc., Williston, VT, USA) that is a cheaper, easier, and less invasive alternative to use in the field while maintaining objective quantification. This device has been reported to overcome many of the obstacles mentioned above (Trask et al., 2007). Posture measured by the VC inclinometer will be compared to posture measured using a rigid-link model motion capture system, the traditional gold standard for posture measurement. It is important to assess the agreement between any new method and traditional standards before it is put into

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[1] A version of this chapter will be submitted for publication. Van Driel, R., Teschke, K., Callaghan, J., Koehoorn, M., Trask, C., Johnson, P. A Comparison of Methods to Measure Trunk Posture: A Motion Capture System versus Two Virtual Corsets ™

practice (Choudhary & Nagaraja, 2005). Motion capture systems track surface markers (light-emitting diodes) placed over the skin to produce three-dimensional body kinematics and were used in this study as the reference method (gold standard) to test the accuracy of the two VC posture measurement system. The goal was to understand the extent to which the methods agree and the nature of their differences when measuring spinal motion between the pelvis (S1) and the thorax (T5). With sufficient agreement the VC posture measurement system may be used in place of other posture monitoring devices, especially in the field or for large epidemiological studies, as it has high value in terms of the price per successful sample (Trask et al., 2007).

2.2 Methods

2.2.1 Study participants

Study participants were staff and student volunteers at the University of Waterloo, Ontario. Eight healthy males who reported no previous history of low back injury or cardiovascular disorders participated. Their mean height was 180 cm (range 171 to 186 cm), age 22 years (18 to 28 years), body mass 84 kg (61 to 96 kg) and body mass index (BMI) 26 kg/m^2 (21 to 29 kg/m^2). All participants read and signed informed consent forms approved by both the University of Waterloo Office of Research Ethics and the University of British Columbia Behavioural Research Ethics Board (shown in Appendix A).

2.2.2 Data collection

Details of the data collection protocol used in the lab can be found in Appendix B.

Task description. Participants were asked to perform a prescribed set of lifting/lowering tasks modeled from the industrial tasks observed in a large study on back injuries in heavy industries (Trask, 2008). Tasks consisted of a combination of three lifting heights: 1) between ground level and shelving located at 0.67 m (approximating waist height), 2) ground level and shelving located at 1.2 m (approximating shoulder height) and 3) between 0.67 m (waist height) and 1.2 m (shoulder height) shelves. Four different loads were lifted each doubling in weight (0 kg, 4.5 kg, 9 kg and 18 kg) and three placement directions (left, right and sagittally symmetric in the center). Each participant performed all possible lifting tasks separately in random order for a total of 36 different trials (3 heights x 4 loads x 3 directions); a sample is shown in Appendix C. Within each trial, participants were asked to continuously lift/lower the object (milk crate L 34.6 cm x W 34.6 cm x H 31.6 cm) three times at their own pace. They were free to lift in a manner that was most comfortable to them using both hands.

Motion capture system for posture measurement. Spinal kinematics were determined from four infrared light emitting diodes (IREDS) that were affixed on each corner of the upper plate and four IREDS affixed to the corners of the lower base plate on a Lumbar Motion Monitor (LMM) system as shown in Figure 2.1. Segment-based co-ordinate systems were determined from an upright standing calibration trial creating a rigid-link model. Segment displacement in three-dimensions was recorded at 30 Hz using an optoelectronic system (Optotrak Certus, Northern Digital Inc, Waterloo, Ontario, Canada). Raw marker co-ordinates were loaded into Visual3D^{TM} Motion Analysis Software (C-Motion, Inc., Ontario, Canada) for processing. Prior to angle calculations, all raw marker data were low-pass filtered (dual pass) with a Butterworth filter (10 Hz cut-off frequency) prior to being exported from the software.

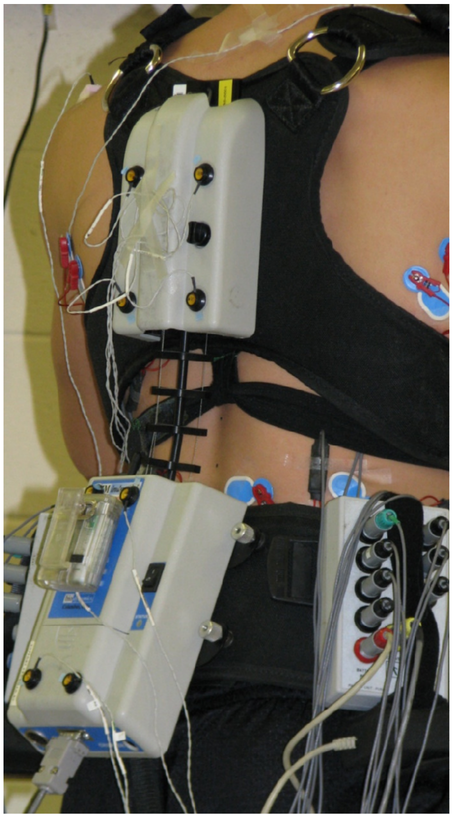

Figure 2.1 Photograph showing four IREDs on the upper and lower LMM plates with the one VC mounted on the lower LMM plate.

Inclinometry system for posture measurement. Two VC inclinometers were used in this study. The VC is a wireless, battery-powered, pager-sized portable logger with 2 megabytes of built-in memory, weighing 72 grams and measuring 6.8 cm by 4.8 cm by 1.8 cm. It uses two orthogonally positioned low pass filtered tri-axial accelerometers. These are linear accelerometers designed to calculate angles based on the acceleration due to the earth's gravitational field in sagittal and frontal planes only. Each VC sampled at a rate of 15 Hz and was low-pass filtered with a high frequency cut-off of 10 Hz. While recording flexion/extension the inclinometers have a reported error of 1.8° (± 1.0°) when used according to the manufacturer's specifications (Johnson et al., 2002). One inclinometer was placed in the center of the lower base plate of the LMM system (seen in Figure 2.1) and the other placed over the sternum, using an elastic and Velcro "bra-like" harness with straps that wrapped over the shoulder and under the arm and around the upper torso (Johnson et al., 2002). The difference in spine position of the lumbar spine (as a unit) was calculated relative to the pelvis by subtracting the lower inclinometer data from the upper inclinometer data (Marras, Fathallah, Miller, Davis, & Mirka, 1992). Prior to launching each inclinometer the devices were set to the zero position while the subject was in a standing upright position. Following collection, data from the inclinometers were downloaded to a PC via Windows-based Virtual Corset control software (VC-323, Microstrain Inc, Williston, VT, USA) (Johnson et al., 2002). Although inclinometer data can be used to estimate postural velocity and acceleration, only posture itself is presented in this paper.

2.2.3 Data synchronization

In order for collected data to be analyzed in parallel, all three devices were synchronized into the same time domain through a 4-step process. This was done using two graphical interactive user interface programs developed in LABVIEW (Version 8.2; National Instruments; Austin, TX, USA). The first step was to match the upper and lower inclinometers together. The difference between the upper inclinometer (VC_u) and the lower inclinometer (VC_l) produces a new variable called delta inclinometer ($\Delta VC = VC_u - VC_l$). This captures the same spinal segment obtained by the rigid-link model to represent torso posture as described above. The second step was to synchronize the VC measured torso posture (ΔVC) with the Optotrack measured torso posture for each trial. Each trial started and ended with the participant's trunk in a flexed position with hand support for approximately four seconds. Trials were easily identified within the inclinometer files by visually spotting the four-second bends at the start and end of each trial. The third step required the precise identification of the beginning and ending of each lifting trial. Data index markers were placed at locations to include the duration associated with the beginning and ending of the lifting motion. The last step allowed for the rigid-link model to be parsed down from 30 Hz to 15 Hz to match the VC sampling rate. The output file from the LABVIEW software calculated various exposure metrics for each method. Although both the motion capture system and the VC recorded data in sagittal and frontal planes, only sagittal data is presented here.

2.2.4 Data analysis

With the synchronous postural data from each device, the 10th percentile, mean and 90th percentile torso posture values were the three outcome measures calculated for each trial. The mean represents central tendency, while the 10th and 90th percentiles represent lower and higher degrees of inclination respectively, found within each lifting trial. Then the group means and standard deviation (SD) values were calculated over all 278 lifting trials for each measurement system.

2.2.5 Statistical analysis

The 10th percentile, mean and 90th percentile of the angular distributions of each lifting trial were used for characterizing posture measurements and methods comparison. Here, an established standard, the Motion Capture System (X_1), was used to evaluate the postural data collected with the two VCs (X_2). Using a Windows statistical software tool (SPSS 16.0, SPSS inc, Chicago, IL, USA), Pearson *r* correlation coefficients and paired-sample *t*-tests were performed as basic approaches to assess the strength of linear relationship and overall agreement respectively.

The Bland and Altman (1986) limits of agreement approach for assessing the agreement between two methods of measurement is widely used (Bland & Altman, 1992). It uses graphical techniques (scatter-plots) and bias calculations, and proposes calculation of 95% “limits of agreement” (LoA), as the mean difference between the methods ± 1.96 standard deviations (95%) of the differences. These limits are expected to contain the difference between measurements by the two methods for 95% of pairs (Bland & Altman, 2007). If insufficient agreement is found, a simple linear calibration of the new method ($X'_2 = a + bX_2$) could be used to account for the differences between X_2 and X_1 (Choudhary & Nagaraja, 2005). In addition to these elements, mixed multiple regression models were used to account for within-subject correlation not accounted for by the simple relationship between the two measures (SAS version 9.1, SAS Institute Inc., Cary, NC USA). The estimated proportion of variance explained by each model was determined by squaring the relationship between the predicted exposure levels and the measured exposure levels by using PROC CORR in SAS.

2.3 Results

Complete sets of paired posture data were successfully measured and processed on 278 individual lifting trials from eight subjects (10 trials were lost from X participants due to either data collection or processing errors). Descriptive statistics for the 10th percentile, mean, and 90th percentile posture metrics for each method are presented in Table 2.1.

Table 2.1 Descriptive statistics (in degrees) for rigid-link model and ΔVC data (n = 278 trials). Positive values denote flexion, negative values denote extension.

	Mean	*SD	Range	Min.	Max.
Rigid-link model 10th percentile	0.70	18	82	-35	47
ΔVC 10th percentile	-3.8	18	87	-44	43
Rigid-link model mean	16	18	80	-26	54
ΔVC mean	16	18	82	-31	51
Rigid-link model 90th percentile	37	23	101	-19	82
ΔVC 90th percentile	39	22	95	-22	73

*SD = standard deviation.

For 10th percentile, mean, and 90th percentile exposure metrics, the rigid-link model and inclinometer methods were highly correlated with Pearson *r* values of 0.97, 0.99, and 0.98 respectively ($p \leq 0.01$).

The results of the paired-sample *t* tests conducted to compare the postures measured by the rigid-link model and ΔVC inclinometer methods for each exposure metric are presented in Table 2.2.

The paired differences were small, but were statistically significant for the 10th and 90th percentile posture measures.

Table 2.2 Mean and standard error on torso posture measurement accuracy across 278 lifting trials using 8 subjects comparing the Virtual Corset™ back posture measure (ΔVC) and the rigid-link model (RLM)

Difference between ΔVC and RLM	Mean	Standard Error	T	df	p-value (2-tailed)
10th percentile	-4.4	0.20	-18	277	<0.0010
Mean	-0.30	0.20	-1.7	277	0.090
90th percentile	2.0	0.30	6.9	277	<0.0010

df = degrees of freedom

Figure 2.2 shows the rigid-link model posture measures plotted against the inclinometer measures for the 10th percentile, mean and 90th percentile exposure metrics. The graphs also show the line of equality. For all three outcome measures data points are close to the line showing that the two methods are highly correlated as the double-VC method consistently underestimates posture at the 10th percentile range and overestimates posture at the 90th percentile. The data points are symmetrically distributed about the line of equality for mean exposures indicating minimal bias.

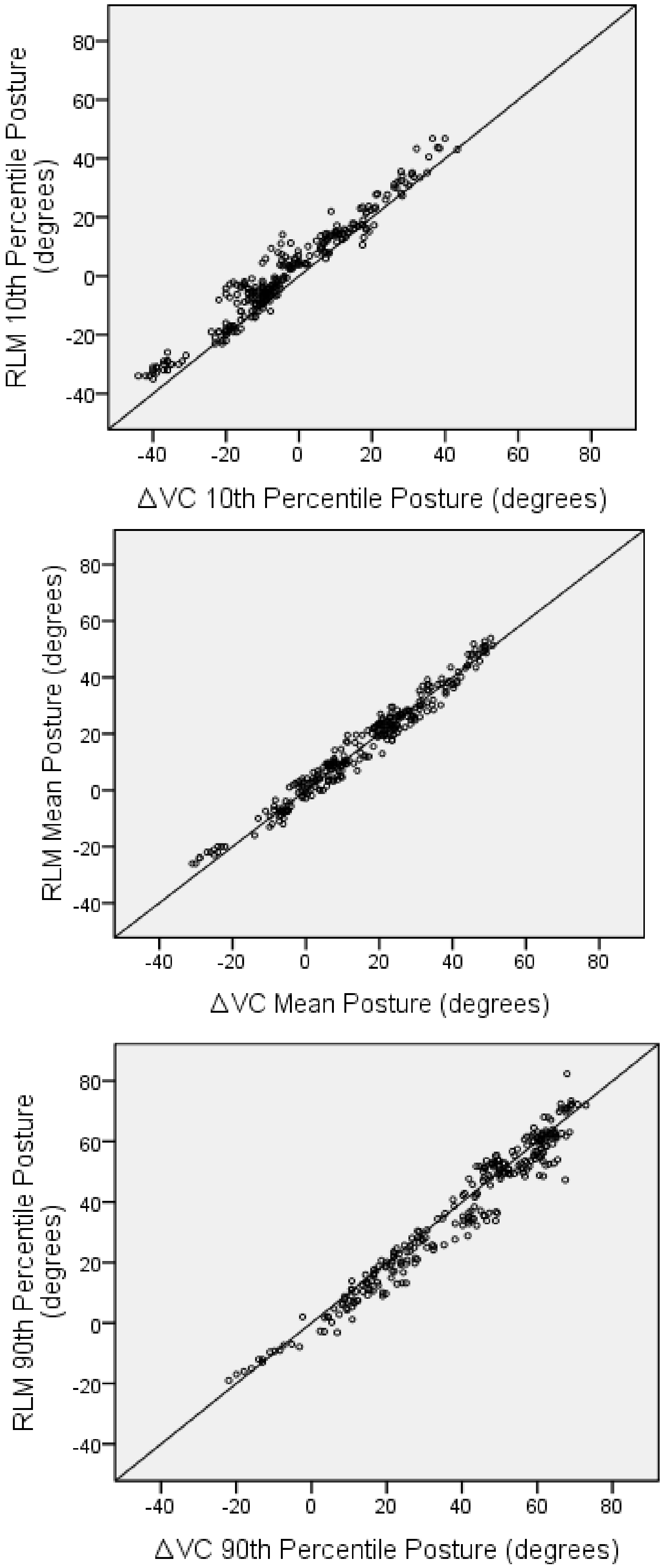

Figure 2.2 Posture measured by rigid-link model method and by the ΔVC inclinometer method for 10th percentile (top), mean (center) and 90th percentile (bottom) exposure with line of equality (n = 278 trials)

A plot of the differences between the methods against their mean may be more informative in examining agreement, also known as Bland and Altman plots. The following Bland and Altman plots include a dotted line at zero, which indicates no bias in agreement relative to rigid-link model posture, solid lines indicate the mean difference, and calculated 95% limits of agreement (LoA). Points indicate the individual differences for each of the 278 trials. Figure 2.3 shows the results for the 10th percentile, mean and 90th percentile metrics. It is often helpful to use the same scale for both axes when demonstrating a plot of the differences against their mean to show discrepancies in relation to the size of the measurements; however, in this case the methods agree so closely that equal scaling would obscure useful information (Bland & Altman, 1999).

For 10th percentile postures, 95% of ΔVC inclinometer readings were within 12.6 degrees below or 3.8 degrees above the rigid-link model posture method. For mean postures, 95% of ΔVC inclinometer readings were within 6.5 degrees below or 5.9 degrees above the rigid-link model posture method. For 90th percentile postures, 95% of ΔVC inclinometer readings were within 7.4 degrees below or 11.4 degrees above the rigid-link model posture method.

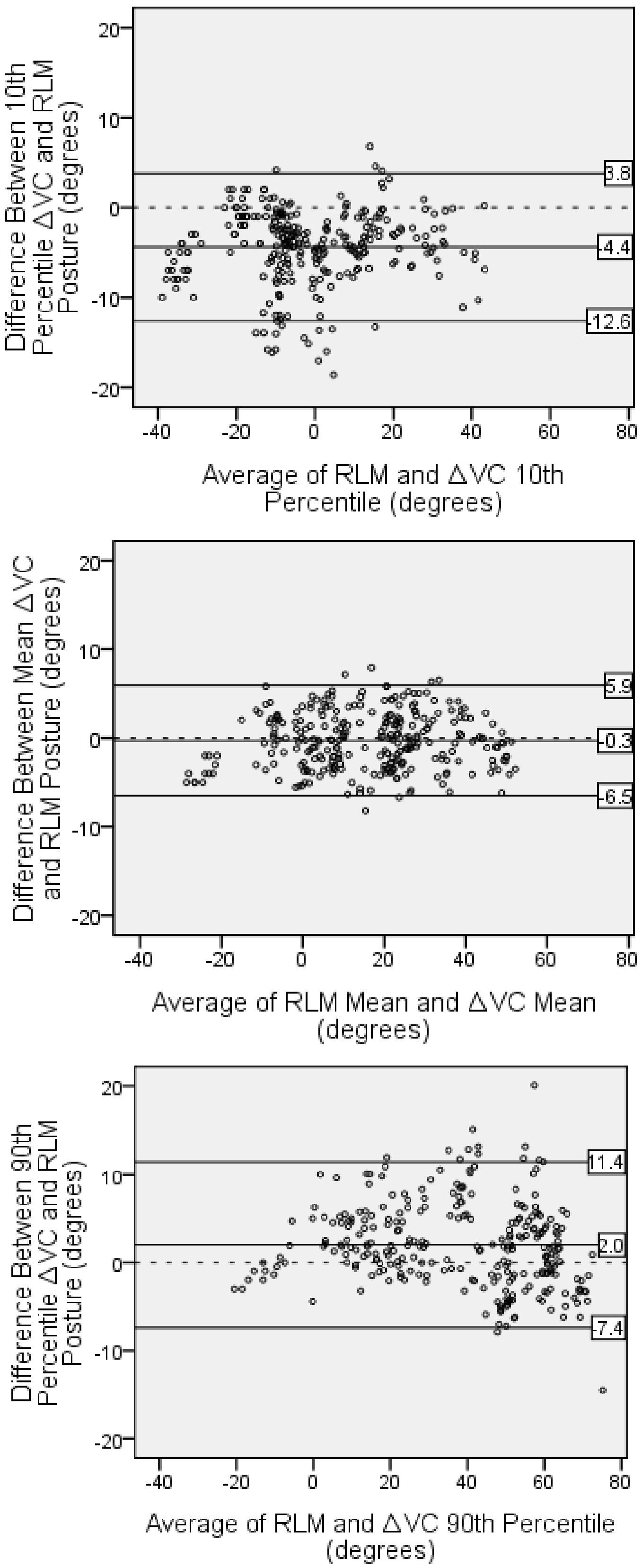

Figure 2.3 Bland and Altman plot for 10th percentile (top) mean (center) and 90th percentile (bottom) posture data with 95% LoA, mean difference, and the broken line at zero (n = 278 trials)

Simple linear regressions using the ΔVC variable to predict rigid-link model measurements for each exposure metric are summarized in Table 2.3. For both the 10th percentile and mean posture measurements, the ΔVC inclinometers explained 97% of the variance in the rigid-link model torso readings with intercepts significantly different from zero: 4.24 and 0.72 degrees respectively. At the 90th percentile posture measurements, the ΔVC inclinometers explained 96% of the variance in the rigid-link model torso readings, with a significant intercept of -2.42 degrees.

The next step was to incorporate 'participant' as a random effect term to control for within-participant correlation not accounted for by the inclinometers (see Table 2.4). The 10th percentile results were similar to the simple linear regression results. However, both the mean and 90th percentile metrics no longer have significant intercept values. The mean intercept increased to 1.35 degrees (from 0.72) and the 90th percentile increased to -1.20 degrees (from -2.43).

Table 2.3 Simple linear regression results of rigid-link model measures as predicted by delta inclinometer for each exposure metric

	Intercept (p-value)	Slope (p-value)	*Percent of Variance Explained
10th percentile	4.2 (<0.0010)	0.95 (<0.0010)	97%
Mean	0.72 (0.0050)	0.98 (<0.0010)	97%
90th percentile	-2.4 (<0.0010)	1.0 (<0.0010)	96%

In each model the rigid-link model measure is the dependent variable and delta inclinometer is the independent variable.

*Percent of the variance in the rigid-link model measurements accounted for by ΔVC inclinometer measurements

Table 2.4 Mixed linear regression models of rigid-link model measures as predicted by delta inclinometer for each metric

	Intercept (p-value)	Slope (p-value)	*Percent of Variance Explained
10th percentile	4.2 (0.0070)	0.94 (<0.0010)	95%
Mean	1.4 (0.18)	0.94 (<0.0010)	97%
90th percentile	-1.2 (0.38)	0.98 (<0.0010)	96%

In each model the rigid-link model measure is the dependent variable and delta inclinometer is the fixed effect. These models include participant as a random effect and was significant ($p < 0.05$) in all models

*Percent of the variance in the rigid-link model measurements accounted for by ΔVC inclinometer measurements

2.4 Discussion

The tasks chosen for this study were intended to be representative for manual work and the mean measured postures were in accordance with similar tasks recorded during work in heavy industries, such as forestry, transportation, warehousing and wood & paper products (Teschke et al., 2008). Although tasks were highly standardized to eliminate variability caused by actual task requirements, trials were always performed in random order and at a pace set by the participants to avoid fatigue. This study took place in the biomechanics spine lab at the University of Waterloo in Ontario, Canada. Thus, the pool of participants who volunteered for this study may not reflect that of the typical workforce with respect to age and physical health. A recent study of trunk posture in heavy industry reported a mean age of 42 years (Teschke et al., 2008) compared to a mean of 22 years in this study.

2.4.1 Relationship between methods

The results in this study showed that the rigid-link model and ΔVC inclinometer methods of posture measurement have a very strong linear relationship, with Pearson *r* correlation coefficients close to 1.0 for 10th percentile, mean, and 90th percentile exposure metrics. For mean postures, there was not a significant difference (0.3 degrees, $p = 0.09$) in measurements as indicated by the paired-sample *t* test. However, the 10th and 90th percentile measures were significantly different on average by -4.4 and 2.0 degrees respectively ($p < 0.05$). These differences, despite some being significant, are quite small relative to the range of posture measures in each category (91 degrees for 10th percentile postures, 85 degrees for mean postures, and 104 degrees for 90th percentile postures). Lift direction (left, center, and right) was considered as a potential explanation of the biases found for the 10th and 90th percentile metrics, but no pattern was observed. The opposing directions of the small biases seen in the 10th and 90th percentile metrics may have some connection to the action of switching directions from a lift to a lower as the torso decelerates and accelerates.

To further describe the relationship and agreement between these methods, additional investigation was required to ensure that what holds true *on average* is also true for individual observations. If the two methods are in perfect agreement, *all* of the paired measurements should lie on the line of equality (Choudhary & Nagaraja, 2005). As shown in Figure 2.2, the mean exposure metric depicts a symmetrical distribution of points on both sides of the line of equality with a narrow spread. For the 10th and 90th percentile exposure metrics, the majority of data points lie above or below the line of equality, respectively. At 10th percentile postures, the inclinometers consistently underestimated postures relative to the rigid-link model method. At the higher end or in 90th percentile postures, the inclinometers overestimated postures relative to the rigid-link model. The calculated 95% limit of agreements quantifies these differences. Given the nature of the tasks, the 10th and 90th percentile postures likely occur at the start or end of the lift/lowers. Due to the low pass filtering of the accelerations and half the sampling rate on the VC's, the accelerations and decelerations and the resulting postures may not be as well captured compared to the motion capture technology. Future work may involve analysis of the validity of velocity and acceleration as measured by the inclinometers.

2.4.2 Agreement between methods

The strength of the limit of agreement approach derives from its intuitive appeal and simplicity. The Bland and Altman plots with the 95% limit of agreement superimposed (Figure 2.3) complement the scatter plots, as they reveal features of departure (Choudhary & Nagaraja, 2005).

At the 10th percentile, most of the differences lie between -13 and 3.8 degrees and centered around -4.4 degrees. Overall, the measurements observed by the two methods fall within the range of -44 to 47 degrees (range=91 degrees). The differences (ΔVC – RLM) range from -19 to

6.8 degrees with the middle 50% between -6.6 and -1.6 degrees representing a range of 5.0 degrees. Since 5.0 degrees constitutes 5.5% of the measurement range (91 degrees), the differences seem to be low enough for the methods to have satisfactory agreement. The mean measures have a relatively symmetrical and narrow band (-6.5 and 5.9 degrees) centered close to zero (at 0.3 degrees). The differences range from -8.2 to 7.9 degrees with the middle 50% falling between -2.8 and 2.1 degrees and thus a range of 4.9 degrees constituting 5.7% of the measurement range (85 degrees), again displaying satisfactory agreement. The 90th percentiles show a shift in the opposite direction from the 10th percentile where most of the differences lie between -7.4 and 11 degrees, centered at 2.0 degrees. The differences range from -15 to 20 degrees with the middle 50% between -1.4 and 5.0 degrees with a range of 6.4 degrees constituting 6.2% of the measurement range (104 degrees) with satisfactory agreement for use in the field by practitioners and researchers. One common departure present for both the 10th and 90th percentiles is a bias between the methods, hence a linear calibration to the inclinometer readings maybe needed; for example, 10th percentile posture = 4.2 + 0.94(VC). An additional problem relating to heteroscedasticity (Choudhary & Nagaraja, 2005) is seen with the 90th percentile exposures where the scatter of differences increases as the posture magnitude increases (right opening megaphone) (Choudhary & Nagaraja, 2005). A log transformation of this data may correct this problem, but would make data interpretation less straightforward (Bland & Altman, 1999).

2.4.3 Ability to predict 'gold standard' posture

In addition to quantifying agreement between measures, the ability of the inclinometers to accurately predict the rigid-link model is also of interest. For each exposure metric the inclinometers explained 96 to 97% of the variation in the rigid-link model method (R^2 from simple linear regression). In addition to predicting an outcome measure by developing regression models, a calibration constant can also be created to eliminate the bias found in the 10th and 90th percentile exposures. Adding 4.2 degrees to 10th percentile measures and subtracting 2.4 degrees from the 90th percentile measures should reduce this bias.

In order to account for within-participant correlations, 'participant' was added as a random effect to mixed regression models. The inclinometers continue to explain most of the variance (95 to

97%). In theory, the new intercept values are expected to reduce any bias in the measurements that may be found among individuals from our participant pool. However, the intercept for the 10th percentile did not change (4.2 degrees) from the simple linear model and the intercepts for the mean and 90th percentile were no longer significant (p's > 0.10). All slope values remained very close to 1 and were still significantly different from zero ($p < 0.0010$).

2.4.4 Summary and conclusion

In the present study, the VC inclinometers were evaluated against a rigid-link model motion capture system. Posture measurements by the two methods were highly correlated, with average differences between -4.4 and 2.0 degrees, and regression slopes near 1.

Based on these results VC inclinometers are likely to provide accurate posture measurements for use in epidemiological studies. Excellent agreement is achievable with corrections in small biases for 10th and 90th percentile measures by the inclinometers. Depending on the goals, work environments and target populations, VCs may also be suitable for lab or field studies. The advantages to using these inclinometers for posture measurement in large studies are its versatility, cost, size, data resolution (up to 15 measurements per second), data-logging capabilities, and measurement of additional risk factors (velocity and acceleration).

This thesis next looks at the option of using just the upper inclinometer in measuring trunk posture in Part 2: Is One Inclinometer Enough?

2.5 References

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3. COMPARISON OF METHODS TO MEASURE TRUNK POSTURE. PART 2: IS ONE VIRTUAL CORSET™ ENOUGH?[2]

3.1 Introduction

Back disorders continue to be of interest among occupational populations. Back injuries and low back pain are among the most frequent and disabling conditions among workers in British Columbia, Canada (WorkSafeBC, 2007). Vieira and Kumar (2004) found evidence in the literature that working postures and musculoskeletal health are related; thus, measuring postures in the workplace is worthy of considerable attention. To measure postures in the workplace, observational tools, goniometers, the lumbar motion monitor, inclinometers, and video analysis systems, are the most common measurement methods used. The choice of measurement methods will vary based on the tasks being assessed and the evaluation objectives. The ideal measurement method should be able to handle the demands of the work environment and worker tasks with valid and reliable assessments for a reasonable cost (Trask et al., 2007). However, many direct monitoring devices are complex, with extensive data generation, and may influence work tasks when utilized in the workplace. Most alternatives are subjective in nature and rely on self-reporting or trained observers, compromising precision and accuracy while at the same time requiring long periods of analysis (Vieira & Kumar, 2004).

In this chapter a comparison was made between measurements from a single torso mounted inclinometer and a video-graphic motion capture system (the gold standard) for measuring trunk posture. An inclinometer is historically known as a hand-held instrument with a gravity weighted pendulum in a fluid-filled disk (Williams, Binkley, Block, Goldsmith, & Minuk, 1993). Inclinometers have since evolved to contain pendulum, electrolytic or mercury-switch uniaxial transducers, each with their associated limitations (Hansson, Asterland, Holmer, & Skerfving, 2001). This study used a pager-sized, wireless, data-logging inclinometer device known as the Virtual Corset™ (VC). Unlike other inclinometers, the VC has the ability to capture dynamic motions. It records angular acceleration, and its data can be processed to measure velocity and posture with high sampling rates (choice of 7.5 or 15 Hz). When using inclinometers for trunk

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[2] A version of this chapter will be submitted for publication. Van Driel, R., Teschke, K., Callaghan, J., Koehoorn, M., Trask, C., Johnson, P. A Comparison of Methods to Measure Trunk Posture: A Motion Capture System versus a Single Virtual Corset ™

posture, it is best represented with the use of two inclinometers to isolate spinal movement (Williams *et al* 1993).

The double VC inclinometer system was assessed for measuring trunk posture in the first part of this thesis, and showed excellent agreement, when compared with a motion capture system (gold standard) using a rigid-link model. In this study, we used the same dataset to compare posture of the spine between the pelvis (S1) and the thorax (T5) as measured by the motion capture system and rigid-link model to postures measured using just a single sternum-mounted VC inclinometer. Postures measured by just the sternum-mounted VC inclinometer are not expected to agree as well as the double-VC inclinometer technique as motion from the lower VC is excluded; however, there may be potential for improvement by incorporating simple anthropometric measures in linear models to predict the gold standard posture measure. Using one inclinometer may be a favourable option for some researchers who do not have the budget or analysis time available to work with two inclinometers.

In general, inclinometers are a cheaper, easier, and less invasive alternative to use in the field while maintaining the objective posture quantification offered by a traditional motion capture system (gold standard). It is important to assess the agreement between any new method and traditional standards before it is put into practice (Choudhary & Nagaraja, 2005). Motion capture systems track surface markers (light-emitting diodes) placed over the skin to produce three-dimensional body kinematics and were used in this study as the reference method (gold standard) to test the accuracy of the inclinometer. The goal was to understand the extent to which the posture measurements from the two systems agree and the nature of their differences. With sufficient agreement the VC inclinometer may be used in place of other monitoring devices, especially in the field or for large epidemiological studies, as it has high value in terms of the price per successful sample (Trask et al., 2007).

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3.2.2 Data collection

Details of the data collection protocol used in the lab can be found in Appendix B.

Task description. Participants were asked to perform a prescribed set of lifting/lowering tasks modeled from the industrial tasks observed in a large study on back injuries in heavy industries (Trask, 2008). Tasks consisted of a combination of three lifting heights: 1) between ground level and shelving located at 0.67 m (approximating waist height), 2) ground level and shelving located at 1.2 m (approximating shoulder height) and 3) between 0.67 m (waist height) and 1.2 m (shoulder height) shelves. Four different loads were lifted each doubling in weight (0 kg, 4.5 kg, 9 kg and 18 kg) and three placement directions were evaluated (left, right and sagittally symmetric in the center). Each participant performed all possible lifting tasks separately in random order for a total of 36 different trials (3 heights x 4 loads x 3 directions), sample found in Appendix C. Within each trial participants were asked to continuously lift/lower the object (milk crate L 34.6 cm x W 34.6 cm x H 31.6 cm) three times at their own pace. They were free to lift in a manner that was most comfortable to them using both hands.

Motion capture system for posture measurement. Spinal kinematics were determined from four infrared light emitting diodes (IREDS) that were affixed on each corner of the upper chest plate and four IREDS affixed to the corners of the lower base plate on a Lumbar Motion Monitor (LMM) system as shown in Figure 3.1. Segment-based co-ordinate systems were determined from an upright standing calibration trial creating a rigid-link model. Segment displacement in three-dimensions was recorded at 30 Hz using an optoelectronic system (Optotrak Certus, Northern Digital Inc, Waterloo, Ontario, Canada). Raw marker co-ordinates were loaded into Visual3D^{TM} Motion Analysis Software (C-Motion, Inc., Ontario, Canada) for processing. Prior to angle calculations, all raw marker data was low-pass filtered (dual pass) with a Butterworth filter (10 Hz cut-off frequency) prior to being exported from the software.

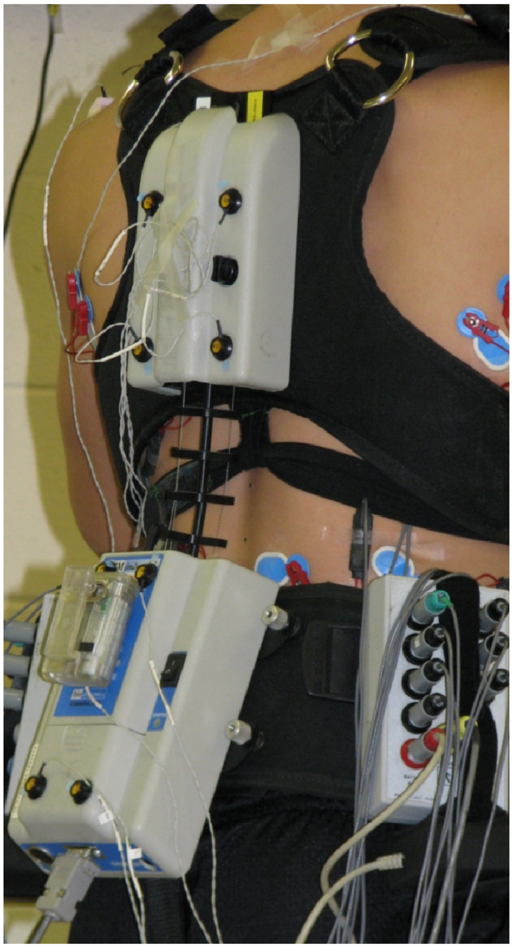

Figure 3.1 Photograph showing four IREDs on the upper and lower LMM plates.

Inclinometry system for posture measurement. One Virtual Corset™ inclinometer was used in this study. The VC is a wireless, battery-powered, pager-sized portable logger with 2 megabytes of built-in memory, weighing 72 grams and measuring 6.8 cm by 4.8 cm by 1.8 cm. There are two orthogonally positioned low pass filtered tri-axial accelerometers. These are linear accelerometers designed to calculate angles based on the acceleration due to the earth's gravitational field in sagittal and frontal planes only. This device sampled at a rate of 15 Hz and low-pass filtered with a high frequency cut-off of 10 Hz. While recording flexion/extension these inclinometers have a reported error of 1.8˚ (± 1.0˚) when used according to the manufacturers specifications (Johnson et al., 2002). The VC was placed over the sternum, using an elastic and Velcro "bra-like" harness with straps that wrapped over the shoulder and under the arm and around the upper torso (Johnson et al., 2002). Prior to launching the inclinometer it was set to the zero position while the subject was in a standing upright position. Following collection, data from the inclinometer was downloaded to a PC via Windows-based Virtual Corset control software (VC-323, Microstrain Inc, Williston, VT, USA) (Johnson et al., 2007). Although inclinometer data can also be used to estimate postural velocity and acceleration, only posture is presented in this paper.

Anthropometry. A total of 31 anthropometric measures (see Table 3.1) were collected from each participant at the end of the lifting sessions. Measurements were made using a large wooden sliding caliper for width and depth measures, a retractable centimeter measuring tape for segment lengths, and a 90 by 90 cm force plate (Model BP900900, Advanced Medical Technology Inc., Watertown, MA, USA) for body mass.

3.2.3 Data synchronization

Data from each collection method was analyzed in parallel after being synchronized into the same time domain through a 3-step process. This was done using two graphical interactive user interface programs developed in LABVIEW (Version 8.2; National Instruments; Austin, TX, USA). The first step was to synchronize the VC data with the output files from Visual3D™ of rigid-link model for each trial. Each trial started and ended with the participant with the trunk in a flexed position with hand support for approximately four seconds. Trials were easily identified within the inclinometer files by visually spotting the four-second bends at the start and end of each trial. The second step required the use of visual precision to identify the start and ending locations of each trial. Data index markers were placed at locations to include the duration associated with the beginning and ending of the lifting motion. The last step allowed for the rigid-link model to be parsed down from 30 Hz to 15 Hz to match the VC sampling rate. The output file from the LABVIEW software calculated various exposure metrics for each method. Although both the Motion Capture System and the VC have recorded data in sagittal and frontal planes, only sagittal data is presented here.

3.2.4 Data analysis

With the synchronous postural data from each device, the 10th percentile, mean and 90th percentile torso posture values were the three outcome measures calculated for each trial. The mean represents central tendency, while the 10th and 90th percentiles represent lower and higher degrees of inclination respectively, found within each lifting trial. Then the group means and standard deviation (SD) values were calculated over all 278 lifting trials for each measurement system.

3.2.5 Statistical analysis

The 10th percentile, mean and 90th percentile of the angular distributions of each lifting trial were used for characterizing posture measurements and methods comparison. Here, an established standard, the motion capture system (X_1), was used to evaluate the postural data collected with the sternum mounted VC (X_2). Using a Windows statistical software tool (SPSS 16.0, SPSS inc, Chicago, IL, USA), Pearson *r* correlation coefficients and paired-sample *t*-tests were performed as basic approaches to assess the strength of linear relationship and overall agreement respectively.

The Bland and Altman (1986) limits of agreement approach for assessing the agreement between two methods of measurement is widely used (Bland & Altman, 1992). It uses graphical techniques (scatter-plots) and bias calculations, and proposes calculation of 95% "limits of agreement" (LoA), as the mean difference between the methods ± 1.96 standard deviations (95%) of the differences. These limits are expected to contain the difference between measurements by the two methods for 95% of pairs (Bland & Altman, 2007). If insufficient agreement is found, a simple linear calibration of the new method ($X'_2 = a + bX_2$) could be used to account for the differences between X'_2 and X_1 (Choudhary & Nagaraja, 2005). In addition to these elements, mixed multiple regression models were used to account for within-subject correlation not accounted for by the simple relationship between the two measures (SAS version 9.1, SAS Institute Inc., Cary, NC USA). The procedure used to select which anthropometric variables offered into the mixed regression models as fixed effects is described in a five-step process in Table 3.1. The overall goal is to produce a model that can explain a high degree of variability in measured rigid-link model posture with a minimum number of terms. The estimated proportion of variance explained by each model was determined using the square of the correlation between the predicted exposure levels and the measured exposure levels by using PROC CORR in SAS.

Table 3.1 Anthropometric measures collected and offered into mixed model regressions.

Process Phase	Anthropometric Variables
Initial Set	1. Age 2. Subject height 3. Mass 4. Shoulder height 5. Elbow height 6. Lumbar length 7. Trunk depth at XP 8. Trunk width at XP 9. Trunk depth at IC 10. Trunk width at IC 11. Inter ASIS 12. Inter PSIS 13. Left AP distance 14. Right AP distance 15. Left upper leg length 16. Right upper leg length 17. Left lower leg length 18. Right lower leg length 19. Left upper arm length 20. Right upper arm length 21. Left lower arm length 22. Right lower arm length 23. Left knee width 24. Right knee width 25. Left ankle width 26. Right ankle width 27. Left foot width 28. Right foot width 29. Width between hands 30. Width between elbows 31. Width between shoulders
Step 1	All bilateral measures were condensed by calculating the average of the left and right sides. This reduced the number of variables above to 23.
Step 2	Two additional variables were created; BMI = mass/subject height^2 and waist height = lower leg length + upper leg length.
Step 3	Where anthropometric measures were found to have strong Pearson correlations ($r \geq 0.70$) with each other, only the variable in each pair that was the most common or easiest to measure was retained, leaving the following 10: 1. Age 2. Subject height 3. Trunk depth at IC 4. Inter ASIS 5. Average upper arm length 6. Average lower arm length 7. Average knee width 8. Average ankle width 9. Waist height 10. BMI
Step 4	Simple linear regressions for each of the remaining variables in Step 3 were done for the 10th percentile, mean and 90th percentile exposure metrics (with posture measured by the rigid-link model measure as the dependent variable). Only those variables that were consistently related to posture ($p \leq 0.05$) are shown below. 1. Age 2. Trunk depth at IC 3. Average lower arm length 4. Average ankle width 5. Waist height 6. BMI
Step 5	All of the variables remaining in Step 4 and posture as measured by the VC inclinometer were offered into a multiple regression. A manual backward stepwise procedure was applied to eliminate the variables with the least significance (highest p-value ≥ 0.10). The model was continuously refitted until all included variables had a p-value < 0.10. The only anthropometric measure remaining in each model was lower arm length.

XP = xyphoid process, IC = iliac crest, ASIS = anterior superior iliac spine, PSIS = posterior superior iliac spine, AP = anterior-posterior, BMI = body mass index

3.3 Results

Complete sets of paired posture data were successfully measured and processed on 278 individual lifting trials from eight subjects (10 trials were lost from X participants due to either data collection or processing errors). Descriptive statistics for the 10th percentile, mean, and 90th percentile posture metrics for each method are presented in Table 3.2.

Table 3.2 Descriptive statistics (in degrees) for rigid-link model and VC data (n = 278 trials). Positive values denote flexion, negative values denote extension

	Mean	*SD	Range	Min.	Max.
Rigid-link model 10th percentile	0.7	18	82	-35	47
VC 10th percentile	5.9	16	64	-15	49
Rigid-link model mean	16	18	80	-26	54
VC mean	29	18	70	-4.0	66
Rigid-link model 90th percentile	37	23	101	-19	82
VC 90th percentile	58	26	104	4.0	100

*SD = standard deviation.

For 10th percentile, mean, and 90th percentile exposure metrics, the rigid-link model and VC measured postures were moderately correlated with Pearson *r* values of 0.68, 0.65, and 0.65 respectively ($p \leq 0.01$).

The results of the paired-sample *t* tests conducted to compare the postures measured by the rigid-link model and the VC inclinometer for each exposure metric are presented in Table 3.3. The paired differences were significantly different for the 10th, mean and 90th percentile posture measures.

Table 3.3 Mean and standard error on torso posture measurement accuracy across 278 lifting trials using 8 subjects comparing the sternum mounted inclinometer posture measure (VC) and rigid-link model (RLM)

Difference between VC and RLM	Mean	Standard Error	T	df	p-value (2-tailed)
10th percentile	5.2	0.80	6.4	277	<0.0010
mean	13	0.90	14	277	<0.0010
90th percentile	22	1.2	17	277	<0.0010

df = degrees of freedom

Figure 3.2 shows the rigid-link model posture measures plotted against the inclinometer measures for the 10th percentile, mean and 90th percentile exposure metrics. The graphs also show the line of equality. For all three outcome measures a large portion of the data lies below the line showing that the torso-mounted VC method is likely to overestimates posture.

A plot of the differences between the methods against their mean may be more informative in examining agreement, also known as Bland and Altman plots. The following Bland and Altman plots include a dotted line indicating zero difference, solid lines indicating the mean, and calculated 95% limits of agreement (LoA). Points indicate the individual differences for each of the 278 trials. Figure 3.2 shows the results for the 10th percentile, mean and 90th percentile metrics. Both axes are shown on the same scale to show discrepancies in relation to the size of the measurements (Bland & Altman, 1999).

For 10th percentile postures, 95% of VC inclinometer readings were within 21 degrees below or 32 degrees above the rigid-link model posture method. For mean postures, 95% of VC inclinometer readings were within 16 degrees below or 42 degrees above the rigid-link model posture method. For 90th percentile postures, 95% of VC inclinometer readings were within 7.4 degrees below or 11 degrees above the rigid-link model posture method.

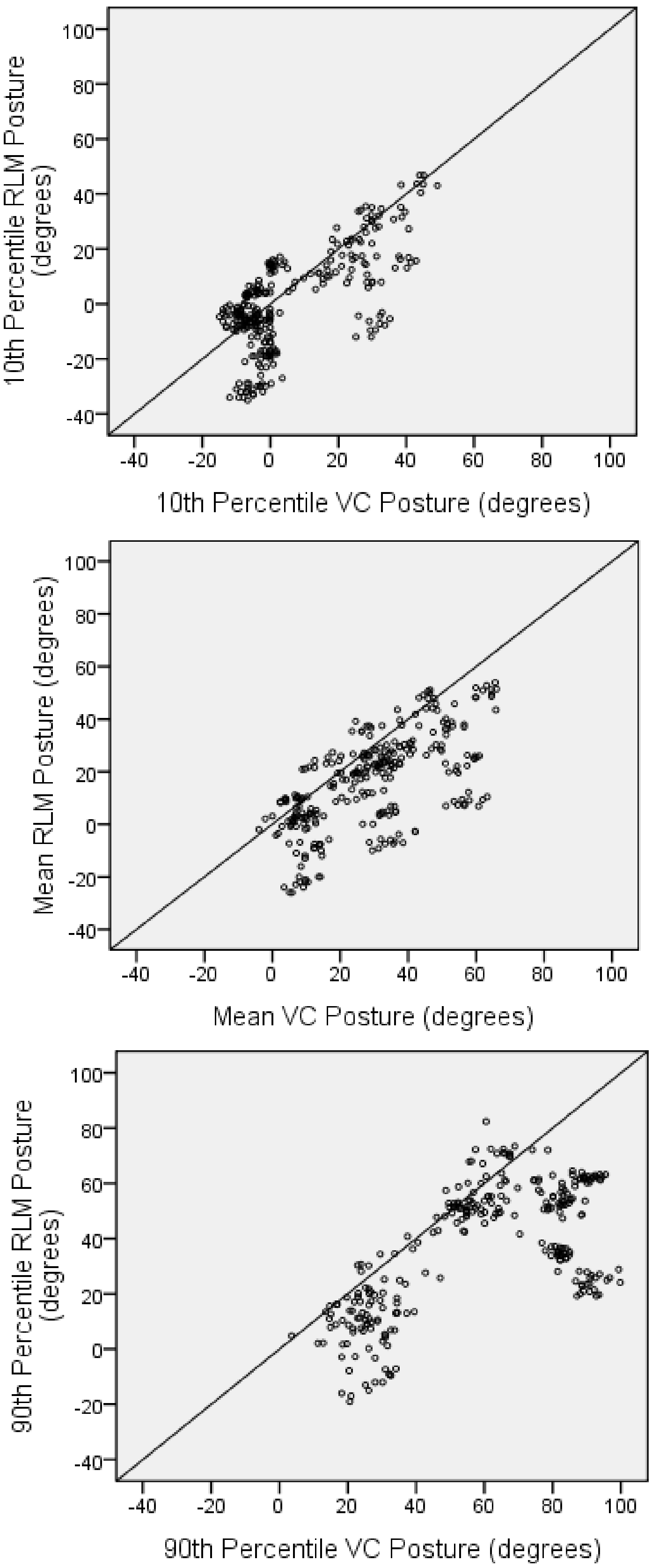

Figure 3.2 Posture measured by the rigid-link model method and by the VC inclinometer method for 10th percentile (top) mean (center) and 90th percentile (bottom) exposures with line of equality (n = 278 trials)

Simple linear regressions using the single VC inclinometer variable to predict rigid-link model posture measurements for each exposure metric are summarized in Table 3.4. For both the mean and 90th percentile postures, the VC inclinometer measurements explained 42% of the variance in the rigid-link model torso readings with intercepts not significantly different ($p < 0.05$) from zero: -2.9 and 3.6 degrees respectively. At the 10th percentile posture measurements, the VC inclinometer explained 47% of the variance in the rigid-link model torso readings, with a significant intercept of -3.7 degrees.

Table 3.4 Simple linear regression results of rigid-link model measures as predicted by the inclinometer for each exposure metric

	Intercept (p-value)	Slope (p-value)	*Percent of Variance Explained
10th percentile	-3.7 (<0.0010)	0.74 (<0.0010)	47%
Mean	-2.9 (0.064)	0.66 (<0.0010)	42%
90th percentile	3.6 (0.17)	0.57 (<0.0010)	42%

In each model the rigid-link model measure is the dependent variable and the inclinometer is the independent variable.

*Percent of the variance in the rigid-link model measurements accounted for by ΔVC inclinometer measurements

To control for within-participant correlation not accounted for by the inclinometer, 'participant' was incorporated in the regression model as a random effect term (see Table 3.5). The 10th percentile and mean results were similar to the simple linear regression results except that the 10th percentile intercept was no longer significant. However, the 90th percentile metric had a noticeable change in the intercept (down to -4.83 from 3.55 degrees) and slope (increased to 0.72 from 0.57).

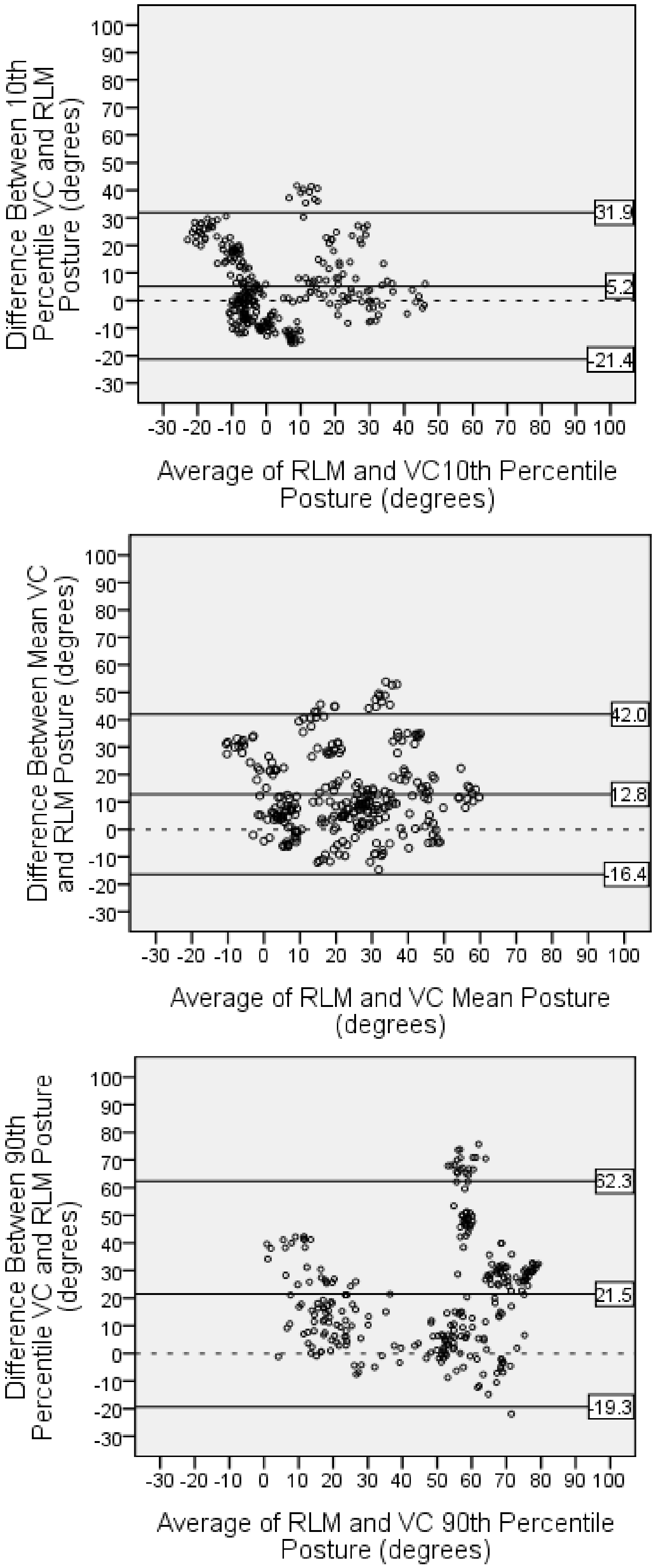

Figure 3.3 Bland and Altman plot for 10th percentile (top), mean (center), and 90th percentile (bottom) posture data with 95% LoA, mean difference, and the broken line at zero (n = 278 trials).

Table 3.5 Mixed linear model regression results of rigid-link model measures as predicted by the VC inclinometer for each exposure metric

	Intercept (p-value)	Slope (p-value)	*Percent of Variance Explained
10th percentile	-3.5 (0.49)	0.77 (<0.0010)	47%
Mean	-5.2 (0.35)	0.75 (<0.0010)	42%
90th percentile	-4.8 (0.48)	0.72 (<0.0010)	42%

In each model the rigid-link model measure is the dependent variable and the inclinometer is the fixed effect. These models include participant as a random effect and it was significant ($p < 0.05$) in all models

*Percent of the variance in the rigid-link model measurements accounted for by the inclinometer measurements

To improve the percent of variance explained in the mixed models, an additional variable (average lower arm length) was added as a fixed effect. For each exposure metric the percentage of variance explained increased by at least 31% (see Table 3.6).

Table 3.6 Mixed linear model regression results of rigid-link model measures as predicted by the VC inclinometer for each exposure metric

		Coefficient (p-value)	*Percent of Variance Explained
10th percentile	Intercept	-217(0.010)	79%
	Inclinometer	0.770(<0.0010)	
	Lower arm length	8.27(0.010)	
Mean	Intercept	-237(0.010)	78%
	Inclinometer	0.750(<0.0010)	
	Lower arm length	9.00(0.010)	
90th percentile	Intercept	-291(0.010)	73%
	Inclinometer	0.720(<0.0010)	
	Lower arm length	11.1(0.010)	

In each model the rigid-link model measure is the dependent variable, inclinometer and lower arm length are the fixed effects. These models include participant as a random effect and it was significant ($p < 0.05$) in all models

*Percent of the variance in the rigid-link model measurements accounted for by inclinometer measurements and lower arm length

3.4 Discussion

The tasks chosen for this study were intended to be representative of manual work found in heavy industries, such as forestry, transportation, warehousing and wood & paper products (Teschke et al., 2008). Although tasks were highly standardized to eliminate variability caused by actual task requirements, trials were always performed in random order and at a pace set by the participants to avoid fatigue. This study took place in the biomechanics spine lab at the University of Waterloo in Ontario, Canada. Thus, the pool of participants who volunteered for this study may not reflect that of the typical workforce with respect to age and physical health. A recent study of trunk posture in heavy industry reported a mean age of 42 years (Teschke et al., 2008) compared to a mean of 22 years in this study.

3.4.1 Relationship between methods

The results in this study showed that posture measurements recorded by the rigid-link model and a single inclinometer were moderately correlated with Pearson *r* correlations between 0.65 and 0.68 for 10th percentile, mean, and 90th percentile exposure metrics.

It can be seen in the paired-sample *t* test results that using a single inclinometer on the upper torso area consistently overestimated spinal posture and this increased at greater magnitudes as posture moved towards greater degrees of flexion. This was expected since with a single inclinometer, movements by the hips and pelvis are also being recorded as described by Williams *et al.* (1993). This was demonstrated as we see the mean difference, standard error and T value all increase as posture increases from 10th to mean to 90th percentiles. For example, mean differences between systems increases from 5.2 to 13 to 22 degrees respectively. Since hip and pelvis motion become more prominent with increasing flexion, a single inclinometer may be best suited for monitoring predominately upright tasks.

To further describe the relationship and agreement between these methods, additional investigation is required to ensure that what holds true *on average* is also true for individual observations. If the two methods are in perfect agreement, *all* of the paired measurements should lie on the line of equality (Choudhary & Nagaraja, 2005). Figure 3.1 emphasizes what was shown in the paired-sample *t* test by displaying majority of the data points below the line of equality, indicating overestimation by the inclinometer. Calculating the 95% LoA quantifies these differences.

3.4.2 Agreement between methods

The strength of the limits of agreement approach derives from its intuitive appeal and simplicity. The Bland and Altman plots with the 95% limit of agreement superimposed (Figure 3.3) complement the scatter plots, as they reveal features of departure (Choudhary & Nagaraja, 2005).

For each exposure metric, 10th, mean, and 90th percentiles, the LoA band is not centered at zero and is wide. This indicates a bias between methods with great variability and poor agreement. The LoA band with a single inclinometer is much greater than that with two inclinometers as reported previously in Chapter 2 of this thesis using a two-inclinometer method. Calibration of the inclinometer readings is needed to bring closer agreement between these methods. This was achieved by accounting for within-participant correlations and the addition of a single anthropometric measure.

3.4.3 Ability to predict 'gold standard' posture

The ability of a single inclinometer to accurately predict the rigid-link model was relatively weak (R^2 0.42 to 0.47) in simple linear regression compared to the use of two inclinometers with R^2 at 0.96 to 0.97 reported in Part 1. The addition of "participant" (random effect) in the mixed model regressions (Table 3.5) however did not improve the percent of variance explained.

The outcome of doing a manual backward stepwise regression to include anthropometric variables continuously favoured the inclusion of lower arm length measures. These multiple regression models (Table 3.6) drastically improved the percent of variance explained by as much as 36%. See Figure 3.4 for an example of rigid-link model mean exposure versus the predicted mean exposure using the resulting multiple regression model (predicted mean = -237 + 0.75(inclinometer) + 9.0(lower arm length)). This improvement can be seen visually when comparing Figure 3.4 with the center of Figure 3.2 showing a drastic change in symmetry about the line of equality. Thus the model that combines single inclinometer posture measurements and a simple anthropometric measure opens great avenues for epidemiologists and ergonomists alike in applying this method in research and field studies. Epidemiologists have successfully used exposure estimation methods based on predictive models with only 30 to 60% of the variance explained (Burstyn & Teschke, 1999). Thus the use of a single VC in a model with more than 70% of the variance explained should be sufficient for use. Researchers will benefit from a reduction in instrument cost, data collection time and analysis time required compared with the use of two VCs.

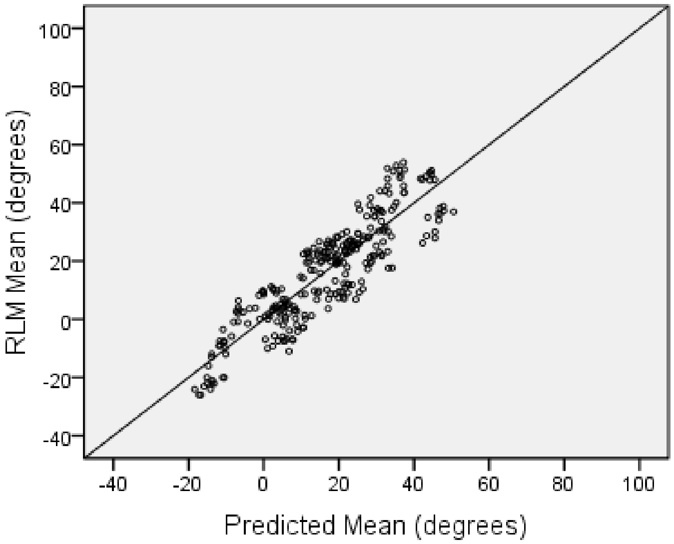

Figure 3.4 Posture measured by rigid-link model mean versus predicted mean based on model including posture measured by a single inclinometer and lower arm length, with line of equality

A limited number of participants were involved in this study (eight), and it is possible that the significance of lower arm length may not hold true for the general population or with an increased sample size. It is recommended for future work to involve more subjects selected from a population with greater variation in physical traits to further investigate the contribution of arm length in posture prediction. The relationship between lower arm length and trunk posture is in the opposite direction to what is biomechanically logical: longer arms result in increased trunk inclination. This suggests that lower arm length is not an appropriate anthropometric measure to improve the relationship between the single VC and the rigid link model. Given this, other anthropometric measures such as BMI, waist height, and trunk depth at the waist should be tried as alternate anthropometric measures to improve the relationship, before moving forward with representing posture using a single VC on a more diverse population.

Of the remaining five variables offered to the regression models (BMI, age, trunk depth at the IC, waist height, and ankle width) one would anticipate that other variables would have had greater significance in trunk posture than lower arm length; in particular BMI, trunk depth and waist height. The fact that waist height was not included suggests that participants may have put more effort into lifting with their knees rather than bending at the waist or stepped in with their bodies towards the shelving unit. BMI was expected to be of greater significance since it combines two anthropometric aspects, segment length (height) and body weight. For 10th percentile and mean postures BMI was the last variable removed; thus, it was close to the final model. A young fit and healthy adult male is unlikely to have larger trunk depth at the IC in proportion to their stature, such that the distance of the load from their spine would be restricted. Therefore it was not surprising that trunk depth was excluded in the final model. However, in a more diverse population with a greater number of individuals, BMI and trunk depth could potentially be of more significance.

3.4.4 Summary and conclusion

In the present study a single VC inclinometer was evaluated against a rigid-link model motion capture system. Posture measurements by the two methods were moderately correlated with poor agreement and only 42% to 47% of the variance was explained by the VC alone. 95% LoA bands were wide and shifted above zero for all exposure metrics. Mixed model regressions greatly improved the variance explained up to 79% with the addition of a simple anthropometric measure, lower arm length.

Based on these results, a single VC inclinometer placed on the upper torso combined with lower arm length measures has potential to provide satisfactory posture measurements for use in epidemiological studies. Depending on the goals, work environments and target populations, VCs may also be suitable for lab or field studies. The advantages to using these inclinometers for posture measurement in large studies are its versatility, cost, size, data resolution (up to 15 measurements per second), data-logging capabilities, and measurement of additional risk factors (velocity and acceleration).

3.5 References

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4. DISCUSSION

This thesis evaluated the comparison between the Virtual Corset^{TM} (VC) inclinometer and a commercially available optoelectronic motion capture system (Optotrak Certus) in measuring sagittal trunk posture. The first study examined the comparison using a two-inclinometer method and the second study addressed the question: is one inclinometer enough?

4.1 Summary of results: two versus one Virtual Corset^{TM}

The results of the first study showed that the double-VC inclinometer method can accurately measure trunk motion. Posture measurements by the rigid-link model and the double-VC method were highly correlated, with excellent agreement, and the VCs accounted for almost all of the variance in posture measurements by the motion capture system. Anthropometric data was available and considered for inclusion into the final predictive models. However, with the limited amount of variance left unexplained, it did not add much value and therefore was not included.

The results of the second study indicated that a single inclinometer on the upper torso combined with a simple anthropometric measure, lower arm length, may also be used for measuring trunk posture, though it is still not as accurate as using 2 VCs. Given that the best agreement with one VC is with 10th percentile postures, an option would be to use this data for analysis of posture classifications. This approach would be similar to that used in the large epidemiology study done on autoworkers by Punnett *et al.* (1991). Less than 20 degrees of bending in any direction was classified as neutral posture, 21-45 degrees as mild forward flexion, and >45 degrees as severe forward flexion (Punnett, Lawrence, Keyserling, Herrin, & Chaffin, 1991). The time spent in a neutral position may be examined rather than the time spent outside of neutral on a scale of 0% to 100%. However, there will still be some attenuation in accuracy in exchange for a reduction in data collection and analysis time, and savings on the purchase of VCs. This trade-off is one that needs to be recognized by the users before a decision is made for the application of this method based on their desired outcome.

This thesis has provided evidence that the double-VC method, and to a lesser extent the single-VC method, can accurately measure sagittal trunk posture and is a suitable method for application in lab studies, field studies, large epidemiological studies, workplace intervention studies, and occupational rehabilitation clinics. The VC inclinometer provides a means for characterizing posture using a direct measurement device without the expense and limitations of more complex motion capture systems or the time commitment and subjectivity of observational methods.

4.2 Strengths and limitations

4.2.1 Study population

The studies in this thesis were designed for the evaluation of estimating spinal compression in addition to trunk posture. Thus participant recruitment was restricted to one gender (males) and excluded any participants with a history of back or cardiovascular disorders. This was done to avoid variability in compression estimates since gender and history of low back pain are thought to affect spinal loading (Marras, Davis, Heaney, Maronitis, & Allread, 2000; Marras, Davis, & Jorgensen, 2002). Of the two genders, males were selected for this study as they continue to dominate the workplace in heavy industries (Teschke et al., 2008). Although there were advantages to selecting one gender, there is also the disadvantage of uncertainty about generalizing the posture results in this study to females. Data collection took place on campus at the University of Waterloo in Ontario, Canada; hence recruitment of a younger age range was inevitable and does not reflect that of the typical workforce (Teschke et al., 2008). However, the prediction models using anthropometric measures have the potential for improvement among the general population as greater variation in body size and shape may allow a greater proportion of variance to be explained. For convenience, this type of young, fit university population is common in many laboratory studies of simulated work tasks (Trask, 2008).

A total of 12 participants were recruited and participated in this study. Due to the complex nature of collecting data for three-dimensional electromyography (EMG) assisted biomechanical models for compression, the study budget and laborious data collection periods did not allow for a large study pool. In addition to the initially small sample, only the results from 8 participants were presented in this thesis, because the VC data for four subjects was faulty. This may have been as a result of three possibilities or a combination thereof: 1) the battery had died; 2) the VC malfunctioned or; 3) the VC did not launch as expected. Trask *et al* (2007) showed that this was not an isolated occurrence; however, when new VCs were used, as in our field study, there was greater success in data collection (89%). Allread *et al* (2000) showed that despite the amount of variability in industrial manual materials handling (MMH) tasks, no improvement in data accuracy of trunk kinematics was found with more than three employees and three repetitions of the same task. Their secondary analysis revealed that the nature and design of MMH tasks are much more variable than variability from employee-to-employee or trial-to-trial within tasks. This suggested that trunk motion is more of a function of task or workplace design than individual characteristics (Allread, Marras, & Burr, 2000).

4.2.2 Data collection and study design

To accurately assess back injury risk from workplace postures, posture determinations need to be reliable and valid (Lea & Gerhardt, 1995; Vieira & Kumar, 2004). The design of these studies allowed the validity of the double and single VC posture measurement methods to be examined. Validity establishes how well a method or device measures what it is intended to measure (accuracy) allowing for the ability of inferences to be made (Lea & Gerhardt, 1995; Vieira & Kumar, 2004). Validity requires reliability, but reliability does not ensure validity. Reliability indicates how well the methods or device is able to produce the same result under the same conditions (stability and consistency). The present study design did not include direct assessment of repeatability of the VCs. It is difficult to do this since there are variations in the way the same participant will perform the same task, by a change in work performance. The validity of the measurements using 2 VCs indicate that reliability must also be high.

By zeroing the VCs directly on the subject in their upright standing position, any error due to the alignment of the inclinometers to the body segment was removed. Yet, placing the upper chest VC in the same location for each participant was a challenge and may have introduced variability due to movement of the harness at the point where the VC is placed. The chest portion of the lumbar motion monitor (LMM) harness would frequently interfere with the harness of the VC. On some participants the upper VC would shift up as high as the jugular notch and on others it would remain on the sternum. This movement will affect the zero position of the VC. In addition, the infrared light emitting diodes (IREDs) were placed on the upper plate of the LMM which is on the back, and this did not allow for the upper VC on the chest to follow the exact same path as the IREDs. Despite this, there was still remarkable concordance between the two methods in the best test of the rigid-link model and the double-VC method, since this discrepancy was calibrated out.

Some may argue that radiography is the gold standard with which all other techniques of spinal posture measurement are to be compared; (Cupon & Warren, 2003; Loebl, 1967). However, radiographic techniques are expensive and pose a risk to health with repeated exposure to radiation; therefore, it is not recommended (Cupon & Warren, 2003). In 1995 Gracovetsky *et al.* found consistent patterns between radiographic and video analysis system measurements in sagittal and frontal planes, therefore we felt comfortable with the choice of the motion capture system as the gold standard in this study.

4.2.3 Data processing

Following the launch of each VC a distinctive manoeuver was performed with both VCs simultaneously so that they may be easily synchronized during the data processing phase. Unfortunately, each VC had a different frequency that drifted slightly from the selected 15 Hz sampling rate. These shifts were checked for visually in the LABVIEW graphical interface application and corrected during data processing. This complication introduced human error and doubled the processing time while visually compensating for the shift in frequencies repeatedly for each of the 36 trials for each participant. It is anticipated that signal drift occurrences will be corrected in newer models of the VC. Due to the difference in sampling rate between the motion capture system (30 Hz) and the VCs (15 Hz), some data resolution was lost as the rigid-link model was parsed down to 15 Hz to match the VCs.

An additional source of human error was introduced while synchronizing the VCs to the rigid-link model both in time and in zero position. In hind sight, it would have been ideal to have a quiet standing upright trial collected for both the VC and the rigid-link model simultaneously so that less error would be introduced when determining the offset applied to the VC data in order to match the rigid-link model position.

On a positive note; all of the data processing was done by the same trained individual several times prior to analysis of the final output results, allowing for consistency. All trial parameters were subsequently checked and double checked using a customized Visual Basic macro to ensure there were no inconsistencies in the final output results.

4.2.4 Data analysis

Before a new method is accepted and applied by practitioners or researchers it is typically evaluated by comparison with an established method or “the gold standard”. In many cases such studies inappropriately use only correlation coefficients or paired sample *t*-tests to examine validity (Bland & Altman, 1999; Bland & Altman, 2005; Bland & Altman, 2007; Choudhary & Nagaraja, 2005; Hansson, Asterland, Holmer, & Skerfving, 2001). In this thesis, the comparison of the two methods of posture measurement was assessed in great depth on multiple levels not typically found in the literature (Hansson et al., 2001; Marras, Fathallah, Miller, Davis, & Mirka, 1992; Mientjes, Norman, Wells, & McGill, 1999; Potvin, Norman, & McGill, 1996; Vieira & Kumar, 2004; Williams, Binkley, Block, Goldsmith, & Minuk, 1993). In addition to correlation coefficients and paired samples *t*-tests, graphical techniques were used, including scatter plots and plots of the difference between the methods against their mean. Limits of agreement were also calculated. Further statistical analysis involved simple linear regressions and mixed effects multiple linear regression models.

The draw-back with in-depth analysis is the added burden in examining many components. Although the VCs have the ability to also measure lateral flexion, velocity and acceleration in each direction, these were not covered in the comparison studies despite the abundance of evidence that three-dimensional dynamic motion in the work environment must be explored (Marras et al., 1992). However, considering that velocity and acceleration are computed by numerical differentiation of the posture data, velocity and acceleration accuracy will be dependent upon the ability of the VC to accurately measure posture. Therefore, the accuracy of posture was evaluated first, and with great accuracy when using two VCs, hence one can infer that velocity and acceleration data will most likely be accurate as well.

4.3 Future work and implications

Facilitating safe postures in the workplace is a way to better control workplace musculoskeletal disorders. Information about posture should be collected and analyzed in a systematic way in order to contribute to a deeper understanding of the relationship between working postures and musculoskeletal disorders (Vieira & Kumar, 2004). On the basis of the published literature, it is clear that inappropriate working postures produce harmful physical exposures that can cause musculoskeletal injury, pain, and kinematic disorders (Vieira & Kumar, 2004). Posture influences the strength that muscles are able to generate. Velocity and acceleration during trunk motion dramatically reduces muscle strength and increases muscle activity, thereby loading the spine with compressive and shear forces (Marras et al., 1992). Most occupational ergonomists consider postures that deviate from anatomically neutral to be physically stressful and should be minimized by correct job, tool and workstation design (Punnett et al., 1991). The ability to study working postures provides a means for ergonomists to establish guidelines for safe work, contributing to better musculoskeletal health at work by reducing biomechanical hazards.

Although postural magnitude is an important risk factor associated with workplace musculoskeletal disorders, other factors such as force, repetition, and duration are also important. In the real world of work tasks, the interaction of these different risk factors always exists and they cannot be assessed independently of one another (Li & Buckle, 1999). The features of the VC allow simultaneous measurement of repetition and duration of postures. High speed motions can be accurately assessed with the VC by selecting the higher sampling rate of 15 Hz. The VC's primary drawback for use in a three-dimensional world is the use of just two orthogonal accelerometers, which disregards motion in the third degree of freedom (twist/rotation). The accelerometers provide a secondary drawback to the VC device as they measure angles relative to the line of gravity. Dynamic acceleration can cause deviation from the line of gravity; hence, angular error is introduced during movements that are not constant in speed and direction (Hansson et al., 2001).

The VC device is not so sophisticated that only researchers or well-trained analysts can use it. It is quick and easy to use, user friendly, and can accommodate complex tasks without unnecessary data collection. Practitioners can use this device as an exposure assessment tool to determine if an ergonomic intervention is necessary for the job and to test whether the intervention was effective. Researchers, on the other hand, may be more interested in detailed information and can use the VCs in such a manner. The VC has the potential to meet requirements for each user group making it a device that can be widely applied (Li & Buckle, 1999). Another face to understanding work postures is in the improvement of rehabilitation programs for injured workers, by the design of treatment programs specific to the demands of each worker's job. Thus, areas for future research include studying assessments of working postures for injured workers to improve their rehabilitation (Vieira & Kumar, 2004). The VC could be used for the development of patient profiles for range-of-motion, velocity, and acceleration capabilities as an indication of the extent of injury and to document when a worker is ready to return to work.

The VC can provide several types of valuable information (sagittal angle measurement, lateral angle measurement, velocity and acceleration) for assessment of the workplace. When detailed posture information is used along with load moment information, a quantitative biomechanical assessment of the workplace is possible (Marras et al., 1992). When the dynamic position and motion of the trunk and load moments are known, one could predict the compressive and shear forces acting upon the spine during a work task. The data collected for this thesis will allow for such compression estimates to be evaluated with an EMG-assisted rigid-link biomechanical model in comparison to VC estimated compression. It is anticipated that VC-estimated compression will be adequately predicted as literature has shown that a large proportion of spinal compression is directly related to trunk flexion (Hoozemans, Kingma, de Vries, & van Dieen, 2006; Potvin, McGill, & Norman, 1991; Schultz & Andersson, 1981; Callaghan, Jackson, Albert, Andrews, & Potvin, 2003).

In future research, the VC method of estimating compression will be used with previously collected VC data from a study of back injuries of heavy industry conducted by the University of British Columbia. In a preliminary comparison between VC estimated compression and EMG estimated compression, the VC predictions overestimated EMG-based compression (Van Driel et al., 2007). The VC predicted compression was based on a single VC (upper only) which was demonstrated in this thesis to overestimate posture without adjustment for lower arm length. Hence, it is likely that compression then would also be overestimated. It would be interesting to incorporate lower arm length (derived from worker height) and perhaps BMI and repeat the comparison analysis. It is expected that BMI will play a greater role among the diverse individuals found in the industrial population than those recruited in this study.

In the heavy industry study, the VC was demonstrated to be a reliable device in many workplace conditions in the field without interference of work tasks or gear (Trask et al., 2007). Perhaps one of the greatest benefits of the VC is that it provides not only an accurate but inexpensive means of monitoring trunk motion in the workplace. Three-dimensional motion capture systems can cost over $100,000, whereas the VC is under $1,000 with minimal operating costs. With extensive data collection options, including full-shift measurement, it is expected that the VC will eventually facilitate making workplaces safer and minimizing the risk of workplace musculoskeletal disorders.

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APPENDIX A: Consent Form and UBC Ethics Certificate

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INFORMED CONSENT FORM/LETTER

Evaluating the Inclinometer as a Novel Approach to Estimate Spinal Compression for Epidemiological and Occupational Field Studies of Back Injuries

PRINCIPAL INVESTIGATORS:
Dr. Mieke Koehoorn, Department of Health Care and Epidemiology, University of British Columbia. (604) 822-5756
Dr. Kay Teschke, School of Occupational and Environmental Hygiene, University of British Columbia. (604) 822-5756
Dr. Jack Callaghan, Faculty of Applied Health Science, University of Waterloo. (519) 888-4567 x 37080

CO-INVESTIGATORS:
Dr. Peter Johnson, Environmental and Occupational Health Sciences, University of Washington. (206) 221-5240
Ms. Judy Village, School of Occupational and Environmental Hygiene, University of British Columbia. (604) 929-7243
Ms. Catherine Trask, School of Occupational and Environmental Hygiene, University of British Columbia. (604) 827-5791

STUDY COORDINATOR: *Mrs. Robin Van Driel*, Graduate student at the School of Occupational and Environmental Hygiene, University of British Columbia. (604) 822-0039. This study will be included as a part of her thesis

SPONSOR: WorkSafeBC Research Secretariat

WHAT IS A CONSENT FORM?
We are asking you to be in a research study. The purpose of this consent form is to give you information to help you decide whether or not to participate. You may ask questions about what we will ask you to do, the risks, the benefits, your rights, or anything else about the research or this form that is not clear. When all of your questions have been answered, you can decide if you want to

be in this study or not. This process is called "informed consent." We will give you a copy of this form for your records.

IS MY PARTICIPATION VOLUNTARY?

Yes. It is up to you to decide if you want to take part in this study. Before you decide, it is important for you to understand what the research involves. This consent form will tell you about the study and why the research is being done. Also, what you will undergo during the study and the possible benefits, risks and discomforts.

If you wish to participate, you will be asked to sign this form. If you do decide to take part in this study, you are still free to leave at any time without penalty or loss of benefits to which you are otherwise entitled. If you do not wish to participate, you do not have to provide any reason for your decision not to participate. To indicate this to the investigators say, "I no longer wish to participate in this study". Please take time to read the following information carefully before you decide.

WHAT IS THE PURPOSE OF THIS STUDY?

Despite a large volume of research investigating the relationship between industrial force and motion exposure and spine injury, little progress has been made in reducing the occurrence of reported injuries. The most sophisticated techniques of force estimation (EMG assisted spine models) have such high demands for instrumentation that they cannot be employed directly in industry. This study will investigate the use of a posture measurement device (Virtual Corset™) to estimate spinal compression compared to two other known methods. Spinal compression is the force that squeezes the bones in our spine and is recognized as a risk factor for back injury. The Virtual Corset™ is a simple and easy-to-use device. Our aim is to collect data on spinal compression using this device in order to evaluate it as a data collection method for use in future workplace risk assessments and back study research. It has the potential to be used on a large scale without relying on complex or less accurate measurements of physical demands.
You have been invited to participate because you are a healthy male with no previous history of back injury.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?

By participating in this study, you will have the opportunity to gain or further your knowledge and understanding of experimental procedures and theories in human biomechanics research.

The information obtained from this research may aid in the understanding, management, and prevention of work-related low back disorders. This is done by being able to test the Virtual Corset™ as a device to eventually be more useful in field studies than current measures.

WHAT ARE THE STUDY PROCEDURES AND REQUIRED TIME COMMITMENT?

As a participant in this research study, you will be asked to perform several repetitive lifting and lowering tasks; therefore, we ask that only those with no history of previous back injury to participate. The testing session should take approximately 3 hours of your time (including orientation and preparation). The data collection procedures are as follows:

Instrumentation

Upon your arrival to the lab the skin overlying your lower back muscles, the erector spinae and internal obliques, will be shaved and cleansed by the researcher so that surface EMG electrodes can be attached (with tape) over the shaved areas. Trunk muscle EMG will be collected throughout all of the procedures using a Bortec system. The specific locations are:

1. Left and right erector spinae (lower back muscles)
2. Left and right internal oblique (lower back muscles)
3. Left and right external oblique (abdominal muscles)
4. Left and right rectus abdominus (abdominal muscles)
5. Left and right latissimus dorsi (upper back muscles)

A pager sized device known as the Virtual Corset™ will be mounted over your chest and lower spine and will be used to monitor spine movement throughout lifting and bending tasks. The Virtual Corset will be affixed using an elastic and Velcro "bra-like" harness with straps that wrap over the shoulder and under the arm and around the upper torso. The mounting position of the Virtual Corset will be centered directly over the sternum, approximately at the level of the 4th sternocostal joint.

The Virtual Corset™ is 67mm long, 50mm wide, 20mm thick and weighs 2 ounces.

With your permission, your body will be videotaped (from the right side) during lifting/lowering tasks to track movement and to verify the results of other data collected. However, your face will be blurred to protect your privacy during analysis.

After these tasks anthropometric (body shape) information will be collected. This includes measures of your height, weight, and trunk depth and width. These measures will be made using a measuring tape, force plate, and calipers.

Procedures

The physical components of the repetitive lifting/lowering tasks that you will be asked to perform differ in the location of the start and end points (as described below), the direction of the lift (in front of your body, to the right or to the left), and the loads to be lifted are 0, 4.5, 9 and 18 kg. The pace of each lift and the total duration of all lifts will be up to you, all we ask is that you let us know if you begin to feel fatigue (feeling of tiredness or muscle discomfort), so we can allow for adequate rest. The physical components of the lifting/lowering tasks will be demonstrated to you by the researchers to ensure that you will perform the lifts in a safe manner. The mass and frequency of lifts was chosen based on previous lifting studies, and is safe based on biomechanical, physiological, and psychophysical studies.

The differences between the lifting/lowering tasks are described as follows.

Lift/lower location: The start and end points of the lift will vary between three locations. These are floor height, waist height and shoulder height.

Mass: The four different mass categories to be lifted/lowered will be 0, 4.5, 9 and 18 kg.

Each participant will be asked to lift and lower each of the 4 weights (0, 4.5, 9 and 18 kg) to each of floor, waist and shoulder height. Each lift and lower step with each weight will be done in front of the body, and to the right and left sides of the body repeated three times.

WHAT ARE THE RISKS OR DISCOMFORTS?

The tasks that you will perform are encountered during every day work/living conditions. The devices that you wear may feel a little uncomfortable because you are not used to them.

Having our research staff observe and videotape you while you perform tasks in a laboratory setting may make you feel uncomfortable. All our research staff have signed affidavits that they will not reveal any information about you or your results.

One of the risks is that information about you from the study will be released. No system for protecting your confidentiality can be completely secure. Because we will keep your name, address, and telephone number in one locked cabinet, the photos in another locked cabinet, and both separate from the other study data, this risk is very small.

If you have sensitive skin, you may feel some irritation from the gel or adhesive material used to secure devices. To minimize the chance of irritation we will clean the skin with isopropyl alcohol and scent-free lotion can be applied. This is similar to the irritation that may be caused by a bandage and typically fades within 2-3 days.

There is always a risk of developing discomfort or soreness in the low back and/or thigh muscles while (or after) performing a repetitive lifting task. The soreness may last for a couple of days if you are not accustomed to this type of work. If the soreness persists for more than 3 days, please contact Dr. Jack P. Callaghan (contact information provided above).

The portable parts of the electrical recording systems are battery operated and isolate you from the main recording lines. There is no risk of electrical shock.

You will be instructed to monitor your level of discomfort and fatigue and will be recorded following every set of nine lifting repetitions throughout the session according to a Likert scale of 1 to 10.

WHO WILL HAVE ACCESS TO THE DATA?

All the measurements will be assigned an alphanumeric identification code, not your name. We will keep a record of the code we assign to you. We will not release that record to anyone else. Only the investigators and the research assistants associated with this study will have access to information about you. Study information identifying you will not be revealed to any individuals or organizations. Your name will not be used in any published reports about this study. All data will be stored indefinitely without identifying information on computer hard drives (password protected) and/or digital storage media (locked in Dr. Callaghan's filing cabinet). A separate consent will be requested in order to use the video recordings for teaching, for scientific presentations, or in publications of this work.

REMUNERATION

As an expression of our gratitude for your participation, you will receive $25 dollars.

MEDICAL SCREENING AND SUITABILITY FOR PARTICIPATION

This questionnaire asks some questions about your health status. This information is used to guide us with your entry into the study. Due to the physical demands of this protocol, individuals with any history or recent symptoms of low back or cardio-respiratory disorders will not permitted to participate.

WHO CAN I CALL?

If you have any questions about this study, please call one of the principal investigators or the research coordinator on the front page of this consent form. If you have additional questions at a later date, please contact Dr. Jack Callaghan at (519) 888-4567 ext. 37080 or by e-mail at callagha@uwaterloo.ca

We would like to assure you that this study has been reviewed by, and received ethics clearance through, the University of Waterloo's Office of Research Ethics (ORE) and the Office of Research Services at the University of British Columbai. However, the final decision about participation is yours. In the event you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes (Director ORE) at (519) 888-4567 ext. 36005 or the Office of Research Services at the University of British Columbia at 604 822-8598.

Sincerely Yours,

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vandriel@interchange.ubc.ca

Dr. Jack Callaghan
(519) 888-4567 ext. 37080
callagha@uwaterloo.ca

CONSENT TO PARTICIPATE:

I have read the information presented in the information letter about a study being conducted by *Robin Van Driel* (Student Investigator) from the School of Environmental Health at the University of British Columbia and *Dr. Jack Callaghan* (Faculty Investigator) of the Department of Kinesiology at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that I may withdraw from the study without penalty at any time by advising the researchers of this decision.

This project has been reviewed by, and received ethics clearance through, the University of Waterloo's Office of Research Ethics (ORE) and the Office of Research Services at the University of British Columbia. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Dr. Susan Sykes (Director, ORE) at (519) 888-4567 ext. 36005 or the Office of Research Services at the University of British Columbia at 604 822-8598.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

Participant's Name (Please Print): ______________________________________

Participant's Signature: ____

Dated at Waterloo, ON: ____

Witnessed: ____

CONSENT FOR VIDEOTAPING OF PARTICIPANT:

As a participant in this study, I agree to being videotaped for the purpose of tracking my movement as well as a means of verifying results from other data collected. My facial features will be blurred to ensure confidentiality. I am aware that I may withdraw this consent at any time without penalty, and the videotape will be erased.

I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Dr. Susan Sykes (Director, Office of Research Ethics) at (519) 888-4567 ext. 36005 or the Office of Research Services at the University of British Columbia at 604 822-8598.

Participant's Name (Please Print): ____

Participant's Signature: ____

Dated at Waterloo, ON: ____

Witnessed: ____

CONSENT TO USE VIDEO AND/OR PHOTOGRAPHES IN TEACHING, PRESENTATION, AND/OR PUBLICATIONS:

Sometimes a certain part of a videotape clearly demonstrates a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific presentation or in a publication.
I agree to allow video recordings in which I appear to be used in teaching, scientific presentations and/or publications with the understanding that I will not be identified by name. I am aware that I may withdraw this consent at any time without penalty, and the videotape will be erased.
I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Dr. Susan Sykes (Director, Office of Research Ethics) at (519) 888-4567 ext. 36005 or the Office of Research Services at the University of British Columbia at 604 822-8598.

Participant's Name (Please Print): ______________________________________

Participant's Signature: ____

Dated at Waterloo, ON: ____

Witnessed: ____

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - FULL BOARD

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
Mieke W. Koehoorn	UBC/Medicine, Faculty of/Health Care & Epidemiology	H07-01384

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
University of Waterloo, Faculty of Applied Health Sciences, Department of Kinesiology, Ontario, Canada

CO-INVESTIGATOR(S):
Catherine Trask
Kay Teschke
Judy Village

SPONSORING AGENCIES:
Workers' Compensation Board of British Columbia

PROJECT TITLE:
Title: Evaluating the Inclinometer as a Novel Approach to Estimate Spinal Compression for Epidemiological and Occupational Field Studies of Back Injuries

REB MEETING DATE:	CERTIFICATE EXPIRY DATE:
August 9, 2007	**August 9, 2008**

DOCUMENTS INCLUDED IN THIS APPROVAL:	DATE APPROVED:
	August 22, 2007

Document Name	Version	Date
Protocol:		
VC vs EMG Research Proposal	N/A	February 1, 2007
Consent Forms:		
Back Study Consent Form	N/A	July 23, 2007

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board
and signed electronically by one of the following:

APPENDIX B: Data Collection Sheet

Date:_________________________

Researcher:____________________

Time:_________________________ AM PM

Participant Code:________________

Prior to participant arrival:

Turn on all equipment in the morning, allowing time for amps to warm up.
Calibrate collection volume using appropriate cubic reference (60 seconds for reg, 5 for align)
Digitize force plate corners 1. +x, +y 2. –x, +y 3. –x,-y 4. +x,-y
Turn on LMM Suppression
Perform shunt cal for force plate_________________________

Upon participant arrival:

Brief participant about ICL, ensure they have read and signed two copies:

Prepare participant for EMG and place over trunk muscle locations (test for recording)*****EMG should be in ODAU2**

1. Right Rectus Abdominus
2. Right External Oblique
3. Right Internal Oblique (posterior)
4. Right L3
5. Right Lat
6. Left Rectus Abdominus
7. Left External Oblique
8. Left Internal Oblique (posterior)
9. Left L3
10. Left Lat

11. Right Internal Oblique (anterior)
12. Right T9
13. Left Internal Oblique (anterior)
14. Left T9

Collect MVC and Rest Trials (collecting ODAU data as raw voltages):
***All EMG to be collected at 2100 Hz

Back Extension: ______________________ (30 seconds)
Abdominal Exertion: __________________ (30 seconds)
Right Lat Pulldown: ___________________ (30 seconds)
Left Lat Pulldown: ____________________ (30 seconds)
Back Rest: _______________________(5 seconds)
Abs Rest: ________________________(5 seconds)

***If you need to recollect an MVC, write over the corresponding trial file, do not add additional

Collect Reference Contractions Trials (collecting ODAU data as raw voltages):
***All EMG to be collected at 2100 Hz

Standing upright without weight: ______________________ (10 seconds)
Forward flexion 45° without weight: __________________ (5 seconds x 2)
Forward flexion 45° without weight: __________________ (5 seconds x 2)
Forward flexion 45° with 25lbs: ___________________ (5 seconds x 2)
Forward flexion 45° with 25lbs: ___________________ (5 seconds x 2)
Forward flexion 60° with 25lbs: ____________________ (5 seconds x 2)
Forward flexion 60° with 25lbs: ____________________ (5 seconds x 2)

Mount VC chest harness

Mount LMM

Place shoulder and pelvic harnesses on participant
Size the LMM ______________________
Place the LMM on participant

Perform upright stand trial for LMM Bias (Collect at 2100 Hz)
____

Ensure force plate has been zeroed***must be plugged into **ODAU1**

Place markers on participant (Calibration markers are in bold)

Strober 1, Right Strober – CALIBRATION SETUP

1. Right 1st Metatarsal
2. Right 5th Metatarsal
3. Right Dorsum
4. Right Heel
5. **Right Medial Ankle**
6. **Right Lateral Ankle**
7. Upper Left Right Shank RB
8. Upper Right Right Shank RB
9. Lower Left Right Shank RB
10. Lower Right Right Shank RB
11. **Right Medial Knee**
12. **Right Lateral Knee**
13. Upper Left Right Thigh RB
14. Upper Right Right Thigh RB
15. Lower Left Right Thigh RB

16. Lower Right Right Thigh RB
17. **Right Greater Trochanter**
18. **Right Iliac Crest**
19. Upper Left Pelvic RB
20. Upper Right Pelvic RB
21. Lower Left Pelvic RB
22. Lower Right Pelvic RB
23.
24.

Strober 2, Left Strober – CALIBRATION SETUP

1. Left 1st Metatarsal (23)
2. Left 5th Metatarsal (24)
3. Left Dorsum (25)
4. Left Heel (26)
5. **Left Medial Ankle (27)**
6. **Left Lateral Ankle (28)**
7. Upper Left Left Shank RB (29)
8. Upper Right Left Shank RB (30)
9. Lower Left Left Shank RB (31)
10. Lower Right Left Shank RB (32)
11. **Left Medial Knee (33)**
12. **Left Lateral Knee (34)**
13. Upper Left Left Thigh RB (35)
14. Upper Right Left Thigh RB (36)
15. Lower Left Left Thigh RB (37)
16. Lower Right Left Thigh RB (38)
17. **Left Greater Trochanter (39)**
18. **Left Iliac Crest (40)**
19. Upper Left Trunk RB (41)
20. Upper Right Trunk RB (42)
21. Lower Left Trunk RB (43)
22. Lower Right Trunk RB (44)
23. Right Acromion (45)
24. Left Acromion (46)

Collect an upright standing trial (Collect Marker data at 30 Hz)
Stand trial__________________ (5 seconds)

Launch, sync, and place both VC's on subject (one in chest harness, second on bottom LMM base)

Collect the appropriate trials as per participant designation

**Include supported forward bend held for ~3-5 seconds before and after each lifting cycle

Collect the following:

Sagittal calibration trial (Light)___________________________
Sagittal calibration trial (Heavy)__________________________

One handed lift (right low to waist)__________________
One handed lift (left low to waist)___________________

Collect LMM in case_____________________________

Record the following anthropometric measures

Birth date:__________________________

Height:__________________________

Mass (kg):_________________________ (can get from FP standing trial)

Shoulder height (cm) ____________________

Elbow height (cm) ____________________

Lumbar length (cm) ____________________

Trunk depth at Xiphoid Process:______________________

Trunk width at Xiphoid Process:______________________

Trunk depth at Iliac Crest:___________________________

Trunk width at Iliac Crest:___________________________

Inter ASIS distance:________________________________

Inter PSIS distance:________________________________

Bilateral AP distance (asis to GT marker): Left_________ Right___________

Bilateral upper leg length: Left__________ Right__________

Bilateral lower leg length: Left__________ Right__________

Bilateral upper arm length: Left__________ Right__________

Bilateral lower arm length: Left__________ Right__________

Width of Knees: Left____________ Right______________

Width of Ankles: Left___________ Right______________

Width of Foot (1st-5th Metatarsal): Left____________ Right____________

Width between hands__________________ elbows______________________
shoulders__________________

Subject to sign Remuneration receipt and get $25 cash

APPENDIX C: Sample Lifting Order

Load	Height	Direction	Trial Name
9	Floor-waist	center	
4.5	Floor-waist	right	
0	Floor-shoulder	center	
9	Floor-shoulder	center	
18	Floor-shoulder	right	
18	waist-shoulder	left	
4.5	waist-shoulder	right	
4.5	waist-shoulder	center	
18	Floor-waist	right	
4.5	Floor-shoulder	left	
9	waist-shoulder	center	
0	Floor-waist	right	
4.5	waist-shoulder	left	
9	Floor-waist	right	
9	Floor-shoulder	right	
18	Floor-waist	center	
0	Floor-waist	center	
9	Floor-waist	left	
0	Floor-waist	left	
18	waist-shoulder	right	
4.5	Floor-shoulder	right	
0	waist-shoulder	center	
0	waist-shoulder	right	
4.5	Floor-waist	center	
0	waist-shoulder	left	
4.5	Floor-shoulder	center	
0	Floor-shoulder	left	
9	waist-shoulder	right	
9	Floor-shoulder	left	
4.5	Floor-waist	left	
9	waist-shoulder	left	
18	Floor-waist	left	
0	Floor-shoulder	right	
18	Floor-shoulder	center	
18	waist-shoulder	center	
18	Floor-shoulder	left	