The Effects of Sagittal Plane Postures on Trunk Rotation Range of Motion

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Confidential Material

All confidential material, including the screening questionnaire, the written consent forms and the raw data (in DVD format) will be stored in a secure cabinet in the AUT University Health and Rehabilitation Research Centre (HRRC) for a period of six years after which time it will be destroyed.

Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Candidate: ______________________ Date: 21st August 2008

Abstract

Axial rotation is regarded as an essential movement of the trunk that allows many individuals to participate in vocations, sports and activities of daily living. Unfortunately when the destabilising nature of rotation is combined with that of spinal flexion, the risk of injuring the spine can increase significantly. Few studies have investigated the potential benefits that maximizing trunk rotation has in certain vocation and sport-related arenas and none have looked at whether adopting certain spinal postures in the sagittal plane can maximise trunk rotation more than others. The aim of the study was to determine the effects of alterations of trunk inclination, spinal posture, pelvic fixation and turning direction on the active range of motion (ROM) of trunk rotation.

Twenty healthy individuals participated in the main study. Retro-reflective markers were placed on key anatomical locations and used to track the movement of the thorax and pelvis during a series of repeated maximal trunk rotations in ten different spinal positions within the sagittal plane. Trunk kinematics and kinetics were recorded simultaneously using an optoelectronic motion analysis and force platform measuring system. A repeated-measures multiple analysis of variance (MANOVA) was used to test for the main effects of trunk inclination, spinal posture, fixation of pelvis and direction of turn on maximum active ROM of trunk rotation, maximum pelvic rotation and the anterior-posterior and lateral displacement of the centre of pressure (COP). To investigate test-retest reliability, ten participants were tested on two separate days. Repeatability for each outcome measure was investigated using interclass correlation coefficients (ICC) and Bland Altman graphs.

The majority of subjects showed reasonable test-retest reliability for trunk rotation measures in each of the test positions, with ICC's ranging between 0.562 – 0.731. Overall, trunk inclination (0°, 22.5°, 45°) forward in the sagittal plane had a significant effect on trunk and pelvic rotation ($p<0.001$) and lateral displacement of the COP ($p<0.005$) during trunk rotation. As trunk inclination increased from 0° to 45° there was an average increase in trunk rotation ROM of approximately 10 % (approximately 3.4°). Furthermore, increasing trunk inclination led to an increase in lateral displacement of the COP and a decrease in pelvic rotation. Spinal posture (neutral, flexed, extended) at a forward inclination of 45° had a significant effect on trunk rotation ($p<0.01$) and pelvic rotation ($p<0.05$), with a neutral spine averaging approximately 3 % (approximately 1.1°) more trunk rotation than a flexed or extended posture.

The position and posture of the spine in the sagittal plane appears to have a significant influence on ranges of trunk rotation. The study suggests that rotating the trunk when adopting a neutral spine inclined to 45° will maximise range of trunk rotation and encourage a natural stabilisation of the lower body. This posture meets the unique set of biomechanical requirements for the sport of golf and may help to reduce the risk of injury in manual material handling tasks. Conversely, rotating the trunk whilst the thoracolumbar spine is flexed leads to a reduction in trunk rotation ROM, encourages greater pelvic and lower body rotation, reduces torque production of the trunk and may increase the risk of lower back injury. These findings have important implications in relation to the teaching of spinal position during vocations, sports and activities of daily living that seek to maximise trunk rotation.

CHAPTER ONE

Introduction

1.1. Introduction

The trunk or torso, defined as the human body without the head, neck or the limbs (Collins, 1995), plays an integral role in human movement. It is capable of generating movements in the sagittal (flexion/extension), coronal (lateral flexion) and transverse (rotation) planes, movements that allow us to actively participate in our external physical environment. Axial rotation within the trunk is an essential component in many movement tasks, allowing individuals to achieve activities of daily living with efficiencies not afforded to those who lack these primary movements of the spinal column. Without trunk rotation, activities can become inefficient, as can be seen with gait, where elimination of trunk rotation has been shown to cause a significant decrease in locomotor velocity and stride length whilst concurrently increasing energy requirements of the associated musculature (Kumar, 2004).

There is often, however, a price to pay for efficient movement, with axial rotation known to destabilise the already inherently unstable spinal column and significantly decrease spinal muscle force production (Kumar, 2004). To that end, it has been found that trunk rotation is associated with more than 60 % of back injuries that occur with industrial vocations and sports, particularly when combined with other factors like bending and lifting (Kumar, Narayan, Stein, & Snijders, 2001; Manning, Mitchell, & Blanchfield, 1984).

Whilst there has been substantial research investigating trunk rotation, focus on key areas such as the effects of trunk inclination or trunk flexion on maximal trunk rotation

ROM appears limited. Of the studies that have investigated these combined movement patterns, variations in defining the test parameters and the methodology undertaken make it difficult to compare findings. It is clear that consistent methodology is required to better allow pooling of data across studies. For the purpose of this thesis, it is important to clearly define trunk inclination, trunk flexion and trunk rotation before exploring in more definitive ways, the interplay that occurs between these key movements with respect to maximal active trunk rotation ROM.

This study will aim to contribute to the current body of published research data investigating trunk rotation, with the intention of determining whether adopting certain spinal postures in the sagittal plane are more advantageous to trunk rotation than others. The impetus behind the undertaking of this thesis was based on a combination of years of clinical observation of patients, hours of golf swing analysis, and theoretical discussions with professional golfers, teaching professionals and colleagues within the physiotherapy industry. The intention of this paper is to provide evidence that the adoption of certain movement and postural strategies can, in theory, enhance the power and accuracy required in golf whilst reducing the risk of vocation or sport-related injuries.

Outcomes of this study will help to provide a platform on which to develop training and rehabilitation strategies for participants involved in sports and vocations that utilise trunk rotation, in varying degrees of trunk inclination or trunk flexion, with the intention of minimising the risk of spinal injury in both the workplace and sporting arenas. This study has significance for researchers, clinicians and the patients who present on a daily basis with flexion-rotation-related spinal pathologies. Furthermore, the findings will be of particular interest to golfers who are searching for improvement in performance, coupled with a decrease in injury risk. This study hopes to provide further objective information to allow a greater understanding of the potential impact of alterations of sagittal plane flexion on trunk rotation ROM.

Whilst there is a vast amount of literature pertaining to the role of both trunk musculature on trunk rotation, and the effect of trunk rotation on the capacity for trunk musculature to produce torque, it is outside the scope of the current study and will not be discussed in any great detail. Similarly, a substantial amount of work has been performed on lateral flexion-rotation coupling of the thoracolumbar spine but again, this is beyond the scope of the present study.

CHAPTER TWO

Review of the literature

2.1. Introduction

This chapter begins by clarifying the existing definitions of trunk movements: *trunk rotation, trunk flexion* and *trunk inclination*; and compares them to the plethora of terms used to describe these motions in the current body of literature. This will be followed by a review of the literature that has quantified trunk rotation ROM in various spinal positions. Next, the focus will turn to some of the pertinent methodological differences that exist between these aforementioned studies, paying particular attention to methodological testing positions, pelvic fixation and measurement devices. Following this, a brief discussion on the specificity of measuring rotational movement within the trunk will be provided. Finally the aim, objective, goals and hypotheses associated with this study will be presented.

2.2. Defining Trunk Motion

The body of research investigating trunk motion has grown significantly over the last three decades. It is unfortunate that during this time, various different terms have been used to describe spinal motion, particularly rotation and flexion about the long axis of the spine. This creates certain difficulties when attempting to understand the research methodology and interpret the research findings. The terms *trunk rotation, trunk flexion* and *trunk inclination* give rise to ambiguity not only in the scientific literature, but also in the clinical setting and the sporting arena due to individual interpretations of their definitions. This indicates a need to accurately define these terms so that they can be easily understood and used comfortably by researchers, clinicians and coaches alike.

2.2.1. **Trunk Rotation**

The term *trunk rotation* is often used interchangeably with the term *spinal rotation* and can be used to describe either: (a) rotation of the trunk as a whole or (b) rotational involvement of bony segments of the thoracic spine, lumbar spine and pelvis ‘within’ the trunk itself. Golf researchers regularly substitute apparently synonymous terms such as *shoulder rotation*, *shoulder turn* and *upper body rotation* when describing rotation of the chest on the pelvis, or use the term *hip rotation* to describe *pelvic rotation* or *lower body rotation* during the golf swing (Burden, Grimshaw, & Wallace, 1998; Gluck, Bendo, & Spivak, 2007; Hume, Keogh, & Reid, 2005; McTeigue, Lamb, Mottram, & Pirozzolo, 1994). Other terms such as *long axis rotation* or *axial rotation* are also used within the literature to describe rotation of the spinal column (Edmondston et al., 2007; Marshall & Elliott, 2000).

In accordance with definitions published by the International Society of Biomechanics (ISB) (Wu et al., 2002) and for the purpose of this thesis, *trunk rotation* is defined as:

- the summation of axial rotational movements that occur ‘within’ the trunk between two or more adjacent vertebral segments of the thoracic and lumbar vertebrae and the axial torsion of the sacrum within the pelvis, around a caudad-cephalad axis of joint coordinate systems that exist between each set of adjacent vertebral segments.

During trunk rotation, the angular displacement of the most cephalad segment (T1 vertebra) will change relative to the most caudad segment (sacrum). This definition serves to remove the difficulties associated with measuring the *intersegmental rotation* that occurs *in vivo* between adjacent pairs of vertebra which have their own, individual instantaneous axis for axial rotation.

It is important to distinguish *trunk rotation* from rotation of the trunk segment as a whole. Therefore for the purpose of this thesis, *trunk segment rotation* is defined as:

- rotation of the trunk as a whole, where all component segments (thoracic and lumbar vertebra, ribs and pelvis) rotate as one unit, simultaneously traversing the same angular displacement during rotation about a caudad-cephalad axis.

By definition, colloquial descriptions such as *shoulder rotation*, *shoulder turn* and *upper body rotation* are synonymous with the term *trunk rotation*, as they all describe the summation of axial rotation that occurs within the trunk or torso. Other terms such as *thoracolumbar rotation* and *thoracic rotation* describe the obvious summation of intersegmental axial rotations of their respective namesakes. These movements are subsets of the axial rotational movement which can occur within the torso. The term, *axial rotation* is often used in the literature so, for the purpose of this study, the term *axial rotation* as it pertains to the trunk will be considered synonymous with *trunk rotation*.

The terms that have been identified to describe axial rotation of the trunk represent the involvement of one or more anatomical structures or articulations. For example, the anatomical structures involved in terms such as thoracic rotation or thoracolumbar rotation involve the summation of the T1-L1 and T1-S1 articulations respectively. Likewise, the anatomical structures associated with the remaining terms that were discussed above have been interpreted or extrapolated from the literature for the purpose of this study and are presented in Table 2.1.

Table 2.1 Representation of the anatomical composition of various terms used to describe rotation of the trunk found within the literature.

Body Segments:	Thoracic Rotation	Thoracolumbar Rotation	Trunk Rotation	Shoulder Rotation	Shoulder Turn	Upper Body Rotation	Axial Rotation	Trunk Segment Rotation	Body Rotation	Lower Body Rotation
T1-L1	✓	✓	✓	✓	✓	✓	✓	✓	✓	X
L1-S1	X	✓	✓	✓	✓	✓	✓	✓	✓	X
Sacrum within Pelvis	X	X	✓	✓	✓	✓	✓	✓	✓	X
Pelvis on Hips	X	X	X	X	X	X	X	✓	✓	✓
Knees	X	X	X	X	X	X	X	X	✓	✓
Ankles	X	X	X	X	X	X	X	X	✓	✓
Feet	X	X	X	X	X	X	X	X	✓	✓

T1=1st thoracic Vertebra; L1=1st lumbar vertebra; S1=1st sacral vertebra

Often, the measurement of trunk rotation kinematics requires quantifying both the whole and the component parts simultaneously, where the rotation of the torso as a whole about an external caudad-cephalad axis, is combined with rotation between the component parts within the torso about one or more intersegmental axes. This makes measuring trunk segment rotation difficult when trunk rotation is occurring simultaneously.

Golf offers a prime example where measurement of the respective parts becomes important. Trunk rotation in golf has been linked to outcome measures like club head speed, ball velocity and driving distance (Gluck et al., 2007). The greater the angular displacement differential a golfer can generate between the shoulders and pelvis during trunk rotation in the backswing, the more rotational torque is produced. Increases in rotational torque correlate directly to increases in clubhead speed and the subsequent increase in the distance that golfers can hit the golf ball (Hume et al., 2005; Lephart, Smoliga, Myers, Sell, & Tsai, 2007). In the golfing world, this shoulder-pelvis rotation differential is known as *X-factor* (see Figure 2.1), which describes the angle that is formed between a horizontal line drawn across the acromioclavicular joints and the hip joints when viewed from above during the backswing (Costis & Midland, 2006; Gluck et al., 2007; Hume et al., 2005; Lephart et al., 2007; McLean, 1992, 1993). In addition, the shoulder-pelvis rotation differential may further increase as the pelvis leads the trunk during the initiation of the downswing. This additional increase is known as *X-factor stretch* and has been shown to have a higher positive correlation to driving distance than the *X-factor* alone (Cheetham, Martin, Mottram, & St. Laurent, 2000).

While measuring the angular displacement of the sternum (or shoulders) from the set-up position to the top of the backswing quantifies how much axial rotation has occurred within the whole body, it does not quantify the amount of trunk rotation or *X-factor* that has occurred. Measuring the change in the relative positions of the sternum on the pelvis allows one to quantify actual *X-factor* that occurs during the backswing.

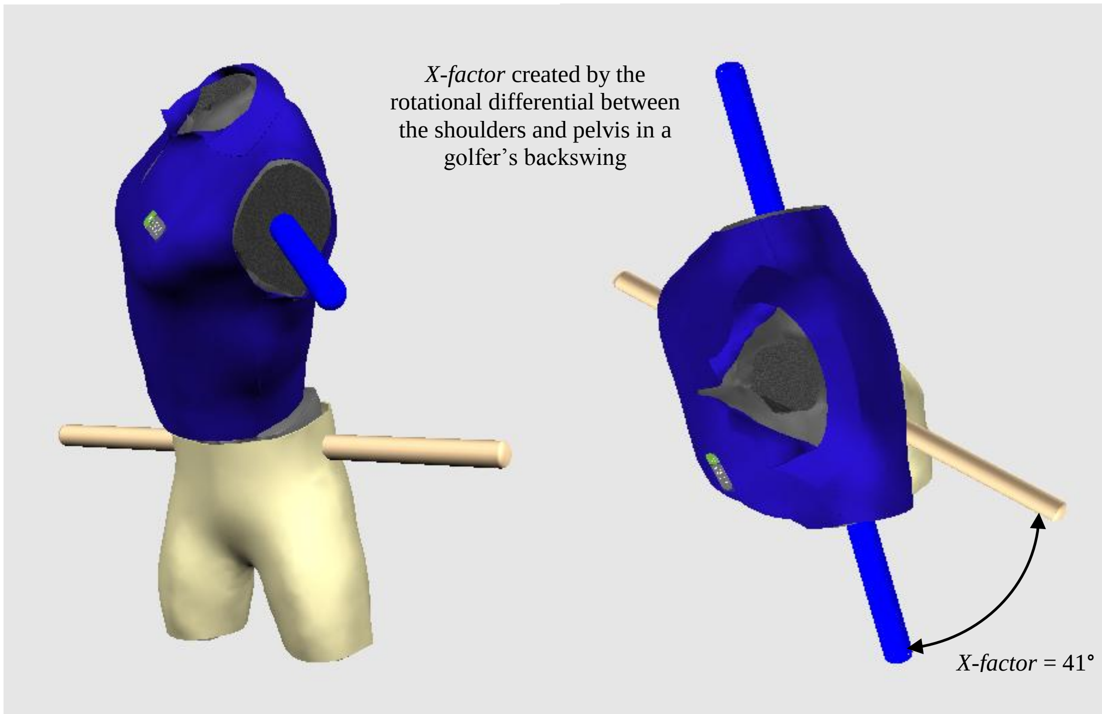

Figure 2.1 Three-dimensional animation of *X-factor* in a golfer's backswing adapted from K-System™ (K-Motion Interactive, Inc, USA)

Measuring the amount of angular displacement of the pelvis relative to its start position quantifies the rotational involvement of the lower body or legs. For the purpose of this study, the term *pelvic rotation* will be used to describe either *trunk segment rotation* or *lower body rotation* as they pertain to the context of the discussion.

2.2.2. **Trunk Flexion**

Like trunk rotation, various terms are used to describe *trunk flexion* within the literature. Whilst the literature reveals that the term *trunk flexion* is generally used to describe flexion of two or more thoracic and/or lumbar segments anteriorly in the sagittal plane (Gunzburg, Hutton, & Fraser, 1991; Haberl et al., 2004; Hindle & Pearcy, 1989; Kumar & Narayan, 2001; Kumar, Narayan, & Zedka, 1998; Kumar, Zedka, & Narayan, 1999), it can also describe movement of the torso as a whole. Terms such as *spinal flexion*, *intersegmental flexion* and *stooping* appear to be used somewhat synonymously, but do little to clarify where 'within' the trunk segment the flexion movement actually occurs. *Spinal flexion* or *intersegmental flexion* describes anterior rotation of a proximal vertebral segment on a distal vertebral segment in the sagittal plane, at two or more adjacent cervical, thoracic, lumbar and sacral vertebra, about a medio-lateral axis of a joint coordinate system that exists between each adjacent vertebral segment (Wu et al., 2002). The term *stooping* appears the most ambiguous of all, and can be taken to mean: intersegmental flexion at the lumbar spine only (S. Lee et al., 2006); intersegmental lumbar flexion combined with pelvic flexion (Gallagher, Hamrick, Cornelius, & Redfern, 2001); intersegmental thoracic, lumbar and pelvic flexions (full flexion of the trunk) whilst standing (Gallagher, Marras, Davis, & Kovacs, 2002); or full intersegmental spinal flexion (back bent) with straight legs (Arjmand & Shirazi-Adl, 2005; Bazrgari, Shirazi-Adl, & Arjmand, 2007).

In accordance with definitions published by the ISB (Wu et al., 2002), and for the purpose of this thesis, *trunk flexion* is defined as:

- the summation of all sagittal plane movements between two or more adjacent vertebral segments of the thoracic and lumbar vertebrae and nutation of the sacrum within the pelvis, about the medial-lateral axis of joint coordinate systems that exist between each set of adjacent vertebral segments forward in the sagittal plane.

2.2.3. **Trunk Inclination**

It is proposed that the term *trunk inclination* is used to describe movement of all thoracic, lumbar and pelvic segments traversing the same angular displacement during sagittal plane movement of the trunk segment, about the medio-lateral axis through the hip joint centres (see Figure 2.2). Trunk inclination moving anteriorly in the sagittal plane will be represented by positive angular displacement integers (i.e. 45°), whilst trunk inclination moving posteriorly will be represented by a negative integer (i.e. -45°). For clarity, *anterior trunk inclination*, *trunk segment flexion* and the colloquial term *'the waiter's bow'* will be considered synonymous.

Figure 2.2 Trunk inclination or 'waiter's bow' – flexing the trunk on hips whilst maintaining a neutral spine position

Although there is disparity in the literature, it appears the term *stooping* most likely describes the combined movement of both trunk flexion and trunk inclination in standing.

2.3. Quantifying Trunk Rotation

2.3.1. Lumbar Spine Rotation

Since the publication of maximal figures for lumbar spine motion over 30 years ago (Kapandji, 1974), the database for normative values of lumbar spine motion has continued to grow. The most recent review of the literature by Troke, Moore, Maillardet, and Cheek (2005) identified 12 studies that used various methods and equipment to measure lumbar ROM in three planes from T12 or L1 to the sacrum. Many of these studies involved significantly varying sample sizes, age ranges and methodologies, with results demonstrating a wide variation in reported range of motions in the lumbar spine with little reference to age- or gender-specificity (Troke, Moore, Maillardet, & Cheek, 2005).

In 2005, a comprehensive database was established for ranges of motion of the lumbar spine, focusing on both age and gender differences (Troke et al., 2005). This study used a modified CA6000 Spine Motion Analyzer to test lumbar axial rotation in 405 subjects, evenly split for gender with ages ranging from 19-90 years. The median value for unilateral axial rotation across the genders and age spectrum was reported to be approximately 7° from T12 to S2. Whilst this is comparable with a number of studies that have reported unilateral lumbar rotation ROM of between 5-11° (Greene & Heckman, 1994; Pearcy, 1985; White & Panjabi, 1990), it is incongruent with the 16-48° reported in other studies cited in the literature review by Troke et al. (2005). One such study, using a 3SPACE ISOTRAK electromagnetic device to measure axial rotation of the lumbar spine, reported an average unilateral rotation from L1–L5 of 27° for males and 31° for females (Hindle, Pearcy, Cross, & Miller, 1990), a rotational range more than four times greater than the radiographic findings of both Pearcy (1985) and Greene and Heckman (1994).

The most recent study by Fujii et al. (2007) using magnetic resonance imaging (MRI) reported an average of 8.8° of unilateral axial rotation of the lumbar spine (Fujii et al., 2007), findings congruent with those of earlier studies which used radiographic (Greene & Heckman, 1994; Pearcy, 1985) and modified CA6000 measurement methods (Troke et al., 2005; Troke, Moore, Maillardet, Hough, & Cheek, 2001). With the high level of accuracy demonstrated by MRI to measure spinal rotation ROM (Ishii et al., 2004), this raises questions as to the reliability and validity of results reported from many of the earlier studies.

The small range of axial rotation available in the lumbar spine is due largely to anatomical constraints, with the orientation of the facet joints in the sagittal plane responsible for limiting axial rotation posteriorly, and the annulus of the intervertebral disc causing a limitation to the movement anteriorly (Gunzburg et al., 1991; Haberl et al., 2004). The amount of rotation in the lumbar spine accounts for only 20 % of total axial rotation available within the trunk, demonstrating its minimal involvement in overall trunk rotation (Fujii et al., 2007). Whilst the anatomy of the thorax is designed to limit thoracic spine motion in certain directions (Sham, Zander, Rohlmann, & Bergmann, 2005; Watkins et al., 2005; Willems, Jull, & Ng, 1996), it is ideally suited to allow a relatively large degree of axial rotation. The alignment of the facet joints of the thoracic vertebrae, particularly between T1-T8, are ideally orientated to contribute the remaining 80 % of axial rotation that occurs in the thoracolumbar spine (Edmondston et al., 2007; Maiman & Pintar, 1992; White & Panjabi, 1990). The integral relationship between the thoracic and lumbar spine demonstrates the need to investigate both regions concurrently, particularly when researching axial rotation of the trunk.

2.3.2. **Thoracolumbar Spine Rotation**

Although numerous studies investigating the rotational ROM of the spine have primarily focused on the lumbar region, it must be acknowledged that a large proportion of vocations and sports initiate rotation in a cephalad to caudad direction, with rotation of the trunk more likely to occur within the more anatomically accommodating thoracic spine than the restrictive lumbar region. It is interesting to note that decreased movement in the thoracolumbar spine has been shown to have a higher correlation with the presence of low back pain than the lumbar spine alone, particularly with relation to a decrease in axial rotation and lateral bending (Mellin, 1987). Although axial rotation has been identified as the dominant motion that occurs in the thoracic region, there are surprisingly few studies investigating normative ROM values of this movement in either the thoracic or the combined thoracolumbar spine. Most studies of thoracolumbar spine motion have investigated muscle activity during isokinetic and isometric trunk axial rotation, including parameters such as torque production (Kumar, Dufresne, & Van Schoor, 1995; Kumar, Narayan, & Garand, 2001, 2002; Kumar et al., 1998; Ng, Richardson, Parnianpour, & Kippers, 2002; Toren & Oberg, 1999), fatigue-related changes (Bonato et al., 2003; Kumar, Narayan, Stein et al., 2001; Ng, Parnianpour, Richardson, & Kippers, 2003), and EMG characteristics such as muscle recruitment and activation sequencing (Kumar & Narayan, 1999, 2006; Kumar, Narayan, & Garand, 2001, 2003; Kumar, Narayan, & Zedka, 1996; Kumar et al., 1999; L. J. Lee, Coppieters, & Hodges, 2005; Marras, Davis, & Granata, 1998; Toren, 2001)

Only a few of these studies investigated the aforementioned parameters at the limits of active or passive axial rotation of the spine (see Table 2.2), with the majority of studies performing testing in rotational ranges less than 40° in either direction. Studies which have included testing of isokinetic axial rotation at the end-of-range rotation have often failed to record or present these ROM values in their findings (Kumar et al., 2003). The relative lack of ROM research within the literature may be attributed to the fact that parameters like trunk velocity and acceleration appear demonstrably better at discriminating low back pain subjects from asymptomatic subjects than ROM testing (Davis & Marras, 2000).

Intersegmental ROM has been described as the sum total of the neutral and elastic zones of adjacent vertebral articulations (White & Panjabi, 1990). In a normal population, the upper two-thirds of the thoracic spine are appreciably more mobile than the lower third, accounting for around 80 % of thoracic spine rotation (Willems et al., 1996). The relative limitation to axial rotation in the lower third of the thoracic spine and the lumbar spine is attributed to anatomical constraints such as zygoapophyseal joint orientation within the region (Grauer & Panjabi, 2002; Haher, O'Brien, Kauffman, & Liao, 1993). White and Panjabi (1990) provided limits and representative angles for intersegmental ROM of the thoracic and lumbar spine based on a review of the literature. They reported limits of unilateral axial rotation between T1 and L1 (including T1-T2 and T12-L1 articulations) of 56-102° with a representative angle of 71°. Unilateral axial rotation between L1-S1 (including L1-L2 and L5-S1 articulations) was reported to be between 4-14° with a representative angle of 9°; and unilateral sacral axial torsion within the pelvis was reported as 3-9° with a representative value of 6°. Based on these values, unilateral trunk rotation (thoracic, lumbar and sacral axial rotation) is considered to range from 63° to 125° with a representative value of 86° (White & Panjabi, 1990). Although White & Panjabi (1990) considered this a careful review of the literature, the reporting of possible age- and gender-related factors or the data collection methodologies appears to have been neglected.

Willems et al. (1996) tested normative ranges of motion of the thoracic spine in 60 subjects sitting with the pelvis fixed using a 3 SPACE Fastrak electromagnetic system, a later model of the 3 SPACE Isotrak system used in earlier kinematic investigation of the lumbar spine (Hindle et al., 1990). Rotational ROM was measured in three regions of the thoracic spine, T1-4, T4-8 and T8-12. The combined average ranges of each thoracic region were 48.1° unilaterally to the right and 43.8° to the left (ROM varied across gender and direction of rotation). Interestingly, over half the available rotational ROM occurred in the T4-T8 thoracic segment. This experiment did not include any lumbar or sacral movement and the findings represent axial rotation ROM in the thoracic spine only. By contrast, Watkins et al. (2005) undertook an *in vitro* study of the thoracic spine (C7-L1) in 10 cadaveric specimens and finding an average of 23° of axial rotation. It is important to note that the axial rotation range in this study varied markedly from 6-51° and the average age of the cadavers was 72 years old.

With respect to the combined measurement of maximal ROM of the thoracic and lumbar spine, seven key papers were identified in the literature. These papers were selected based on whether maximal range of thoracolumbar rotation was reported or could be extrapolated from the data presented in the respective studies. These studies are summarised in Table 2.2 and reviewed below. The majority of these papers monitor rotational movement between the clavicle and the pelvis. Whilst it could be assumed that these papers have included the torsional component of the sacrum in their reported measures, it appears that in all but one paper by (Fujii et al., 2007); sacral involvement has not been specifically stated.

Table 2.2 Comparative studies investigating thoracolumbar range of motion

Year	1989	1994	1996	1999	2001	2007	2007
Author(s)	Parnianpour et al	Petersen et al	Kumar et al	Boden & Oberg	Toren	Edmondston et al	Fujii et al
Total Subject No.	9	21	50	20	18	52	10
(Male No.)	Not stated	8	27	20	18	25	6
(Female No.)	Not stated	13	23	-	-	27	4
Ages (Yr)	χ=24 SD=6	χ=30 SD=5.6	χ=22 SD=3.7 (M) χ=22 SD=4.2 (F)	χ=34 SD=6.2 (M)	χ=33 SD=5.9 (M)	χ=23	χ=26
Spinal Region Tested	Not stated	T7-S2	Clavicle - Pelvis	5cm distal to Clavicle - Pelvis	Clavicle - Pelvis	Trunk	Trunk
Measurement Method	B200 Triaxial Dynamometer	Spne Motion Analyzer	Axial Rotation Tester with	Optoelectronic Camera	Optoelectronic Camera	Optoelectronic Camera	MRI
Test Position	Standing	Standing	Sitting	Sitting	Sitting	Sitting	Supine
Pelvis Fixation	Not stated	No	Yes	Yes	Yes	Yes	Yes
Movement	Active	Active	Active	Passive	Active	Active	Passive
Reliability reported	No	Yes	Yes	No	No	Yes	Yes
Validity reported	No	Yes	Yes	No	No	No	Yes
Rotational Axis	Not reported	Not reported	Lumbosacral joint - vertical spinal axis	Craniosacral axis	Longitudinal trunk axis	Not reported	Not reported
Gender Specific	No	No	Yes	Yes	No	Yes	No
Age related	No	No	No	No	No	No	No
Parameters Tested	ROM, Isoinertial	ROM, Reliability	ROM, muscle activation	ROM, torque resistance	ROM, Muscle activity	ROM, Coupling	ROM, Coupling
Results							
Right Axial Rotation	-	χ=46°	71.3°-74.1°	-	-	-	-
Left Axial Rotation	-	χ=45°	70.1°-72.1°	-	-	-	-
Mean Axial Rotation	81° (SD 8°)	-	-	53.7° (SD 9.2°)	54.9° (SD 6.9°)	40.9°	56.9° (SD 7.5°)

χ=mean; SD=Standard Deviation; M=Male; F=Female; ROM=Range of Motion; MRI=Magnetic Resonance Imaging

In an isoinertial strength study, Parnianpour, Li, Nordin, and Kahanovitz (1989) found an average unilateral axial rotation of 81° when nine subjects were tested with a triaxial dynamometer in a standing position. This small study was considered to possess several limitations including the non-reporting of key methodological issues such as participant gender, pelvis fixation, the rotational axis of the trunk, and the spinal levels involved during testing, making it difficult to interpret the results.

A later, more comprehensive, gender-specific study by Kumar et al. (1996) measured mean active unilateral axial rotation in 50 subjects using an Axial Rotation Tester. This testing was undertaken in sitting with the pelvis fixed, and the testing apparatus aligned with the subject's vertical spinal axis through the lumbosacral joint. Axial rotation ROM of the spine between the clavicle and the pelvis (T1-pelvis) was measured using a potentiometer and reported averages between 71.3-74.1° and 70.1-72.1° in 27 males and 23 women respectively.

Using an optoelectronic camera system, Boden and Oberg (1998) measured passive axial rotation ROM in sitting with the pelvis fixed for 20 male subjects. Whilst a mean value of 53.7° for unilateral axial rotation was found, the subjects used verbal cues to stop the passive rotation of their spines which could have led to an under- or overestimation of ROM. A comparable study measured active unilateral axial rotation in 18 male subjects and demonstrated an average of 54.9° in either direction (Toren, 2001). Similar results were found by Fujii et al. (2007) who used MRI to measure passive axial rotation of the trunk in 10 subjects. Although sacral movement within the pelvis was not included, an average unilateral axial rotation ROM of 56.9° was reported. With a rotational measurement error of 0.43° per spinal articulation, the use of MRI as a measurement method appears to be highly accurate (Ishii et al., 2004).

Two contrasting studies investigating thoracolumbar rotation have reported unilateral rotational ranges well below that of other studies. The first study investigated intra-and inter-observer reliability of thoracolumbar spine motion using a CA6000 Spine Motion Analyzer to measure the trunk rotation of 21 subjects in standing (Petersen, Johnson, Schuit, & Hayes, 1994). Whilst they reported a mean thoracolumbar rotational ROM of around 43°, the researchers noted that only the levels between T7 to S2 were tested (Petersen et al., 1994), which is therefore likely to account for the reduced rotational range. Similar results were found in the second study by Edmondston et al. (2007) who investigated the influence of spinal posture on axial rotation of the thoracic spine using an optoelectronic camera system. Fifty two subjects were instructed to rotate their trunks to the end of their available range in a neutral sitting posture, producing an average of 40.9° of unilateral axial rotation. This reduced rotational range may be due to unique methodological differences utilised in this study, particularly with reference to the use of the optoelectronic camera system and the impact of the arm position used in the experimental procedure.

The importance of quantifying maximal trunk rotation ROM is dependent on the functional requirements of the physical tasks being undertaken by people on a daily basis. These rotational requirements may differ widely within and between vocations and sporting activities. In a comprehensive vocational study of 475 manual material handling tasks, a triaxial electrogoniometer was used to measure trunk rotation (Allread, Marras, & Burr, 2000). The study demonstrated a mean unilateral trunk rotation value of 26° ± 9°. Whilst this showed that most manual material handling tasks did not require trunk rotation to the physiological limits as described in the numerous papers outlined in Table 2.2 (e.g. ranging from 40.9-81°), it does not exclude trunk rotation from a role in low back injuries, particularly as average rotational velocity, combined with external load, maximal flexion and maximal lateral velocity have been shown to be associated with low back disorders (Allread et al., 2000; Marras et al., 1995; Marras et al., 1993). Contrasting the sub-maximal trunk rotation requirements of the manual handling tasks in the study by Allread et al. (2000) was the rotational requirements of tractor drivers in the agricultural sector identified in studies by Boden and Oberg (1998) and by Toren (2001). Both studies identified that full axial rotation in sitting was a functional requirement of the job and investigated its effect on trunk muscle activity accordingly.

Similarly, sports such as golf require not only rotation of the trunk to its physiological limits, but the rotation available in other body segments needs to be considered also. A simple method, offered as an inexpensive clinical assessment tool for measuring active rotation in standing, used a plumb bob that was attached to a bar resting on the subject's shoulders to determine the total angular displacement of the trunk from the start to the finish position during active rotation (Evans, Refshauge, & Adams, 2006). Results for 24 subjects revealed an average unilateral trunk rotation range of 128° ± 7°. This test was designed to assess the limits of full active trunk rotation in standing. The only reference to fixation in the methodology was to keep the knees straight and the feet on the ground during active rotation of the body. It should be noted that the resulting rotational ranges found in this study describe a combination of trunk rotation (rotation within the trunk) and trunk segment rotation (rotation of the trunk in space). Whilst this is a useful measure to determine functional rotational ranges of the whole body, it is unable to provide any insight as to the proportion of rotation that occurs within the trunk segment itself.

It is clear from the literature, that methodological differences exist across the studies identified which investigated trunk rotation ROM (see Table 2.2). These are likely to account for the considerable differences seen in the reporting of maximum trunk rotation ROM. Whilst it is acknowledged that testing trunk rotation in a sitting posture offers a distinct advantage by being able to isolate spinal rotation in the experimental setting, extrapolation of the results to ‘real-world’ environments may not be representative of the trunk ranges that occur in vocations and sports which utilise the mechanical advantage of trunk rotation in standing postures. Furthermore, whilst equipment reliability has been reported in most studies investigating axial rotation ROM, only three studies (Edmondston et al., 2007; Petersen et al., 1994; Smith, Mayer, Gatchel, & Becker, 1985) which performed repeatability studies for their testing protocols were identified. Edmondston et al. (2007) used six subjects in their replication study and reported an acceptable level of repeatability. Smith et al. (1995) using ten subjects in their repeatability study, calculated Pearson correlation coefficients of 0.75 which was considered acceptable test-retest repeatability by the authors. Peterson et al. (1994) studied the intraobserver and interobserver reliability of trunk movements in 21 subjects and reported interclass correlation coefficients (ICCs) of 0.85 and above for trunk rotation measurements across sessions. These high ICC values were considered to demonstrate good reliability of the testing methodology.

2.4. The Effects of Spinal Posture on Trunk Rotation

The physical demands of many sports and vocations often require axial rotation to take place in spine curvatures that differ from their normal anatomical positions. Whilst the combination of spinal movements in two or more planes is often thought to predispose the passive spinal structures to injury (Panjabi, 1992a, 1992b), people continue to perform them repetitively throughout their daily lives (Kumar et al., 1998).

One of the movement patterns commonly thought to increase the chances of injuring the spine is the combination of spinal flexion and axial rotation (or bending and twisting), particularly at the end of movement ranges where there may be sufficient deformation of tissue to damage the posterolateral fibres of the lumbar intervertebral discs (Hindle & Pearcy, 1989; Kumar et al., 1998). Flexion and rotation have certainly been shown to be risk factors associated with low back pain, particularly when performed during lifting (Hoogendoorn et al., 2000). Most studies which have formally investigated flexion (Gunzburg et al., 1991; Kumar, Narayan, Stein et al., 2001; Kumar et al., 1998; Kumar et al., 1999; Wessel, Ford, & van Driesum, 1994) or extension (Gunzburg et al., 1991; Kumar & Narayan, 1999; McGill, 1992; Wessel et al., 1994) combined with axial rotation have concentrated on the lumbar spine. Additionally, the majority of these studies have focused on measuring strength parameters (e.g. torque production) during these combined motions, with just a few investigating the impact of trunk flexion and extension on trunk rotation ROM.

2.4.1. **Flexion–Rotation**

In vitro studies by Gunzburg et al. (1991) and Haberl et al. (2004) investigated the role of spinal flexion on axial rotation ROM of the lumbar spine, reporting that lumbar flexion demonstrated a trend toward reducing axial rotation ROM. *In vivo* studies have reported contradictory results, finding both a reduction (Burnett et al., 2007; Gunzburg et al., 1991), and an increase (Hindle & Pearcy, 1989), in axial rotation of the spine with forward trunk flexion. These conflicting results may be due to methodological differences that exist between studies, with some opting to flex the spine cephalad to caudad in sitting and standing (Burnett et al., 2007; Gunzburg et al., 1991), whilst others flexed the spine caudad to cephalad in sitting (Hindle & Pearcy, 1989). Hindle and Pearcy (1989) reported that 35 % of full thoracolumbar flexion in the sagittal plane in sitting allows up to 40 % greater axial rotation of the lumbar spine than in neutral standing, decreasing somewhat at 65 % of the thoracolumbar flexion. In contrast, Burnett et al. (2007) reported a significant decrease in axial rotation ROM in full thoracolumbar flexion compared to a neutral spine in both sitting and standing postures. Axial rotation of the lumbar spine also appeared to be significantly less in a neutral sitting posture compared to a neutral standing posture.

A study by Boden and Oberg (1998) found that passive torque resistance to axial rotation increased as an exponential function of the increasing rotation of a neutral spine, due to the resistance inherent in the myofascial and connective tissues of the thoracolumbar spine being stretched toward their physiological limits. In this situation, an electromyographic study shows that as the trunk rotates further into its axial range, trunk muscle activity must increase to generate enough torque to overcome the increasing resistance of the passive structures, in order to achieve end-of-range rotation (Kumar et al., 2003). Whilst trunk muscle activity has been shown to increase at an exponential rate as linear load increases when the trunk is flexed and rotated (Kumar & Narayan, 2001), an earlier study by Kumar and Garand (1992) found that a progressive increase in axial rotation of the trunk during stooped lifting caused a concurrent decrease in the torque-producing capabilities of the trunk musculature. It would appear that the requirements of the trunk musculature to produce increased levels of torque when performing tasks in a combined flexion-axially rotated position, is inhibited by the very fact that the flexed and rotated position simultaneously limits the torque-producing capabilities of the same trunk musculature. This paradox is likely to lead to a significant increase in tissue tension occurring within the spine during lifting in these combined positions and may be a central factor in increasing the risk of low back injury (Kumar & Narayan, 2001; Kumar et al., 1998; Kumar et al., 1999; Wessel et al., 1994).

Despite a limited number of studies investigating trunk rotation ROM in a flexed spinal posture, the general consensus in the literature is that lumbar flexion leads to a decrease in trunk axial rotation ROM (Burnett et al., 2007; Gunzburg et al., 1991; Haberl et al., 2004). The load that bending and twisting places on the passive structures of the spine, combined with a decreased capacity to produce or resist torque when the lumbar spine is maximally flexed and rotated simultaneously, is believed to increase the risk of injury to the lumbar spine. In sports that require maximal axial rotation of the trunk (e.g. golf), the literature, although mainly undertaken in the lumbar spine region, theoretically supports adoption of a neutral spine posture to maximise the rotary ROM available in the spine. However, the current literature review was unable to identify any studies that have investigated axial rotation ROM of the trunk in varying degrees of forward trunk inclination whilst maintaining a neutral spine posture.

2.4.2. **Extension-Rotation**

It has been advocated that avoiding flexion of the lumbar spine during lifting and twisting activities decreases the risk of spinal injury (McGill, 1992). This is most likely due to the coupling effect of the lumbar facet joints that limit axial rotational range in neutral and hyperlordotic postures. Certainly, *in vitro* investigations of the role of extension on axial rotation ROM of the lumbar spine support this concept, reporting that lumbar extension led to a reduction in axial rotation (Haberl et al., 2004). However, *in vivo* studies again reported conflicting results, with one recent study demonstrating that lumbar extension (defined as full anterior pelvic tilt promoting full lumbar lordosis) led to a significant reduction in lumbar axial rotation compared to a neutral spine posture in both sitting and standing (Burnett et al., 2007), whilst another study found no significant difference in trunk axial rotation ROM in extension (defined as segmental thoracic extension from cephalad to caudad until movement at T12-L1 was detected), compared to a neutral spine posture in sitting (Edmondston et al., 2007).

Similar to the impact of flexion-rotation on torque production mentioned in the previous section, the combination of lumbar extension and axial rotation of the trunk also leads to a decrease in linear torque production of the trunk muscles, indicating that these muscles work less effectively when the spine is rotated and extended simultaneously (Kumar & Garand, 1992). No studies could be found in the literature where trunk rotation was tested with subjects maintaining full thoracolumbar extension in a forwardly inclined trunk position.

2.5. Trunk Rotation Measurement - Methodology

2.5.1. Testing Positions

As mentioned previously, the position in which subjects are tested (i.e. standing versus sitting) may have an impact on the ROM during trunk axial rotation. There is evidence to suggest that sitting causes a decrease in lower thoracic axial ROM compared to standing (Gregersen & Lucas, 1967), particularly if a flexed sitting posture is adopted (Willems et al., 1996). Contrary to this, a recent study by Burnett et al. (2007) reported a significant increase in trunk axial rotation of a neutral spine in sitting compared to standing.

Although bending and twisting in a standing posture is commonly seen in a large number of manual vocations, sports and leisure activities there appears to be a lack of agreement on the impact that combined postures have on trunk rotation ROM. The lack of studies in the literature and the contradictory results reported using similar test positions indicates that further investigation into testing positions is warranted.

2.5.2. Pelvic Fixation

Most test methods have sought to monitor or fixate the pelvis in order to isolate and accurately measure trunk rotation. Pelvic fixation allows rotational movement to occur about the cranio-sacral axis of the thoracic and lumbar regions, including the axial torsion of the sacrum within the pelvis, and helps to give an accurate representation of the ROM that occurs within the trunk. Throughout the studies investigating trunk rotation (Boden & Oberg, 1998; Edmondston et al., 2007; Kumar et al., 1996; Ng, Kippers, Richardson, & Parnianpour, 2001; Parnianpour, Li, Nordin, & Kahanovitz, 1989; Toren, 2001; Wessel et al., 1994; Willems et al., 1996), various methods of pelvic fixation have been utilised, with most studies being conducted in sitting posture. Fixation of the pelvis in this position has varied as follows: a knee separator and

Velcro™ straps that fixed the hips, thighs, shins and ankle (see Figure 2.3) (Kumar et al., 1995); a concave seat and pelvic fixation device (see Figure 2.4) (Boden & Oberg, 1998; Toren, 2001); pelvis and thigh straps (see Figure 2.5) (Willems et al., 1996); a hip strap only (see Figure 2.6) (Edmondston et al., 2007); and stabilisation arms (see Figure 2.7) (Wessel et al., 1994).

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Figure 2.3 Axial rotation tester with pelvic and leg fixation (adapted from Kumar et al, 1995)

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Figure 2.4 Shoulder frame with pelvic fixation device (adapted from Toren, 2001)

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Figure 2.5 Seat with pelvic and leg fixation (adapted from Willems et al, 1996)

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Figure 2.6 Box seat with pelvic fixation (adapted from Edmondston et al, 2007)

A comparative study by Petersen et al. (1987) demonstrated that blocking the sacrum with a pad and the anterior-superior iliac spines (ASIS) with stabilisation arms in sitting, significantly limited pelvic movement when compared to the same task performed using a pelvic strap. This fixation technique was used in a later study by Wessel et al. (1994) as seen in Figure 2.7.

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Figure 2.7 Dynamometer seat with fixation arms (adapted from Wessel et al, 1994)

Of the four studies that tested aspects of trunk rotation in standing (Burnett et al., 2007; Ng et al., 2001; Parnianpour et al., 1989; Petersen et al., 1994) only two fixated the pelvis during testing. Ng et al. (2001) used a novel compressive device (see Figure 2.8) to fixate the pelvis when measuring axial rotation of the lumbar spine with a protractor. Unfortunately, the second study by Parnianpour et al. (1989) had poor methodological reporting, so it can only be speculated that they fixated the pelvis of subjects in standing using the Velcro™ straps supplied with the B200 Isostation dynamometer.

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Figure 2.8 Metal frame and pelvic restraint device (adapted from Ng et al, 2001)

All of the aforementioned fixation techniques, whether in sitting or standing, have the potential to allow unwanted pelvic movement to occur during testing. Movement can occur not only between the subject and the fixation device but also between the subject’s soft tissue and the bony anatomy beneath. Some studies recognise the error inherent in any form of pelvic fixation, and acknowledge that true ROM values may be overestimated from their research findings. Although the studies by Boden and Oberg

(1998) and Toren (2001) attempted to monitor the pelvis via placement of retro-reflective markers on a pelvic tracking frame, this did not account for potential movement of the pelvis within the tracking frame itself. Specifically monitoring the kinematics of the pelvis during trunk rotation would help to minimise some of the error in maximal ROM measures that can occur with pelvic fixation devices.

The current literature review was unable to identify any studies investigating axial rotation of the trunk which examined the possibility that fixation of the pelvis in either standing or sitting may lead to an increased range of trunk rotation. Rotational movements seen in the workplace or during sporting activities are often the summation of discrete rotations occurring at the trunk, hips, knees and ankles and feet. With this in mind, further investigation into the effects of pelvic fixation is warranted, particularly as it pertains to the concept of ‘relative flexibility’. The term *relative flexibility* can be defined as the application of force to a body resulting in greater movement occurring at the body segment that exhibits the least amount of active or passive resistance to the applied force (Comerford & Mottram, 2000). Simplistically, when a force is applied to the body the body segment that ‘gives’ will move more than the body segment that is ‘restricted’.

The concept of relative flexibility can be applied to body rotation to provide movement solutions that best suit the needs of the performed task. On one hand, teaching people how to limit the lower body involvement in rotation to maximise trunk rotation may be advantageous to sports such as golf (Gluck et al., 2007; Hume et al., 2005). On the other hand, encouraging rotational involvement of the lower body in an effort to decrease the amount of trunk rotation required to achieve a vocational task such as lifting and loading, will help to minimise the effects that end-of-range axial rotation has on muscle activation and torque production in the sagittal plane, potentially decreasing the risk of spinal injury (Kumar & Garand, 1992; Wessel et al., 1994).

2.5.3. **Measurement Devices**

Observational assessment of the range and quality of spinal motion is an integral part of the clinical reasoning process. These observations can identify key determinants that influence the direction of a treatment approach. Unfortunately, the human eye has difficulty in detecting the subtleties of timing and sequencing of spinal movement in sports and vocations that occur at high speeds. In recent years, there have been significant advances in the field of spinal kinematics, particularly in the development of measurement devices that can accurately quantify spinal movement. Early techniques that measured only ROM such as planar and biplanar X-ray (Pearcy, 1985) and inclinometry (Mayer, Kondraske, Brady Beals, & Gatchel, 1997) have given way to stereophotogrammetry (Cappozzo, Della Croce, Leardini, & Chiari, 2005), tri-axial potentiometry/electrogoniometry (Allread et al., 2000; Marras, Fathallah, Miller, Davis, & Mirka, 1992; A. H. McGregor, McCarthy, Dore, & Hughes, 1997) and electromagnemometry (A. M. Bull & McGregor, 2000). In addition to measuring ROM, these newer techniques can also quantify variables such as velocity and acceleration to better describe the kinematics of spinal motion, particularly when movement occurs at high speeds. The differences that exist between stereophotogrammetric, electrogoniometric and electromagnetic motion tracking systems determine the versatility of each system when used to record human movement. The measurement accuracy for ROM for each system has often been validated against one of the standard imaging protocols, the bi-planar X-ray, three-dimensional (3-D) referencing frames or more recent MRI techniques (Fujii et al., 2007; Marras et al., 1992; A.H. McGregor, Anderton, Gedroyc, Johnson, & Hughes, 2001).

2.5.3.1. ***Tri-axial Electrogoniometer***

A common tri-axial electrogoniometer used to measure lumbar rotation is the Lumbar Motion Monitor (Allread et al., 2000). This versatile exoskeleton system, that uses a series of potentiometers for measuring 3-D motion, has been validated against a 3-D reference frame and a 2-D video motion analysis system by Marras et al. (1992). It was found to have approximately half the relative position error and comparable velocity and acceleration estimates of the 2-D video motion analysis system when measuring lumbar spine movement (Marras et al., 1992). The exoskeleton system is inexpensive compared to video motion analysis systems (Marras et al., 1992) and does not require connecting leads to the device, allowing the research subject to participate easily in their vocation-or sport-related movement. Unfortunately, devices such as this only span from the pelvis to the mid thoracic spine so it is unlikely that they are able to quantify full trunk rotation ROM.

2.5.3.2. ***Electromagnetic Motion Systems***

Electromagnetic motion measurement equipment such as the “Flock of Birds ™” is a popular device used to measure trunk kinematics (A. M. Bull & McGregor, 2000). Skin-mounted sensors detect a low frequency magnetic field from a primary source. The sensor position is then calculated relative to the source point. It gives accurate and reliable information about spinal movement provided extraneous variables such as the presence of metal or other electromagnetic fields is accounted for (A. M. J. Bull, Holt, Wragg, & Mcgregor, 2004; R. Lee, 2002). Aside from the limitation of cost; accessing the information from the sensors requires a series of leads to be attached the subjects during testing, making their use in measuring complex motion quite cumbersome. Furthermore, soft tissue artifact errors that can occur with skin-mounted sensors must be taken into account when defining ‘true’ ROM values (Cappozzo et al., 2005; Cutti, Paolini, Troncossi, Cappello, & Davalli, 2005; Lucchetti, Cappozzo, Cappello, & Della Croce, 1998).

2.5.3.3. ***Optoelectronic or Stereophotogrammetry***

Optoelectronic or stereophotogrammetry systems allow for accurate assessment of dynamic movement in three dimensions (R. Lee, 2002). These systems utilise multiple high-speed cameras to capture multiple retro-reflective or light-emitting diode markers placed on strategic anatomical sites on the body. Although this technology is also costly, optoelectronic motion-tracking systems are non-invasive and allow for minimal disruption to normal movements in the research setting. A limitation often associated with using these systems to determine intersegmental movements arises from soft tissue artifact errors that occur with movement (Cutti et al., 2005; Lucchetti et al., 1998).

Recent technological advances have made optoelectronic systems easier to use (R. Lee, 2002), and the reported errors of ± 2° for anatomical movements (Pearcy, Gill, Hindle, & Johnson, 1987) and a high degree of agreement with stereoradiography of the lumbar spine (Pearcy, 1985), suggests it is a reliable tool for assessing simple spinal motion. The use of optoelectronic systems for assessing complex motion is somewhat dependent on having enough cameras to limit the intermittent disappearance of markers during the movement. Using a greater number of markers can reduce this problem but leads to more complex, time-consuming data analysis due to the multiple markers points.

Whilst electrogoniomic, electromagnemomic and optoelectronic systems offer a high degree of accuracy in the research setting, their use is impractical for the average clinician. Less expensive 3-D modelling systems, like the K-System™ (K-Motion Interactive, Inc, USA) that use a combination of accelerometers, angular rate gyros and magnetometers, may offer not only more clinically convenient results than the expensive aforementioned counterparts, but more accurate and consistent results than current clinical methods like inclinometry (Mayer et al., 1997) or plumb bob testing (Evans et al., 2006) presently offer.

2.5.4. **Measurement Accuracy**

When investigating ROM of the spine in a research setting, accurate quantification becomes an essential requirement of any measurement device designed for the task. A review of the literature indicates that accurate measurement of maximal trunk rotation ROM values requires the pelvis and thorax to be monitored concurrently. One of the primary considerations when measuring trunk rotation lies in the minimisation of the measurement error inherent in any system utilised for the task. When measurement error cannot be completely eliminated, it should be duly noted by the researchers when presenting their study findings.

Of the measurement systems available on the market, it appears that MRI, optoelectronic or electromagnetic measurement systems are the most suited to quantifying trunk ROM. At present, MRI appears to provide an accurate measure of maximal trunk rotation ROM (Fujii et al., 2007) however its use may be limited by its prohibitive cost. Furthermore, whilst this system is capable of differentiating the angular displacement between the spinal segments and the pelvis, the supine test position and passive regulation of axial rotation, may not facilitate normal physiological rotational movement within the trunk (Fujii et al., 2007). By comparison, electromagnetic and optoelectronic systems appear to be more versatile, as unlike MRI, they are capable of measuring active spinal ROM as a function of movement in situations that more closely resemble activities of daily living. It is important to note that while electromagnetic systems such as the 3 SPACE Fastrak system or the 'Flock of Birds™' system demonstrate errors in measurement accuracy of less than 1° (A. M. Bull & McGregor, 2000; Willems et al., 1996), the error associated with movement of the sensors on the skin needs to be considered. This potential movement error can be reduced by employing techniques that allow for maximum adhesion of the sensors to the subjects skin.

With reference to optoelectronic systems, defining appropriate marker placements on the individual is crucial to accurately measure the ability of the thorax to rotate on the pelvis. The markers must be placed such that they provide the greatest amount of rotational information in three dimensions with the least number of markers and the smallest amount of error. Because retro-reflective markers are placed on the skin, they are at risk of providing soft tissue artifact error in kinematic measurements. Therefore, the effect of soft tissue artifact error is counteracted in part by appropriate fixation of markers and cluster-marker sets on to easily identifiable bony landmarks that discourage soft tissue movement (Cappozzo et al., 2005).

2.6. Summary of Literature Review

It is apparent from the literature review that deficits exist in the current knowledge base regarding trunk rotation ROM. Firstly; there is a lack of information concerning normative ROM values for trunk rotation in a neutral standing posture with and without pelvic fixation. Secondly, there appears to be no information on the effects of alterations in trunk inclination on trunk rotation ROM. Thirdly, the majority of methodologies that have been used to quantify maximal trunk rotation ROM appears to have failed to adequately account for potential rotational movement of the pelvis. This may have led to reported trunk rotation ROM values being overestimated within the literature. Finally, whilst most studies have sought to fix the pelvis during testing, there appears to be no information on the effects of pelvic fixation on active trunk rotation ROM, when standing, or in flexed, extended or inclined trunk postures.

Using the definitions for *trunk rotation, trunk flexion* and *trunk inclination* outlined in this review, this thesis will attempt to address some of these apparent deficiencies within the literature, and increase knowledge in these areas. To that end, the aim, objective, goals and hypotheses for this present study are outlined below.

2.7. Aim

The aim of the study is to determine the effects of alterations in trunk inclination, spinal posture, pelvic fixation and turning direction on the active ROM of trunk rotation.

2.8. Objective

To measure maximum active ranges of motion of trunk rotation, pelvic rotation and displacement of the COP of the ground reaction force for different trunk inclinations, spinal postures, pelvic fixation and turning directions using a 3-D motion analysis and force platform measuring system.

2.9. Goals

The goals of this study are fivefold:

i. to measure maximum active trunk rotation ROM in standing;

ii. to determine whether alterations in trunk inclination have an effect on maximum active trunk rotation ROM;

iii. to determine whether alterations in spinal posture in the sagittal plane have an effect on the maximum active trunk rotation ROM;

iv. to determine whether fixation of the pelvis effects maximum active trunk rotation ROM; and

v. to investigate the effects of trunk inclination, spine posture and pelvic fixation on pelvic rotation ROM and displacement of the COP during active trunk rotation.

2.10. Hypotheses

The purpose of this study is to investigate the effects that trunk inclination, spinal posture, pelvic fixation and direction of turn have on the body during axial rotation of the trunk. The following statistical hypotheses are:

i. Alterations in trunk inclination will have no significant impact on trunk or pelvic rotation ROM during trunk rotation.
ii. Alterations in trunk inclination will have no significant impact on displacement of the COP during trunk rotation.
iii. Alterations in spinal posture will have no significant impact on trunk or pelvic rotation ROM during trunk rotation.
iv. Alterations in spinal posture will have no significant impact on displacement of the COP during trunk rotation.
v. Pelvic fixation will have no significant impact on trunk or pelvic rotation ROM during trunk rotation.
vi. Pelvic fixation will have no significant impact on displacement of the COP during trunk rotation.
vii. Direction of turn will have no significant impact on trunk or pelvic rotation ROM during trunk rotation.
viii. Direction of turn will have no significant impact on displacement of the COP during trunk rotation.

CHAPTER THREE

Methodology

3.1 Introduction

This chapter presents the methods used in this study to meet the aims and objectives outlined in Chapter Two. Initially, the study design is introduced, followed by the recruitment and screening procedures for the study participants. A specific outline of the independent variables under scrutiny in the study is then followed with a description of the experimental measures used in the collection of the kinematic and kinetic data during trunk rotation and the experimental procedures themselves, including data collection and data processing. Finally, statistical analysis of the collected data is described.

3.2 Method

3.2.1 **Study Design**

This study was divided into two components, both using a randomised, repeated measures design. The first component investigated the effect of three different trunk inclinations (0°, 22.5°, 45°), pelvic fixation and direction of turn (3x2x2 design) on maximum active trunk rotation, pelvic rotation and displacement of the COP of the ground reaction force. The second component investigated the effect of three different spinal postures (neutral, flexed, extended), pelvic fixation and direction of turn (3x2x2 design) on maximum active trunk rotation, pelvic rotation and displacement of the COP of the ground reaction force. Kinematic analysis involved 3-D motion analysis of thorax and pelvic segments during trunk rotation whilst kinetic analysis measured alterations in ground reaction forces to determine positional shifts in the body COP during trunk rotation. Trunk rotation or trunk axial rotation was defined as the summation of intersegmental rotations of the thoracic, lumbar and sacral spine segments.

A test-retest reliability study was also conducted on ten participants to investigate the reliability of trunk rotation measures.

3.2.2 **Study Participants**

Participants were male volunteers, aged 18 years and over who met the following inclusion/exclusion criteria.

Inclusion Criteria:

- Male
- Aged 18 yrs and over

Exclusion criteria:

- A history of cervical, thoracic, lumbar, pelvic or shoulder pain that:
  - restricted activities of daily living; or
  - required 1-week vocational absence in the last calendar year; or
  - that required treatment of any kind within the last 3 months;
- All neurological conditions;
- Previous spinal, thoracic or abdominal surgery;
- Participants who had competed in an asymmetrical sport at an elite level.

Participants in the study were recruited from the AUT University campus student and faculty populations and a private physiotherapy practice via faculty notice boards, campus electronic bulletin board and word-of-mouth (see Appendix i). Volunteers were given a participant information sheet that outlined their involvement and the potential risks of the study (see Appendix ii). Volunteers were assessed for eligibility by a post-graduate trained musculoskeletal physiotherapist following completion of their screening questionnaire and written consent form (see Appendix iii and iv). The eligibility assessment included identification of obvious spinal deformities such as scoliosis or significant thoracic kyphosis (associated with Scheurmann's disease) that would have excluded the volunteers from further participation in the study.

All volunteers who met the study criteria were included in the study and given a unique identification number. A systematic random sampling strategy was used to allocate participants to each testing session as they volunteered. Only one volunteer did not meet the inclusion criteria outlined in the screening questionnaire and was therefore excluded from participating in the study (see Figure 3.1). Twenty male participants (mean age 31.2 ± 8.1 yr; mean height 1.77 ± 0.06 m; mean weight 76.7 ± 11.3 kg; 15 right handed; 5 left handed) were recruited for the study.

The re-test reliability study involved retesting ten participants whose selection was dictated by participant availability within two weeks of initial testing. Difficulties in placement of certain markers were overcome by restricting the gender of the participants to males, which in turn reduced potential gender-bias variability in the outcome measures.

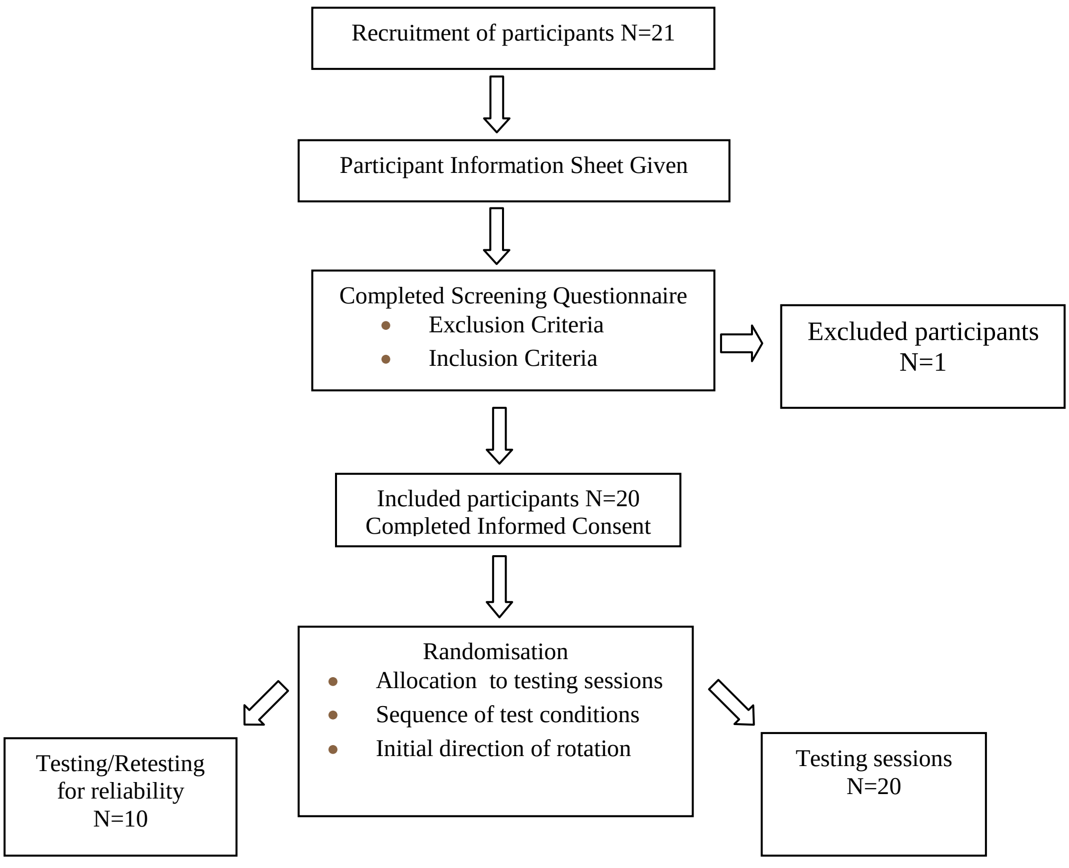


Figure 3.1 Study design

This study was conducted at the AUT University Health and Rehabilitation Research Centre (HRRC), Auckland, New Zealand. Ethical approval for the study was granted by the Auckland University of Technology Ethics Committee (AUTEC). Written informed consent was obtained from all participants prior to taking part in the study.

3.2.3 **Randomisation**

All participants were tested for active ROM trunk rotation in ten different test conditions involving three trunk inclinations; three spinal postures and fixation of the pelvis (see Table 3.1 and 3.2). The order of sequencing of the test conditions was determined by computer-generated random numbers for each participant. Each condition was sampled three times, with the initial direction of rotation also randomly allocated to participants, with the direction of subsequent rotations alternating thereafter.

3.2.4 **Independent Variables**

3.2.4.1 Trunk Inclination

Anterior trunk inclination describes flexing the trunk forward in the sagittal plane about the medial-lateral hip joint axis from a standing position while maintaining a neutral spine posture (seen in Figure 2.2). For this study, a neutral spine posture was considered as the participant’s normal resting thoracic kyphosis and lumbar lordosis curves found when standing. The trunk inclination start position for each of the test conditions was determined using a handheld digital inclinometer (Protech Autotilt, Wedge Innovations, Sunnyvale, California) mounted to a custom-moulded rigid thermoplastic plate attached to the sternum (seen in Figure 3.15). The sternum was chosen as the attachment point for the inclinometer as its position and relative rigidity in the thoracic cage was considered to most closely resemble movement of the most cephalad aspect of the trunk about the spinal axis in the sagittal plane. The inclinometer measured the ‘sternal angle’ defined as the angular displacement of the sternum in the sagittal plane relative to the vertical axis. The ‘resting sternal angle’ was defined as the sternal angle in a neutral spine posture (normal standing posture).

The resting sternal angles were measured and found to be between -4° and -20° posterior to the coronal plane. This variation was due to individual differences in the shape and tilt of the thoracic cage of the study participants. The resting sternal angle (designated as 0° for the study) was the start position for test position 1 and 2 for each participant. Test positions 3 and 4 were determined by inclining the trunk forward through 22.5° from the resting sternal angle. Test positions 5 and 6 were determined by inclining the trunk forward through 45° from the resting sternal angle. Test positions 1-6 maintained a neutral spinal posture. Test positions are outlined in Table 3.1 and Figure 3.2.

Table 3.1 Test positions for trunk inclination (see Figure 3.2)

Test Position	Trunk Inclination (0°, 22.5°, 45°)	Spinal Posture (Flexed/Extended/Neutral)	Pelvis Fixation (Free/Fixed)
1	0°	Neutral	Free
2	0°	Neutral	Fixed
3	22.5°	Neutral	Free
4	22.5°	Neutral	Fixed
5	45°	Neutral	Free
6	45°	Neutral	Fixed

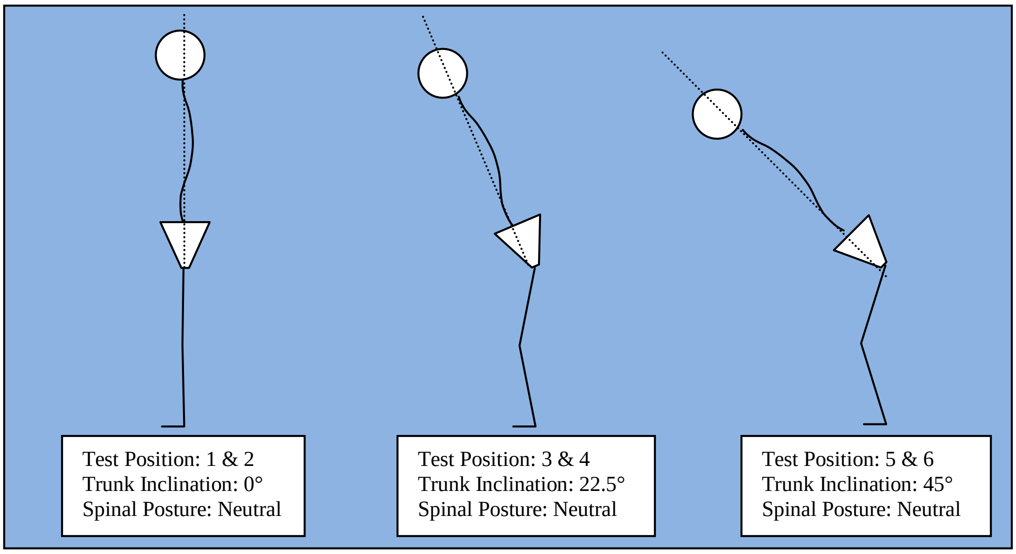


Figure 3.2 Test positions for trunk inclination

3.2.4.2 ***Spinal Posture***

Spinal posture describes the shape of the spine in the sagittal plane within the trunk, and is defined as alterations in the thoracic and lumbar curves into flexion or extension from the *neutral* posture at a trunk inclination of 45°. The start position for *flexed* posture (trunk flexion) involved each participant flexing the spine segmentally from the cervical spine through to the sacrum until the inclinometer on the sternal plate (outlined in the previous section) had moved through 45° from standing (test position 7 and 8). The *extended* posture (trunk extension) involved each participant extending the spine segmentally from the cervical spine through to the sacrum then inclining the trunk forward about the medial-lateral hip joint axis until the inclinometer had moved through 45° from the resting sternal angle (test position 9 and 10). Start positions are outlined in Table 3.2 and Figure 3.3.

Table 3.2 Test positions for spinal posture (see Figure 3.3)

Test Position	Trunk Inclination (0°, 22.5°, 45°)	Spinal Posture (Flexed/Extended/Neutral)	Pelvis Fixation (Free/Fixed)
5	45°	Neutral	Free
6	45°	Neutral	Fixed
7	45°	Flexed	Free
8	45°	Flexed	Fixed
9	45°	Extended	Free
10	45°	Extended	Fixed

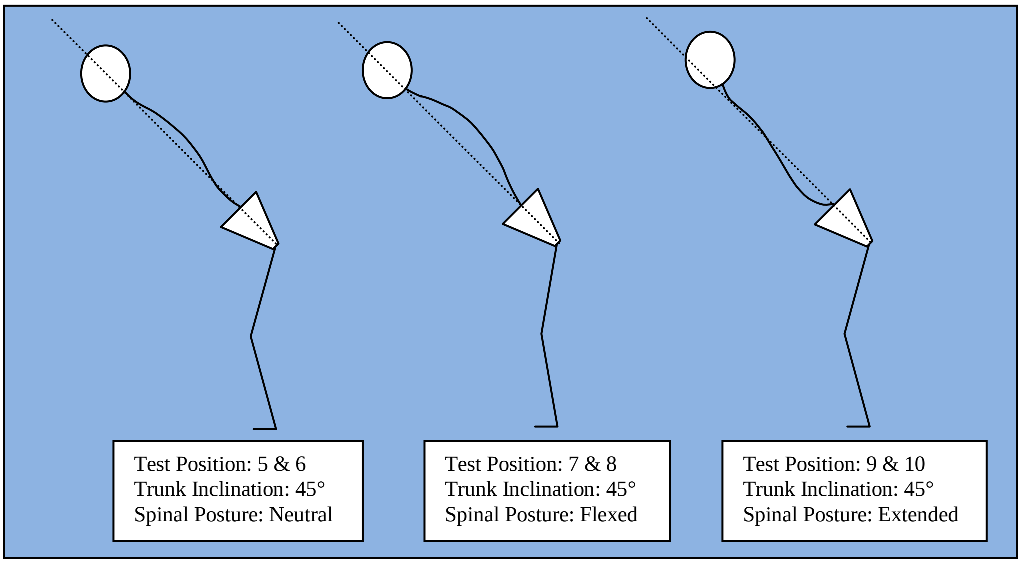


Figure 3.3 Test positions for spinal posture

3.2.4.3 ***Pelvic Fixation***

Pelvic fixation describes whether the pelvis was fixed or allowed to move freely during a specific test condition. A custom-built pelvic fixation device was retro-fitted to the laboratory floor around the force platform. This consisted of a platform that provided anchoring points for an adjustable belt system that was designed to secure the pelvis. Additional weights were strategically placed on the platform to eliminate potential flex in the customwood base. The adjustable non-stretch webbing belt was worn around the pelvis at the level of the pubic symphysis and four adjustable non-stretch webbing guy ropes were tightened accordingly to limit pelvic movement during active trunk rotation (see Figure 3.4). The waist belt had a rubber inlay designed to minimise slipping of the belt on the participants.

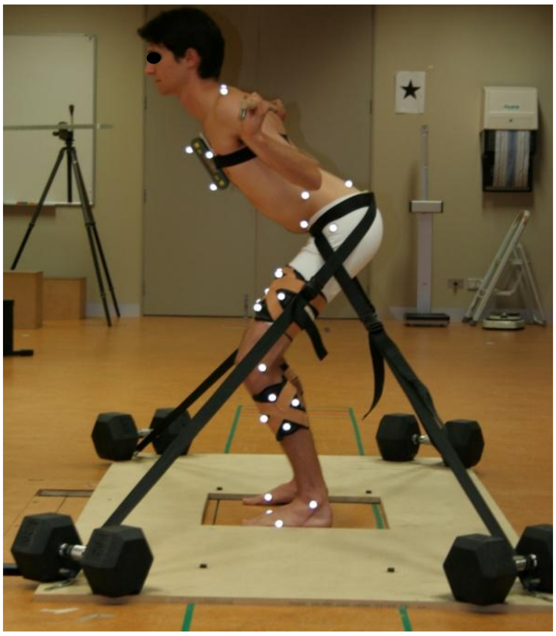


Figure 3.4 Pelvic fixation device

3.2.4.4 ***Direction of Turn***

Direction of turn describes whether the participant was turning to the left or right during experimental sampling. Whilst the starting direction for turning was randomised, each participant turned in both directions during each trial.

3.3 Experimental Measures

3.3.1 **Kinematics**

3.3.1.1 ***Motion Analysis***

A nine-camera motion analysis system (Qualysis Medical AB, Sweden) was used to record 3-D kinematic data of the thorax, pelvis and lower limb segments during active trunk rotation. The cameras were positioned to provide the maximum field-of-view of the experimental area (see Figure 3.5)

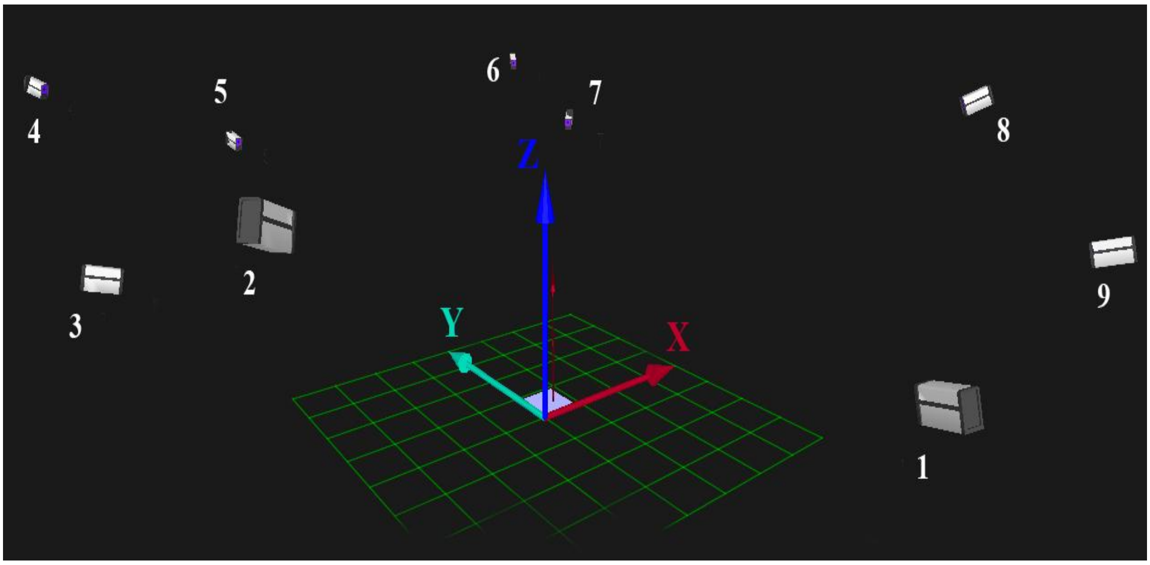


Figure 3.5 Camera placements of Qualysis system

The sampling rate for the motion analysis system was set at 240 Hz. The average movement residue (RES) for the retro-reflective markers during system calibration was minimal (less than 2 mm).

3.3.1.2 ***Tracking Markers***

The system, using infrared technology, individual retro-reflective markers that were fixed to 23 bony landmarks and five cluster marker sets fixed to the thorax, pelvis, thighs and shanks. Anatomical placements for the 19 mm-diameter retro-reflective markers are outlined below (see Figure 3.6 and 3.7).

- Spinous process of C7
- Acromioclavicular joint line bilaterally
- Anterior superior iliac spine (ASIS) bilaterally
- Superior aspect of the iliac crest bilaterally
- Posterior superior iliac spine (PSIS) bilaterally
- Superior tip of the greater trochanter bilaterally
- Medial and lateral epicondyle of the distal femur bilaterally
- Medial and lateral malleoli of the ankles bilaterally
- Lateral aspect of the 5th metatarsophalangeal joint line bilaterally
- Medial aspect of the 1st metatarsophalangeal joint line bilaterally

These anatomical markers were identified by palpation and marked by an experienced musculoskeletal physiotherapist, providing a reference marker set for construction of a skeletal model using a commercial biomechanical analysis software programme (Visual 3D, C-Motion Inc, USA).

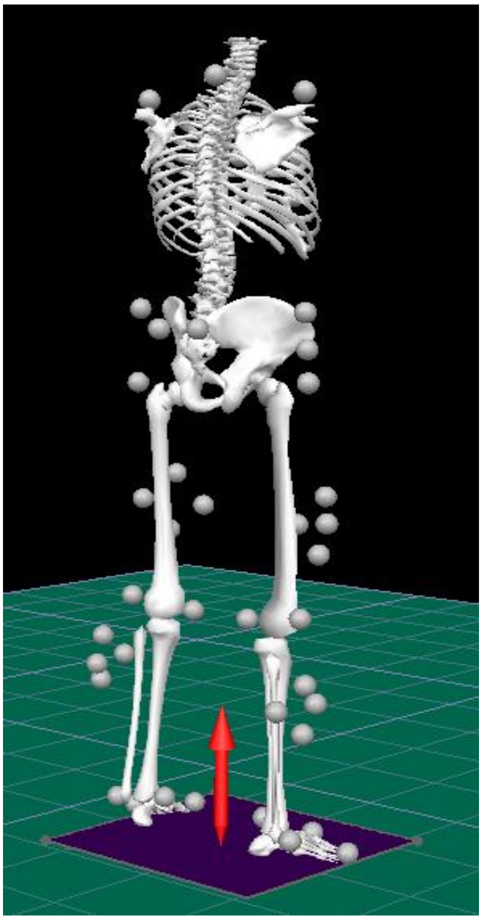


Figure 3.6 Marker placement – posterior view

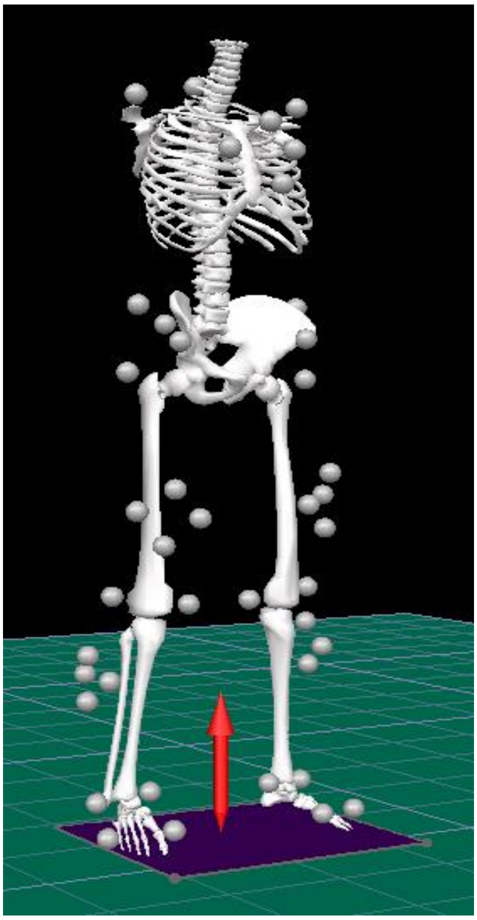


Figure 3.7 Marker placement - anterior view

Five cluster marker sets (defined as a group of four retro-reflective markers clustered together to track movement of a segment in six degrees of freedom) were fixed to the sternal plate and mid-segment locations on the thigh and shank segments bilaterally (see Figure 3.6 and 3.7).

3.3.1.3 ***Biomechanical Model***

In accordance with the modelling approach by Hanavan (1964), the anatomical placement of the markers (see Figure 3.6 and 3.7) was used to construct an eight-segment rigid link dynamic biomechanical model of the thorax, pelvis, and lower limbs.

These markers were used to create cylinders that represented the thorax, pelvis, thigh, shank and foot segments which were scaled according to the anthropometric data collected for each individual (Hanavan, 1964) (see Figure 3.8). The cluster markers were used to track the movement of the thorax and lower limb segments (Cappozzo, Cappello, Della Croce, & Pensalfini, 1997).

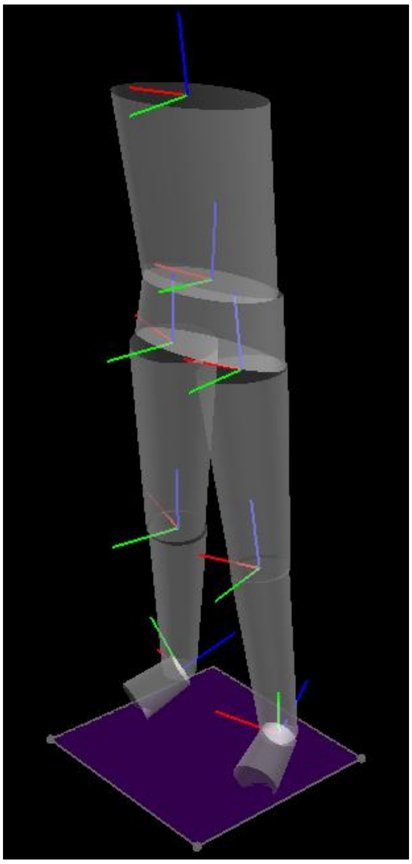


Figure 3.8 Geometric object construction for body segments

Initial data analysis using Visual 3D utilised the markers on the ASIS, PSIS and superior aspect of the iliac spine bilaterally to track the movement of the pelvis. Whilst these marker placements appear to be a standard method for tracking the pelvis during gait analysis (Cappozzo, 1991; Cappozzo, Catani, Della Croce, & Leardini, 1995), pilot study analysis revealed variability in the anterosuperior pelvic adipose deposition between participants combined with a substantial increase in soft tissue artifact error of the ASIS and superior iliac spine markers during trunk rotation. This meant that these tracking markers were not representative of the actual movement of the pelvis. Therefore a ‘virtual marker’ cluster set, developed from the PSIS markers, was used to track the movement of the pelvis (see Figure 3.9).

This virtual marker cluster set was constructed to establish at least three non-colinear points around each PSIS to allow measurement of six degrees of freedom of the pelvis in 3-D space (Cappozzo et al., 1997). The Visual 3D software was used to generate a superior and inferior virtual marker anteromedially to the markers attached to each PSIS. This allowed the continuous monitoring of pelvic movement in the event that any of the PSIS markers became obscured from the field-of-view during motion capture.

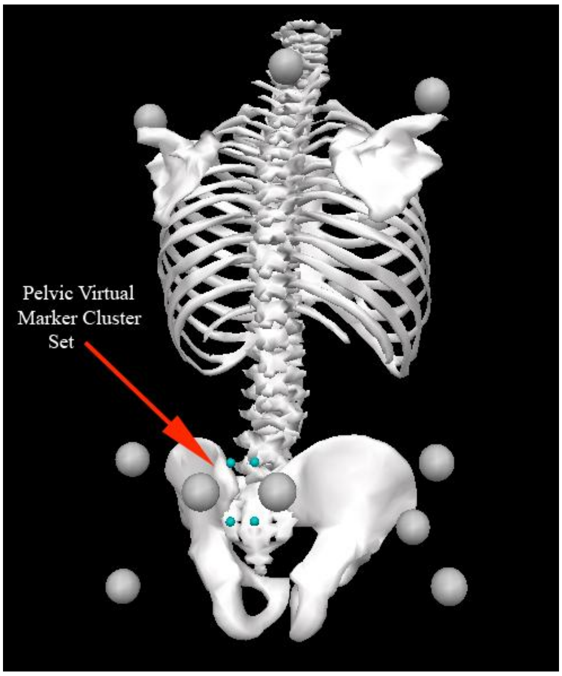


Figure 3.9 Pelvic virtual marker cluster set around PSIS markers

3.3.1.4 *Laboratory and Segment Orientation*

The orthogonal axes used to define the position of the thorax (X_T, Y_T, Z_T) and pelvic (X_P, Y_P, Z_P) segments were orientated such that the +X axis pointed laterally to the right in the coronal plane, the +Y axis pointed anteriorly in the sagittal plane and the +Z axis pointed vertically, perpendicular to the X and Y axes (see Table 3.3, Figure 3.10)

The coordinate system used to define the laboratory orientation (X_L, Y_L, Z_L) were orientated such that the + X axis pointed posteriorly in the sagittal plane, the + Y axis pointed laterally to the right in the coronal plane and the + Z axis pointed vertically, perpendicular to the X and Y axes (see Table 3.3, Figure 3.10).

Table 3.3 Axis orientations for thorax, pelvis, laboratory and force platform

Body Segment	Orthogonal Axis	Orientation
Thorax	$+X_T$	Lateral to the right in the coronal plane
	$+Y_T$	Anterior in the sagittal plane
	$+Z_T$	Vertical and perpendicular to X_T and Y_T axes
Pelvis	$+X_P$	Lateral to the right in the coronal plane
	$+Y_P$	Anterior in the sagittal plane
	$+Z_P$	Vertical and perpendicular to X_P and Y_P axes
Laboratory	$+X_L$	Posterior in the sagittal plane
	$+Y_L$	Lateral to the right in the coronal plane
	$+Z_L$	Vertical and perpendicular to X_L and Y_L axes
Force Platform	$+X_F$	Posterior in the sagittal plane
	$+Y_F$	Lateral to the right in the coronal plane
	$+Z_F$	Vertical and perpendicular to X_F and Y_F axes

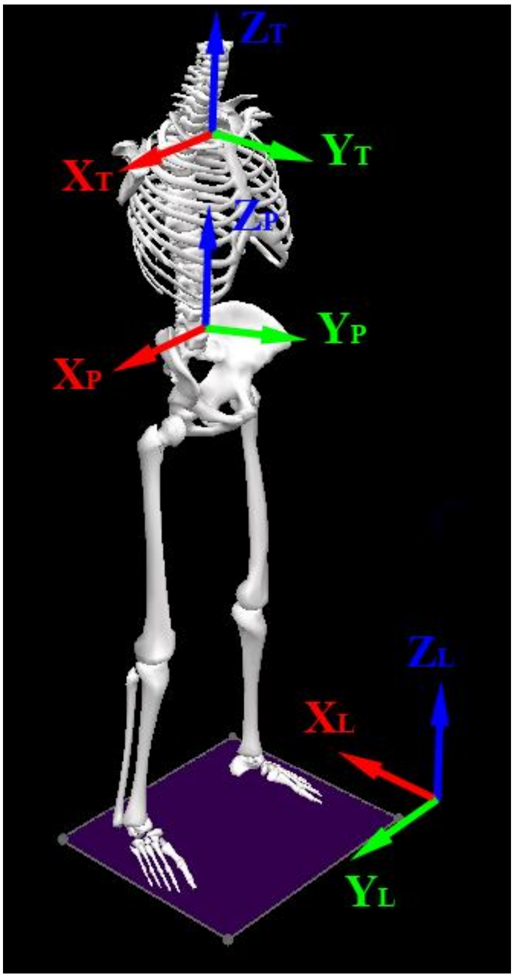


Figure 3.10 Axes orientation for body segments and laboratory

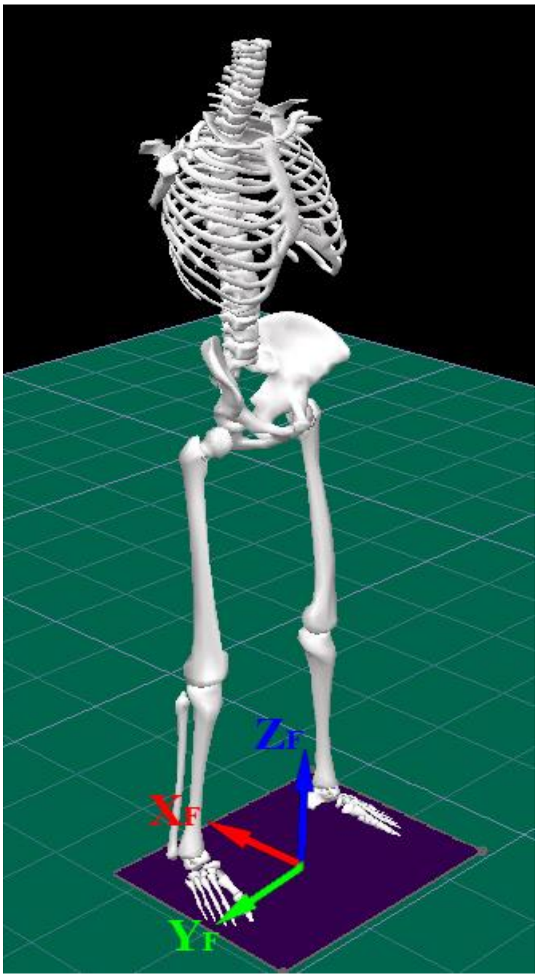


Figure 3.11 Axis orientation for force platform

*3.3.1.5 **Digital Video***

A digital video camera (Panasonic, USA), sampling at a rate of 60 Hz, was used in conjunction with the 3-D motion system to capture each experimental test simultaneously with the infrared motion tracking system and provided a visual back-up for the captured motion data.

3.3.2 **Kinetics**

3.3.2.1 ***Ground Reaction Forces***

During the experiment, participants were required to stand on an AMTI (Advanced Mechanical Technology Inc., USA) force platform. The force platform, sampling at a rate of 1200 Hz, recorded the magnitude of 3-D ground reaction forces and displacement of COP during each experimental condition. Force platform orientation is outlined in Table 3.3 and can be seen in Figure 3.11.

All kinematic and kinetic data was synchronised using the motion analysis software (Qualysis Track Manager, Version 1.10.283, Qualysis Medical AB, Sweden), tracking markers were identified and labelled and the static and motion capture files exported in C3D format for processing in Visual 3D.

3.4 Experimental Procedures

3.4.1 **Familiarisation Training**

Familiarisation training of the experimental procedure occurred prior to the experiment with all participants. This involved teaching participants how to reproduce the positional components of all ten test positions (trunk inclination, spinal posture, and pelvic fixation) as outlined in Table 3.1 and 3.2.

For trunk inclination, each participant was instructed on how to flex their trunk in the sagittal plane about their hip joint axis whilst maintaining a neutral spine (see Figure 2.2). This trunk segment flexion movement (the waiter’s bow) limits inter-segmental sagittal movement within the spine. A piece of dowel was held against the sacrum; mid-thoracic spine and posterior surface of the head to provide adequate proprioceptive feedback to the participant to eliminate inter-segmental spinal flexion occurring during the movement.

For spinal posture, each participant was instructed how to flex or extend their thoracolumbosacral spine in the sagittal plane (see Figure 3.12a, b, c).

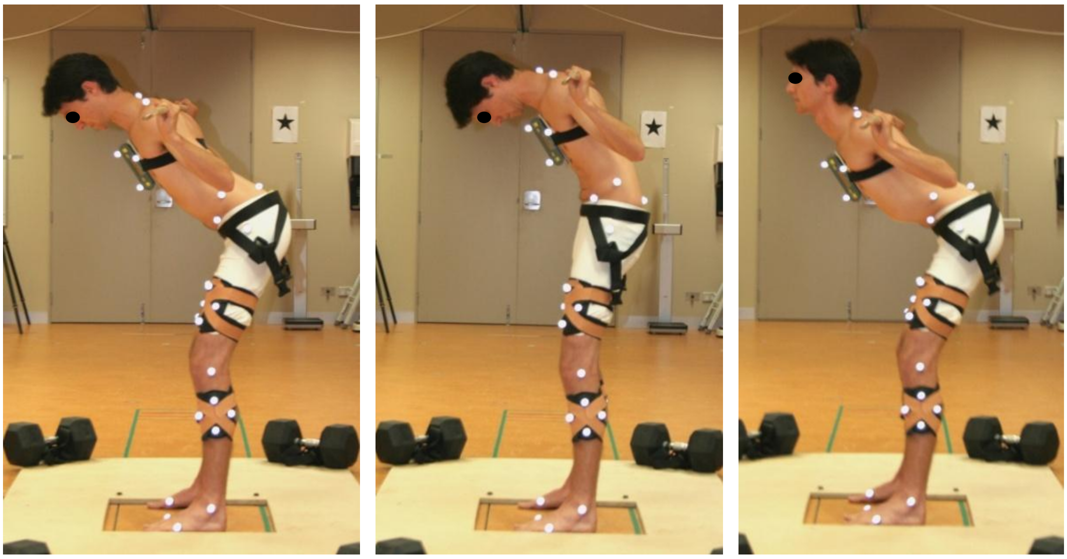


Figure 3.12 Spinal postures at 45° trunk inclination: a) Neutral; b) Flexed; c) Extended

For spinal flexion, the participants were instructed to segmentally flex their spine from the head down, involving flexion of the cervical spine which then followed into the thoracic and lumbar spine regions, until the inclinometer positioned on the sternum had reached the desired inclination of 45°.

For spinal extension, the participants were instructed to segmentally extend their spine from the head down, involving initial retraction of the head, cervical extension and progressive thoracolumbosacral extension (Willems et al., 1996). Once the thoracolumbosacral spine was fully extended, the participant then flexed about the medial-lateral hip joint axis until the inclinometer positioned on the sternum read 45°.

Each participant was taught to rotate their trunk about their spinal axis in varying degrees of trunk flexion without distorting the thoracolumbosacral spine in other planes (i.e. whilst maintaining a neutral spine). This was achieved by having each participant place the piece of dowel horizontally behind their shoulders, at approximately the level of T4, then rotating the dowel in a circular motion about their spinal axis whilst standing (trunk inclination = 0°). The use of the dowel encouraged segmental rotation from T1 down to the sacrum in a sequential fashion, and minimised scapulothoracic motion during rotation.

Once the participants had become familiar with turning around their spinal axis, they then inclined their trunk anteriorly about their hips in the sagittal plane and repeated the rotation movement at trunk inclinations of 22.5° and 45° (see Figure 3.13). Trunk rotation was also practiced in the trunk flexion and trunk extension positions at a 45° trunk inclination. This allowed participants to orientate themselves to performing trunk rotation in varying inclined positions and altered spinal postures. As the focus of the experiment was primarily on the effects of sagittal plane postures on trunk rotation ROM, all participants were encouraged to eliminate movement in the other planes of motion to control for these possible confounders (i.e. no side flexion in the coronal plane or further flexion/extension in the sagittal plane during rotation). Rigid handles were fixed to the dowel anteriorly to accommodate participants who lacked sufficient external rotation ROM of the shoulders to comfortably maintain the dowel in the testing position.

Once each participant was familiar with, and could consistently perform the required rotational movement about their spinal axis in the required trunk inclinations and spinal postures, they were fitted with markers and the pelvic fixation belt prior to data collection. Participants were taught how to use the pelvic fixation device prior to undertaking their first pelvis-fixed experimental condition.

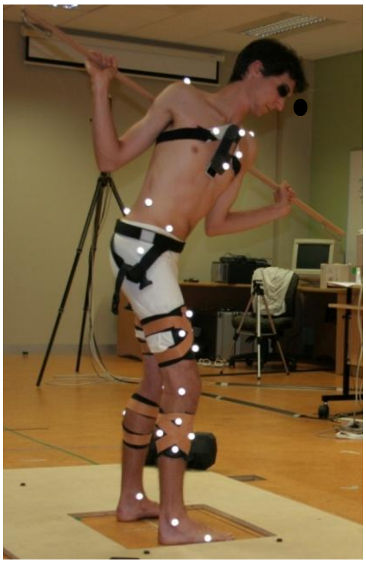


Figure 3.13 Trunk rotation around the spinal axis at a 45° trunk inclination

3.4.2 **System Calibration**

Prior to testing each participant, the nine-camera motion capture system was calibrated as per the manufacturer's protocol (Qualysis Medical, AB, Sweden), the AMTI force platform zeroed and calibrated for laboratory position and axis orientation.

3.4.3 **Participant Preparation**

On completion of familiarisation training all participants were attired in close-fitting sportswear and had their height (m), weight (kg) and age (yr) recorded. Participants were instructed to stand whilst retro-reflective makers were placed on the skin overlying bony landmarks of the thorax; pelvis and legs using double-sided hypoallergenic tape (see section 3.3.1.2). The cluster markers were fixed to the thorax, thighs and shanks using a combination of hypoallergenic tape, stretchy Velcro™ bands and rigid sports strapping tape (see Figure 3.14).

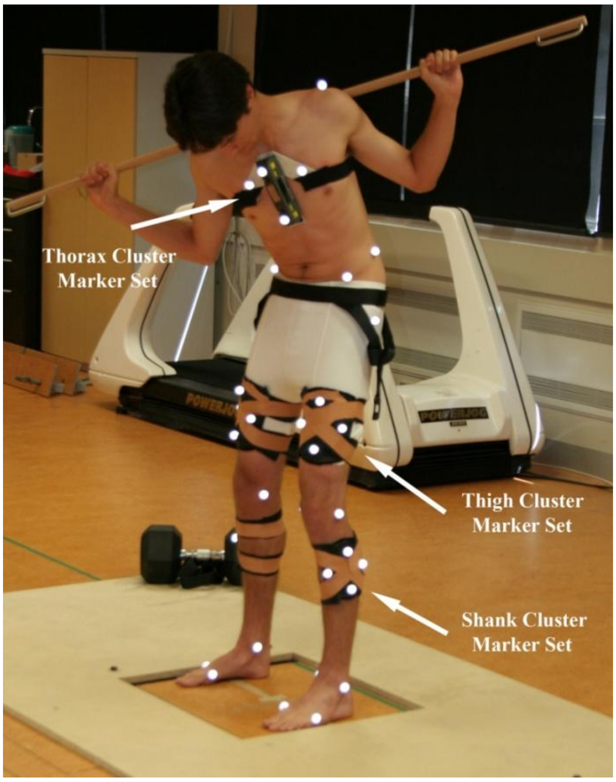


Figure 3.14 Thorax and lower limb cluster marker sets

The digital inclinometer was fitted to the sternal plate using Velcro™ and double-sided adhesive tape. Retro-reflective markers were fixed to the inclinometer and sternal plate using double-sided hypoallergenic tape and formed the cluster marker set for the thorax motion segment. The sternal plate was attached to the sternal body and manubrium using double-sided adhesive tape and a stretchy Velcro™ band (see Figure 3.15).

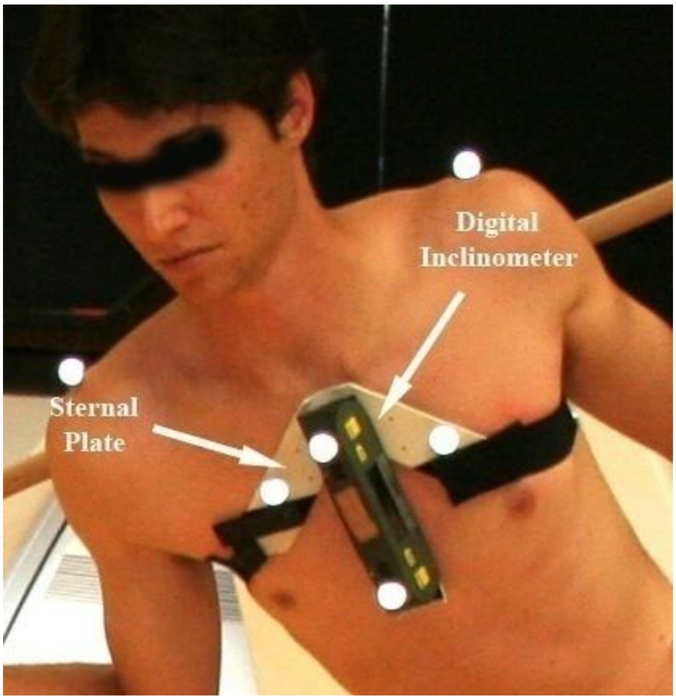


Figure 3.15 Sternal plate with inclinometer and cluster marker set

3.4.4 **Test-Retest Measures**

Based on the number of participants used in previous reliability and repeatability studies (Edmondston et al., 2007; Petersen et al., 1994; Smith et al., 1985), ten participants underwent a test-retest reliability study to determine the reliability of experimental procedures and outcome measures, with retesting occurring within seven to 14 days after participants initial test session. Findings of the test-retest reliability study showed favourable results. Data from a further ten participants was added to data collected from the test sessions of the participants involved in the reliability study. The order in which the test conditions were performed for all retests in the reliability study was randomised as per the original protocol (see section 3.2.3).

3.4.5 Testing Session

Initially, each participant was instructed to walk onto the force platform and stand with the lateral aspect of their feet, just inside the lateral edges of the force platform (approximately shoulder width apart). Once stationary, a six-second recording of the participant's position was captured with the motion analysis system, along with kinetic data from the AMTI force platform and the inclinometer angle of the sternal plate. This recording was used to create a 'static file' incorporating the position and orientation of the body segments via the anatomical and cluster markers, which were then exported in C3D file format. The resting sternal angle in this static capture file was considered the 0° start position for the trunk inclination.

Each participant was then tested in each of the ten test conditions as per their randomisation format. Three trials were performed for each condition. Trial 1 began by instructing the participant to start turning in one direction as per the randomisation format. The participant was instructed to turn as far as they could in one direction and pause, then as far as they could in the other direction and pause, then back to the start position with ongoing verbal encouragement throughout the trial. Participants were instructed to maintain the neutral, flexed or extended spinal postures during the trunk rotation trials and this was monitored by the researchers. Participants who were identified as having visibly moved out of the test position during rotation were asked to repeat the movement trial in the correct manner.

The use of a metronome ensured each trial was completed over a time period of ten seconds, to control for the effects that angular velocity of the trunk may have on the trunk rotation ranges of motion. The influence of velocity on torque production on the musculotendinous and ligamentous structures of the trunk has been shown to be minor if angular velocity is kept below 60°/sec (McGill & Hoodless, 1990). All test positions involved the participants adopting a small degree of knee flexion (1/4 squat position) to negate the possible effects that potential differences in hamstring length between participants may have had on restricting trunk rotation.

In the five pelvis-fixed test conditions the participants were instructed to generate tension in the webbing guy ropes by actively extending through the hips and knees. This was verbally reinforced throughout all trials of the pelvis-fixed conditions. The participants were instructed to rest between trials to minimise possible effects from fatigue. No adverse reactions to any aspect of the methodology were reported.

3.4.6 **Outcome Measures**

Outcome measures recorded for each participant were:

i. Unilateral Trunk Rotation - defined as unilateral axial rotation (°) of the thorax on the pelvis about the respective z axes of the local segments coordinate system

ii. Unilateral Pelvic Rotation - defined as unilateral pelvic rotation (°) about z axis of the pelvis (see Figure 3.10).

iii. Displacement of COP - defined as translation (m) of the COP along the x (anterior-posterior or AP) or y (lateral) axes of the force platform (see Figure 3.11)

3.4.7 **Data Processing**

Each trial tracked using the Qualysis motion capture software and exported to Visual 3D. The anatomical and cluster markers captured in the static file, combined with the anthropometric data of each participant (Dempster, 1955), provided the necessary input parameters for calculating the shape and mass of the appropriate geometric object used to represent each body segment. The combined segments formed a rigid-link model with joints depicted as hinge joints rotating about fixed axes. The rigid-link model was then assigned to the imported motion files. The data from the motion files was filtered with a second-order Butterworth bidirectional low-pass filter with a frequency cut-off of 12 Hz, to eliminate noise artifacts typically associated with skin movement artifact error. Similarly, the same method, using a frequency cut-off of 70 Hz, was used to smooth and eradicate noise within the force platform data. The respective cut-off frequencies were selected after analysis of the frequency power spectrum of both signals to determine where the majority of the frequency component signal lay.

All relevant kinematic and kinetic data was subsequently exported as 'ASCII' files for importing into a Microsoft Excel Spreadsheet prior to undergoing statistical analysis.

3.5 Statistical Analysis

Test-retest reliability was calculated using Interclass Correlation Coefficients (ICC) and Bland Altman graphs for the ten participants who undertook the reliability study.

All data was analysed using SPSS v15.0 (SPSS Inc., Chicago) statistical computer software package. A repeated-measures multiple analysis of variance (MANOVA) was used to test for the main effects of the four independent variables: trunk inclination, spinal posture, fixation of pelvis and direction of turn on the dependent variables measured (maximum active ROM of trunk rotation, the maximum pelvic rotation and the AP and lateral displacement of the COP). The statistical significance level was set at $p<0.05$.

Data was initially scrutinised using a box plot method for statistical outliers, with two outliers identified. Review of the motion capture and video data associated with these outliers revealed that the participants had failed to adequately maintain the required test position during one of the three trials. These outliers were subsequently removed prior to commencement of statistical analysis. Where significant, *post hoc* analysis was performed using Fisher's Least Significant Differences (LSD).

CHAPTER FOUR

Results

4.1 Introduction

This chapter presents the findings from this study and is divided into five sections to represent the main areas of investigation. The first section provides the results of the reliability study. Following this, the second and third sections present the results of the investigation into the effect of trunk inclination and spinal posture on each of the dependent measures. The chapter concludes by presenting the results pertaining to the effect of both pelvic fixation and direction of turn on the dependent measures.

4.2 Reliability Study

Test-retest reliability, expressed in terms of interclass correlation coefficients (ICC) and/or Bland Altman graphs, were obtained for the measurement of each dependent variable (see Table 4.1), each of the test conditions (see Table 4.2 and 4.3), and the reproducibility of the start positions (see Table 4.4). The ICC measure is expressed as a decimal value between 0 and 1 (Bliese, 1998), with values approaching 1 indicating perfect reliability between the test and retest measures. A categorisation of reliability outlined by Landis and Koch (Landis & Koch, 1977) and used recently by Troke, Schuit and Petersen (Troke, Schuit, & Petersen, 2007) when investigating reliability of lumbar ROM measures reports ICC values of 0.41-0.60 as *moderate* reliability, 0.61-0.80 as s*ubstantial* reliability and above 0.81 as *almost perfect*.

4.2.1 **Dependent Variables**

Ten participants were tested as part of the reliability study. To determine the reliability of measures between the test and retest sessions, the ICC and confidence interval (CI) for the four dependent variables or trunk rotation, pelvic rotation, AP displacement of COP and lateral displacement of COP were calculated (see Table 4.1).

Table 4.1 Reliability for dependent variables for test-retest measures of trunk rotation, pelvic rotation, AP & lateral displacement of the COP

Dependent Variable	ICC	95% CI
Trunk Rotation	0.655	0.562 – 0.731
Pelvis Rotation	0.918	0.893 – 0.937
AP Displacement COP	0.427	0.306 - 0.533
Lateral Displacement COP	0.738	0.665 - 0.796

Based on this classification scheme by Landis and Koch (1977), the reliability for maximum trunk rotation ROM could be considered *substantial* (ICC=0.655). Results revealed the actual error between repeated measures of trunk rotation ROM across the test and retest sessions averaged between 1-2°. The reliability for pelvic rotation was *almost perfect* (ICC=0.918). The reliability for AP displacement of the COP was *moderate* (ICC=0.427) and the reliability for lateral displacement of the COP was *substantial* (0.738). The level of agreement, particularly for trunk rotation and pelvic rotation demonstrates that participants' ability to perform trunk rotation for each of the test conditions is reproducible on two separate days.

4.2.2 **Independent Variables**

Table 4.2 and 4.3 summarises the ICC's and confidence intervals calculated for reliability of all measurements taken in each of the ten test conditions (see Table 3.1 and 3.2). All ICC values ranged between 0.943 and 0.985 which demonstrated an almost perfect level of agreement between the test and retest measures, with a highly significant correlation between the test and retest sessions.

Table 4.2 Reliability for trunk inclination testing

Independent Variable	ICC	95% CI
Trunk Inclination		
0° - Pelvis Free	0.954	0.929 - 0.970
0° - Pelvis Fixed	0.982	0.972 - 0.989
22.5° - Pelvis Free	0.943	0.913 - 0.963
22.5° - Pelvis Fixed	0.982	0.971 - 0.988
45° - Pelvis Free	0.966	0.948 - 0.978
45° - Pelvis Fixed	0.987	0.980 - 0.992

Table 4.3 Reliability for spinal posture testing

Independent Variable	ICC	95% CI
Spinal Posture		
Neutral - Pelvis Free	0.966	0.948 - 0.978
Neutral - Pelvis Fixed	0.987	0.980 - 0.992
Flexed - Pelvis Free	0.958	0.935 - 0.973
Flexed - Pelvis Fixed	0.985	0.977 - 0.991
Extended - Pelvis Free	0.953	0.928 - 0.970
Extended - Pelvis Fixed	0.984	0.975 - 0.990

Despite a relatively small sample size, the moderate to high ICC values demonstrate that the measurement of the four dependent variables (trunk rotation, pelvic rotation, AP and lateral displacement of the COP) are highly repeatable irrespective of alterations in the trunk inclination, spinal posture, pelvic fixation or direction of turn. The results suggest that participants were able to reproduce the postures and movements between test sessions. Whilst these ICC demonstrate a strong relationship between the data from test and retest sessions, presentation of the data in the form of a Bland Altman graph (Bland & Altman, 1986) can help to visually verify the repeatability of the data between the test and retest sessions. When repeatability between the testing sessions is high, the data points will be randomly distributed about the mean, indicating that there is no bias evident between the test-retest sessions. As an example, the ICC for test-retest repeatability of trunk rotation at a 45° inclination with the pelvis free demonstrated *substantial* test-retest reliability when turning to the left (ICC=0.626) and right (ICC=0.684). With reference to the Bland Altman graphs presented in Figure 4.1 and 4.2, the mean difference between the test and retest sessions in this instance was close to zero and the data points for the majority of participants lay close to the mean when turning in both directions, suggesting that the participants were capable of reproducing the trunk rotation in the test position on subsequent days. The limits of agreement on the Bland Altman graphs are set at 1.96 standard deviations (see Figure 4.1 and 4.2) and demonstrate that we are 95% confident that the that trunk rotation values will vary no more than ±6.3° when turning to the left and ±5.6° when turning to the right in the current test position. It should be noted that the outliers demonstrate that at least one of subjects appeared less able to reproduce trunk rotation in this test position between sessions, which acts to widen the limits of agreement.

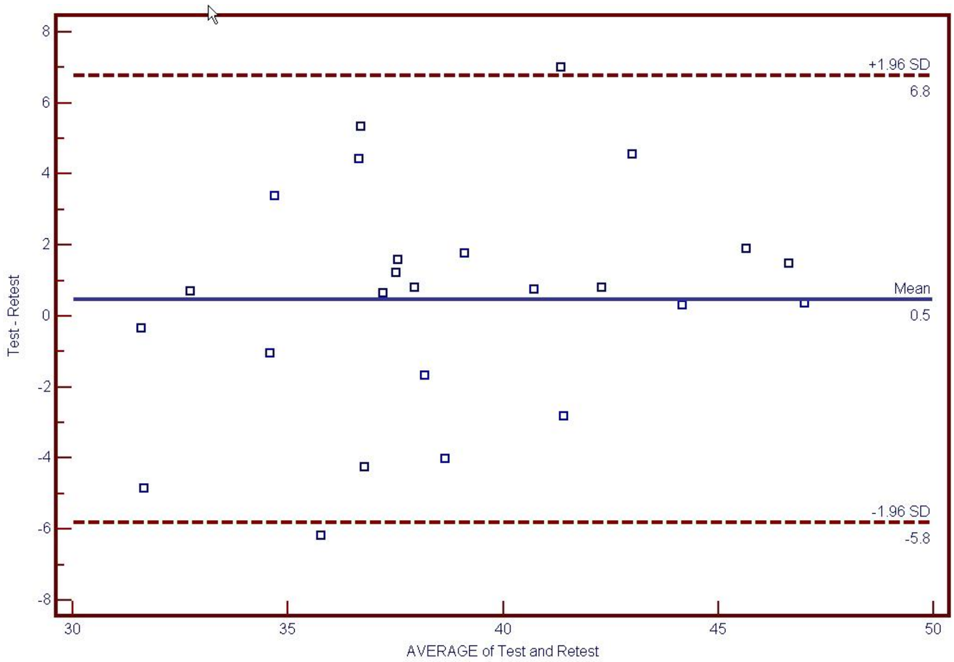


Figure 4.1 Bland and Altman graph for left trunk rotation at 45° trunk inclination with a neutral spine

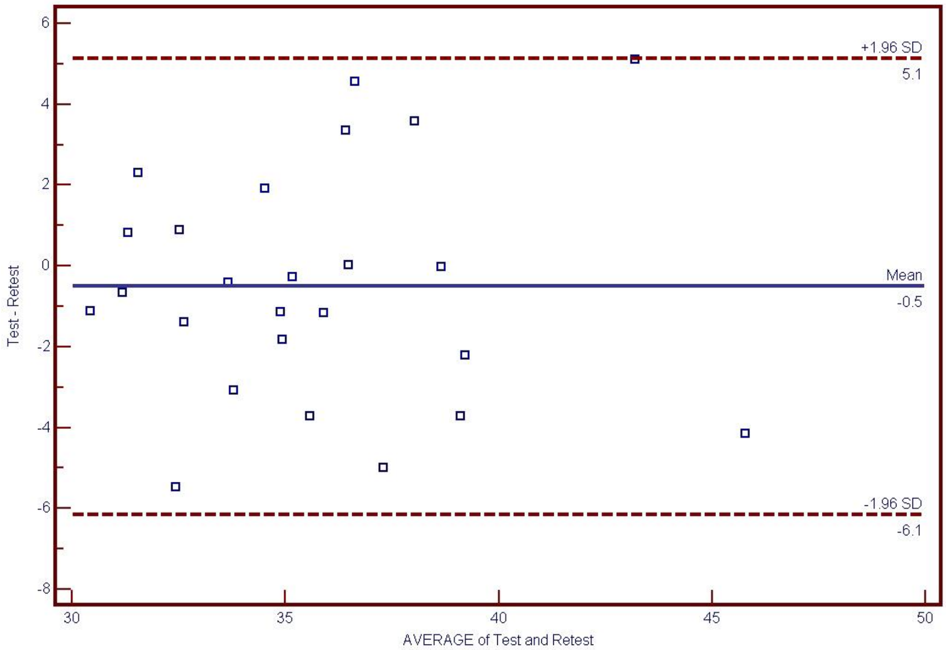


Figure 4.2 Bland and Altman graph for right trunk rotation at 45° trunk inclination with a neutral spine

4.2.3 **Start Positions**

Table 4.4 summarises the ICC's and confidence intervals calculated for reliability of the start positions for trunk inclination (0°, 22.5°, 45°) and spinal posture (neutral, flexed, extended). These ICC values of 0.965 and 0.603 demonstrated *almost perfect* and *substantial* reliability for reproduction of the trunk inclination and spinal posture start positions respectively, and represent the participant's ability to reproduce the start positions across the three trials for each test condition.

Table 4.4 Reliability for trunk inclination and spinal posture start positions

	ICC	95% CI
Start Positions for:		
Trunk Inclination (0°, 22.5°, 45°)	0.965	0.947 - 0.977
Spinal Posture (Neutral, Flexed, Extended)	0.603	0.451 - 0.720

Table 4.5 outlines the mean start position for all participants for each of the ten test positions (see Table 3.1 and 3.2) as recorded by the motion analysis system, compared to the participants' calibration position using the sternal-mounted inclinometer. This demonstrates the relative positional error in using the inclinometer to monitor the start position of each test position compared to the motion analysis system averaged between 0.8 and 4.8°.

Table 4.5 Average start positions (°) for the ten test positions as recorded by the motion analysis system (mean ± standard deviation)

Test Position	0° - Neutral	22.5° - Neutral	45° - Neutral	45° - Flexed	45° - Extended
Pelvis Free	1.7 (3.8)	21.4 (4.3)	42.0 (4.4)	45.8 (5.3)	40.9 (4.8)
Pelvis Fixed	2.1 (3.1)	21.4 (4.4)	41.9 (4.9)	46.8 (4.7)	40.2 (4.7)

4.3 Main Study

4.3.1 Trunk Inclination

Trunk inclination (0°, 22.5°, 45°) was found to have had a significant main effect on three of the dependent variables, trunk rotation ($p<0.001$), pelvic rotation ($p<0.001$), and lateral displacement of the COP ($p<0.005$). The descriptive statistics for maximum unilateral trunk rotation, pelvic rotation and displacement of the COP at each of the three trunk inclinations are presented in Tables 4.6, 4.7 and 4.8.

Table 4.6 Average maximum values for trunk rotation ROM, pelvic rotation ROM, lateral and AP displacement of COP with alterations in trunk inclination (mean ± standard deviation)

Trunk Inclination	0°	22.5°	45°
Unilateral Trunk Rotation (°)	35.7 (6.4)	36.9 (5.8)	39.1 (5.2)
Unilateral Pelvic Rotation (°)	36.4 (29.7)	28.6 24.9)	23.0 (21.7)
Right Lateral Displacement of COP (m)	0.021 (0.018)	0.031 (0.024)	0.029 (0.020)
Left Lateral Displacement of COP (m)	-0.027 (0.015)	-0.030 (0.019)	-0.028 (0.021)
Anterior Displacement of COP (m)	-0.031 (0.017)	-0.029 (0.017)	-0.028 (0.018)
Posterior Displacement of COP (m)	0.011 (0.009)	0.013 (0.009)	0.014 (0.013)

Anterior and left lateral displacements of the COP are represented by negative integers (-)

Table 4.7 Maximum and minimum values for trunk rotation ROM, pelvic rotation ROM, lateral and AP displacement of COP with alterations in trunk inclination

Trunk Inclination	0°		22.5°		45°	
	Max	Min	Max	Min	Max	Min
Unilateral Trunk Rotation (°)	49.6	21.7	49.4	24.7	50.7	29.4
Unilateral Pelvic Rotation (°)	90.8	1.8	88.9	1.8	86.5	1.8
Right Lateral Displacement of COP (m)	0.069	0.008	0.096	0.007	0.114	0.007
Left Lateral Displacement of COP (m)	-0.062	-0.001	-0.108	-0.005	-0.109	-0.001
Anterior Displacement of COP (m)	-0.072	-0.002	-0.071	-0.000	-0.074	-0.001
Posterior Displacement of COP (m)	0.040	0.001	0.034	0.001	0.076	0.001

Anterior and left lateral displacements of the COP are represented by negative integers (-)

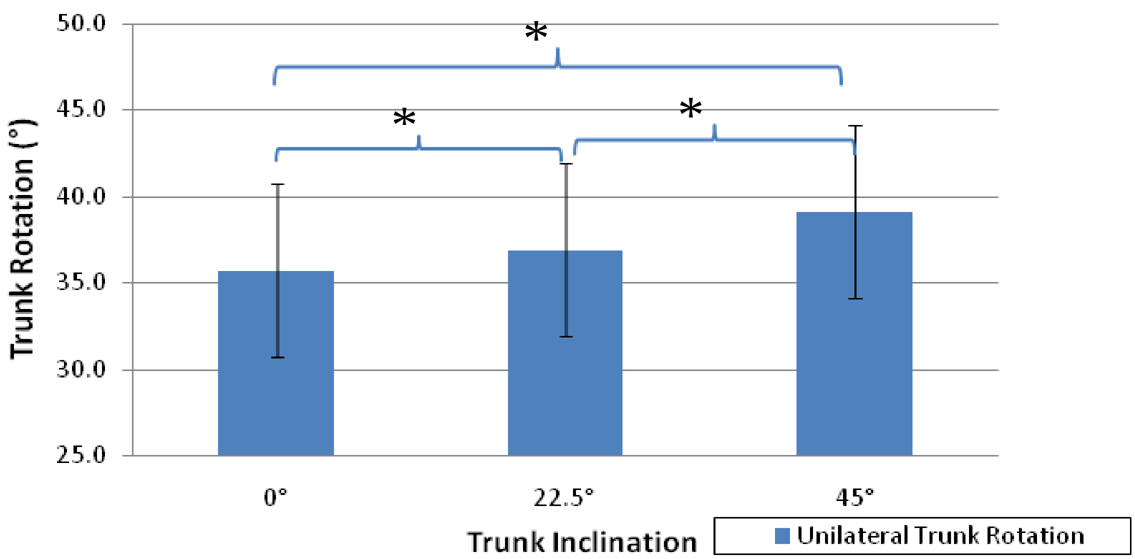
Table 4.8 Descriptive statistics for the four dependent measures for trunk inclination (mean ± standard deviation)

	Trunk Inclination											
Inclination	0°				22.5°				45°			
Pelvic Fixation	Free		Fixed		Free		Fixed		Free		Fixed	
Direction of Movement	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Trunk Rotation (°)	33.6 (5.0)	30.5 (4.4)	40.5 (4.9)	38.1 (6.1)	35.8 (5.5)	32.8 (4.8)	41.0 (4.7)	38.0 (4.9)	39.2 (5.4)	37.2 (5.1)	40.5 (4.8)	39.4 (5.2)
Pelvic Rotation (°)	63.6 (15.3)	64.2 (15.0)	8.6 (2.3)	9.3 (4.4)	48.5 (20.6)	49.4 (19.7)	8.3 (4.0)	8.3 (3.9)	37.5 (21.9)	39.3 (21.6)	8.2 (2.7)	7.0 (3.0)
Displacement of COP - Lateral (y) (m)	0.026 (0.022)	0.035 (0.015)	0.016 (0.010)	0.018 (0.009)	0.038 (0.024)	0.037 (0.014)	0.021 (0.010)	0.019 (0.012)	0.035 (0.015)	0.036 (0.017)	0.020 (0.010)	0.024 (0.014)
Direction of Movement	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior
Displacement of COP - AP (x) (m)	0.016 (0.008)	0.040 (0.014)	0.056 (0.005)	0.022 (0.016)	0.012 (0.007)	0.042 (0.014)	0.013 (0.010)	0.015 (0.009)	0.013 (0.008)	0.039 (0.017)	0.012 (0.009)	0.015 (0.009)

COP=centre of pressure; AP=anterior-posterior

4.3.1.1 ***Trunk Rotation***

Figure 4.3 displays the results of the *post hoc* analysis of the significant effect of trunk inclination on trunk rotation, showing that a significant difference in maximum unilateral trunk rotation ROM existed between all three trunk inclinations ($p<0.01$). As trunk inclination increased, there was a significant increase in maximum unilateral trunk rotation ($p<0.01$), with marginal means of 35.7°, 36.9°, 39.1° for 0°, 22.5°, 45° of inclination respectively (see Table 4.6). The maximum mean trunk rotation across all trunk inclination test conditions was 50.7° and occurred at 45° trunk inclination (see Table 4.7).



* = significant effect ($p<0.01$)

Figure 4.3 Average maximum unilateral trunk rotation ROM for three trunk inclinations (mean ± standard deviation)

An interaction effect ($p<0.001$) was found between trunk inclination and pelvic fixation for the maximum trunk rotation range during trunk rotation (see Figure 4.4).

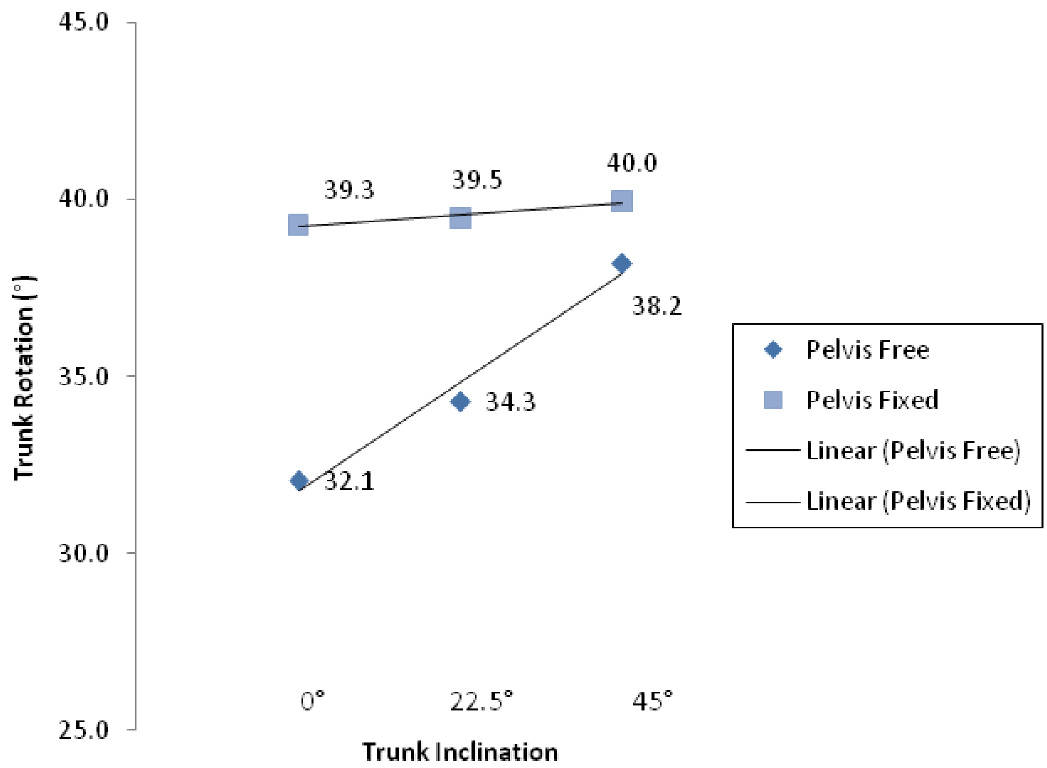
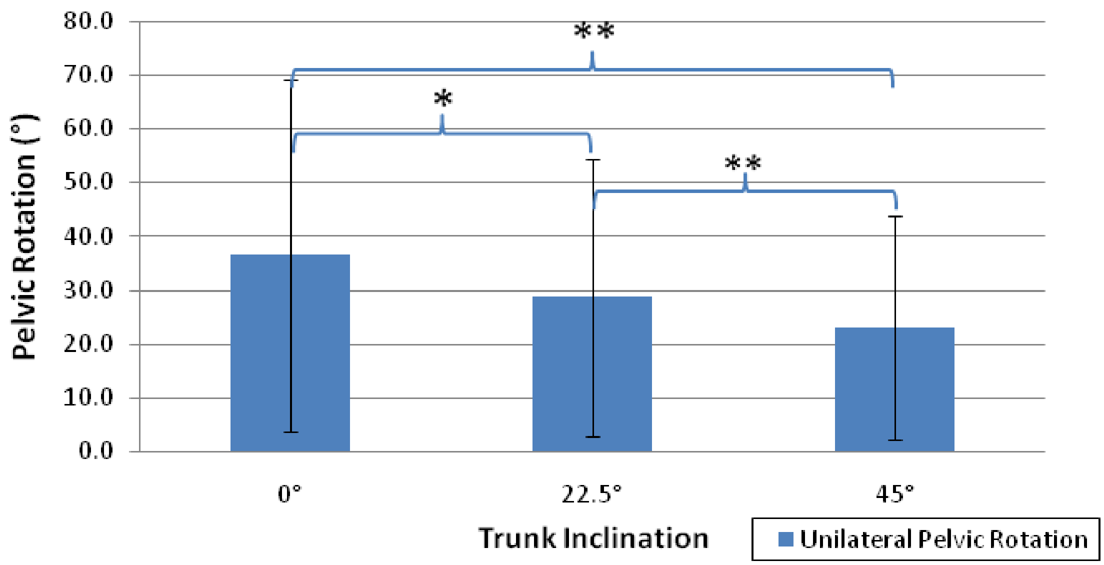


Figure 4.4 Mean maximum trunk rotation for each trunk inclination with the pelvis fixed and the pelvis free during trunk rotation

Figure 4.4 shows the interaction effect between trunk inclination and pelvic fixation, demonstrating that when the pelvis is fixed, increases in trunk inclination exert less influence on the ability for the trunk to maximally rotate.

4.3.1.2 ***Pelvic Rotation***

Figure 4.5 displays the results of the *post hoc* analysis of the significant effect of trunk inclination on pelvic rotation, showing that a significant difference in pelvic rotation ROM existed between all three trunk inclinations. As trunk inclination increased there was a significant decrease in unilateral pelvic rotation, with mean values of 36.4°, 28.6°, 23.0° of rotation reported for 0°, 22.5°, 45° of inclination respectively (see Table 4.6).



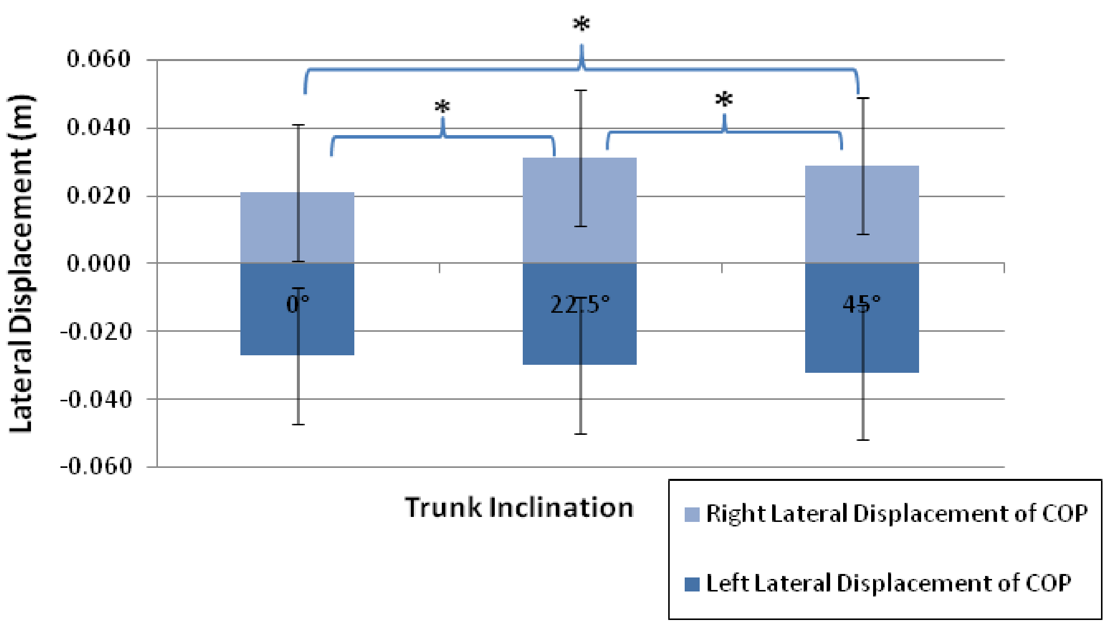
* = significant effect (p<0.005); ** =significant effect (p<0.001)

Figure 4.5 Average unilateral pelvic rotation ROM for three trunk inclinations (mean ± standard deviation)

4.3.1.3 ***Lateral Displacement of the COP***

Figure 4.6 displays the results of the *post hoc* analysis of the significant effect of trunk inclination on lateral displacement of the COP, showing that a significant difference in lateral displacement of the COP existed between all three trunk inclinations. Trunk inclination at 22.5° and 45° averaged significantly more ($p<0.005$) lateral displacement (0.006 m and 0.005 m respectively) compared to 0°, as did lateral displacement between 22.5° and 45° ($p<0.005$) (0.006 m more at 22.5°) (see Table 4.6).

The average lateral displacement of the COP was 0.024 m at 0°, 0.031 m at 22.5° and 0.029 m at 45° (see Table 4.6). As trunk inclination increased, the maximum values for lateral displacement of the COP for the group increased also (see Table 4.7).

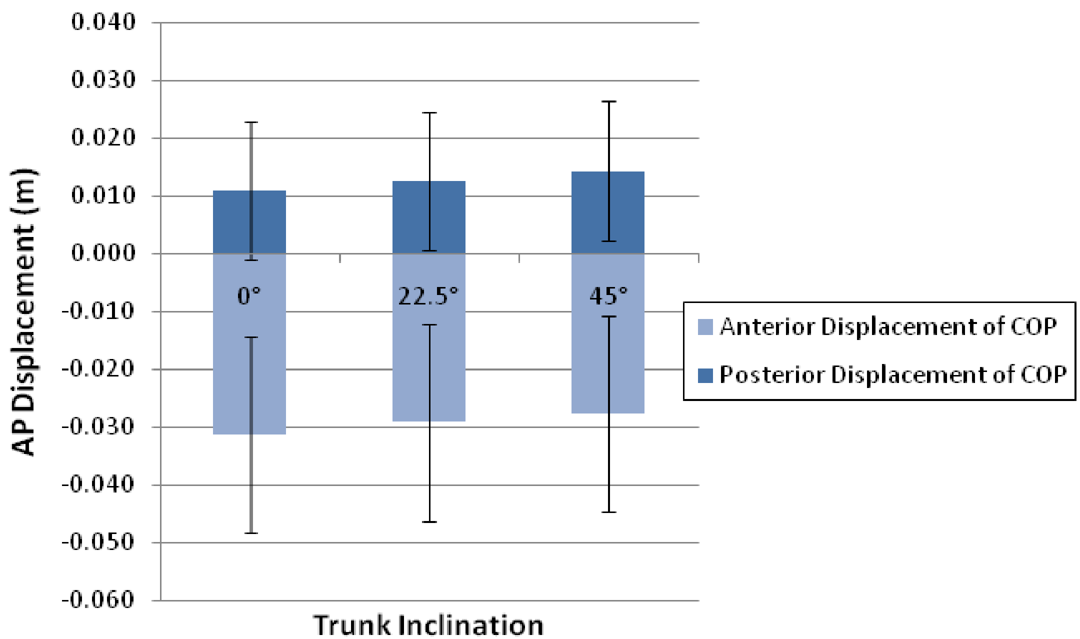


* = significant effect ($p<0.005$)

Figure 4.6 Average lateral displacement of the COP during trunk rotation in three inclined postures (mean ± standard deviation)

4.3.1.4 ***AP Displacement of the COP***

Alterations in trunk inclination did not significantly affect AP displacement of the COP during maximal trunk rotation (see Figure 4.7). The mean anterior displacement of the COP was 0.031 m at 0°, 0.029 m at 22.5° and 0.028 m at 45° (see Table 4.6). This was at least twice as far as posterior displacement of the COP in all positions (0.011 at 0°, 0.013 at 22.5° and 0.014 at 45°) (see Table 4.6).



NB: no significant effect (p>0.05)

Figure 4.7 Average AP displacement of the COP during trunk rotation in three inclined postures (mean ± standard deviation)

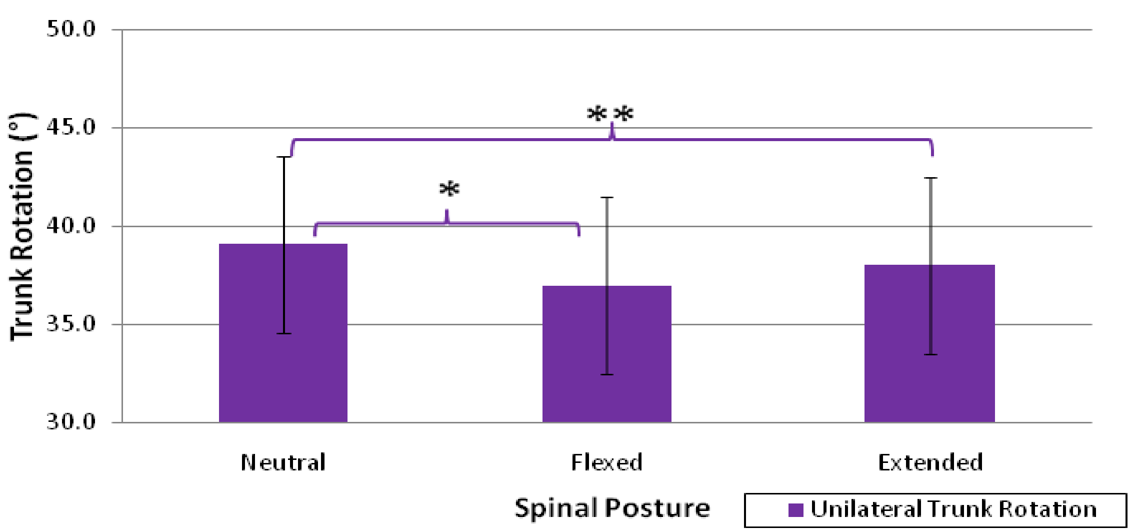
4.3.2 Spinal Posture

Spinal posture (neutral, flexed, extended) had a significant main effect on two of the dependent variables, trunk rotation ($p<0.01$) and pelvic rotation ($p<0.05$). The descriptive statistics are presented in Tables 4.9, 4.10 and 4.11.

*4.3.2.1 **Trunk Rotation***

Figure 4.8 displays the results of the *post hoc* analysis of the significant effect of spinal posture on trunk rotation, showing that a significant difference in maximum unilateral trunk rotation ROM existed between all three spinal postures. A neutral spine yielded significantly more trunk rotation than both flexed (1.2° more) and extended spinal postures (1.1° more) (see Table 4.10).

The minimum unilateral trunk rotation value across all spinal postures occurred in neutral (26.3°) whilst the maximum value was recorded in extension (50.7°) (see Table 4.11).



* = significant effect (p<0.01); ** =significant effect (p<0.05)

Figure 4.8 Average maximum unilateral trunk rotation ROM for three spinal postures (mean ± standard deviation)

Table 4.9 Descriptive statistics for the four dependent measures for spinal posture (mean ± standard deviation)

	Spinal Posture											
Posture	Neutral				Flexed				Extended			
Pelvic Fixation	Free		Fixed		Free		Fixed		Free		Fixed	
Direction of Movement	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Trunk Rotation (°)	39.2 (5.4)	37.2 (5.1)	40.5 (4.8)	39.4 (5.2)	36.6 (5.3)	36.1 (4.5)	37.3 (4.1)	37.8 (4.0)	38.4 (3.8)	34.8 (4.0)	39.6 (4.3)	38.9 (4.6)
Pelvic Rotation (°)	37.5 (21.9)	39.3 (21.6)	8.2 (2.7)	7.0 (3.0)	39.6 (21.0)	40.5 (19.8)	7.8 (2.9)	6.1 (2.9)	31.7 (18.1)	32.4 (17.1)	7.2 (2.5)	6.6 (2.8)
Displacement of COP - Lateral (y) (m)	0.035 (0.015)	0.036 (0.017)	0.020 (0.010)	0.024 (0.014)	0.034 (0.017)	0.041 (0.023)	0.020 (0.012)	0.020 (0.012)	0.035 (0.015)	0.036 (0.014)	0.019 (0.009)	0.022 (0.011)
Direction of Movement	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior
Displacement of COP - AP (x) (m)	0.012 (0.008)	0.041 (0.017)	0.013 (0.009)	0.014 (0.010)	0.014 (0.007)	0.045 (0.018)	0.008 (0.010)	0.015 (0.008)	0.018 (0.016)	0.039 (0.020)	0.016 (0.010)	0.009 (0.006)

COP=centre of pressure; AP=anterior-posterior

Table 4.10 Average maximum values for trunk rotation ROM, pelvic rotation ROM, lateral and AP displacement of COP with alterations in spinal posture (mean ± standard deviation)

Spinal Posture	Neutral	Flexed	Extended
Unilateral Trunk Rotation (°)	39.1 (5.2)	37.9 (4.5)	38.0 (4.5)
Unilateral Pelvic Rotation (°)	23.0 (21.7)	23.5 (22.0)	19.5 (17.7)
Right Lateral Displacement of COP (m)	0.032 (0.021)	0.031 (0.022)	0.031 (0.019)
Left Lateral Displacement of COP (m)	-0.029 (0.020)	-0.029 (0.019)	-0.029 (0.020)
Anterior Displacement of COP (m)	-0.028 (0.018)	-0.031 (0.019)	-0.025 (0.019)
Posterior Displacement of COP (m)	0.014 (0.013)	0.013 (0.012)	0.021 (0.018)

Anterior and left lateral displacements of the COP are represented by negative integers (-)

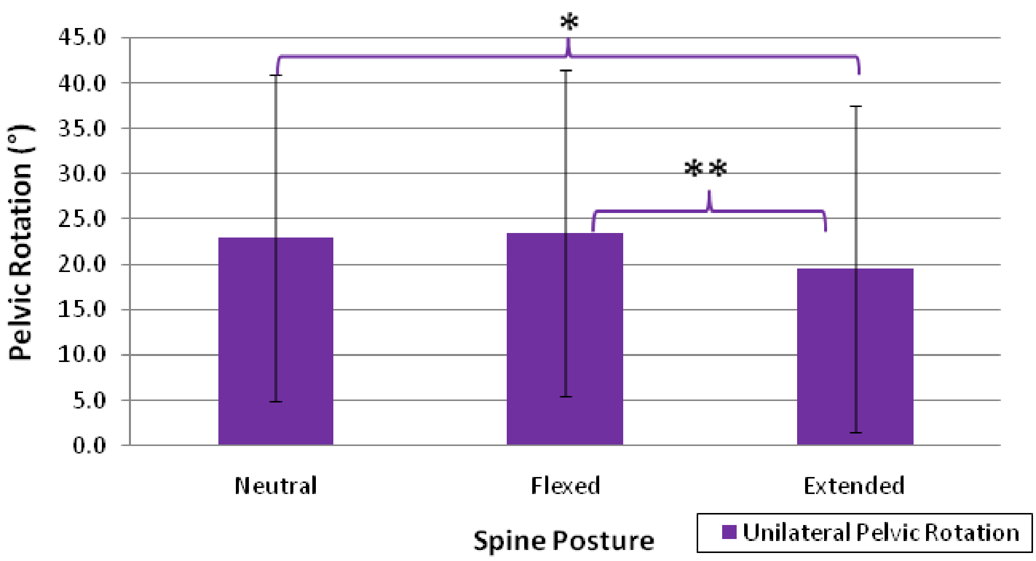
Table 4.11 Maximum and minimum values for trunk rotation ROM, pelvic rotation ROM, lateral and AP displacement of COP with alterations in spinal posture

Spinal Posture	Neutral		Flexed		Extended	
	Max	Min	Max	Min	Max	Min
Unilateral Trunk Rotation (°)	49.5	26.3	47.4	27.5	50.7	29.4
Unilateral Pelvic Rotation (°)	78.0	1.1	74.2	2.6	86.5	1.8
Right Lateral Displacement of COP (m)	0.114	0.007	0.091	0.005	0.110	0.007
Left Lateral Displacement of COP (m)	-0.109	-0.001	-0.095	-0.003	-0.110	-0.005
Anterior Displacement of COP (m)	-0.074	-0.001	-0.082	-0.004	-0.089	-0.001
Posterior Displacement of COP (m)	0.076	0.001	0.054	0.000	0.075	0.001

Anterior and left lateral displacements of the COP are represented by negative integers (-)

4.3.2.2 ***Pelvic Rotation***

Figure 4.9 displays the results of the *post hoc* analysis of the significant effect of spinal posture on pelvic rotation, showing that a significant difference in pelvic rotation ROM existed between all three spinal postures, with neutral and flexed spinal postures yielding significantly more pelvic rotation ($p<0.05$ and $p<0.005$ respectively) than an extended spinal posture with the pelvis-fixed or pelvis-free conditions (see Table 4.10). There was no significant difference in pelvic rotation ($p>0.05$) between a neutral and flexed spine whilst undertaking active trunk rotation.

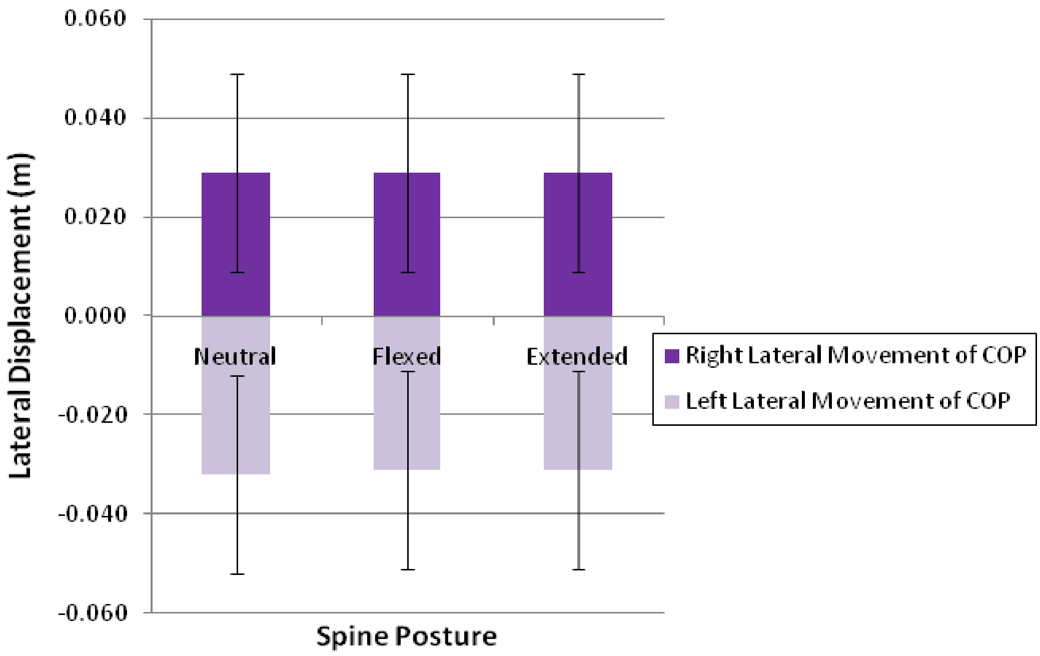


* = significant effect (p<0.05); **= significant effect (p<0.005)

Figure 4.9 Average unilateral pelvic rotation ROM for three spinal postures (mean ± standard deviation)

4.3.2.3 ***Lateral Displacement of the COP***

Alterations in trunk inclination did not significantly affect lateral displacement of the COP during trunk rotation (see Figure 4.10). The average lateral displacement of the COP was 0.031 m at in neutral; 0.030 m in flexion and 0.030 m in extension (see Table 4.10). Whilst right lateral displacement was consistently higher in the three spinal postures, this was not statistically significant (see Table 4.10).

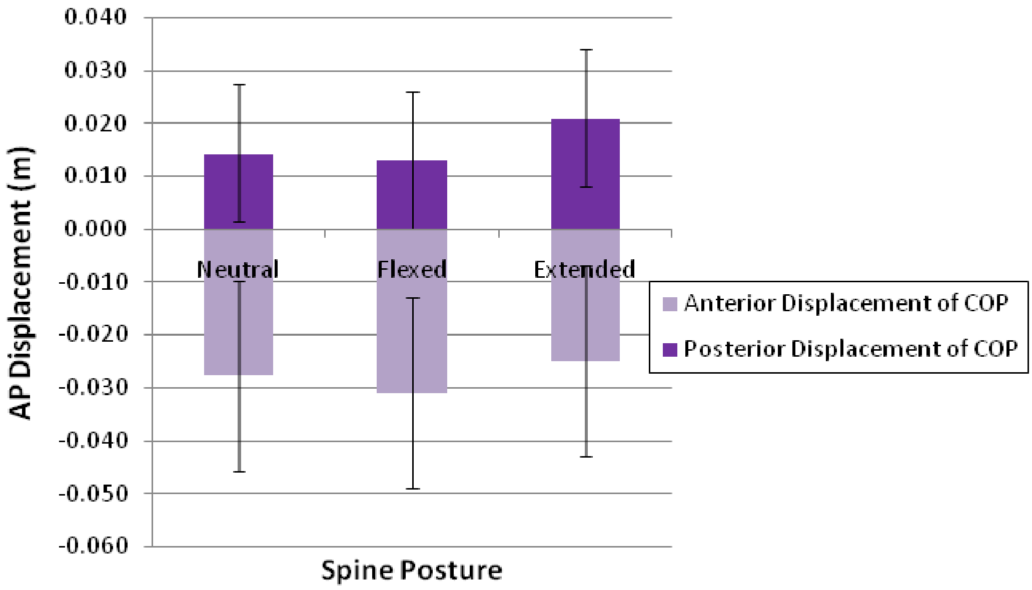


NB: no significant effect (p>0.05)

Figure 4.10 Average lateral displacement of the COP during trunk rotation for three spinal postures (mean ± standard deviation)

4.3.2.4 ***AP Displacement of the COP***

Alterations in trunk inclination did not significantly affect AP displacement of the COP during trunk rotation (see Figure 4.11). The average anterior displacement of the COP (0.028 m in neutral; 0.031 m in flexion and 0.025 m in extension) was consistently greater than posterior displacement of the COP in all positions (0.014 in neutral, 0.013 in flexion and 0.021 in extension) (see Table 4.10).



NB: no significant effect ($p>0.05$)

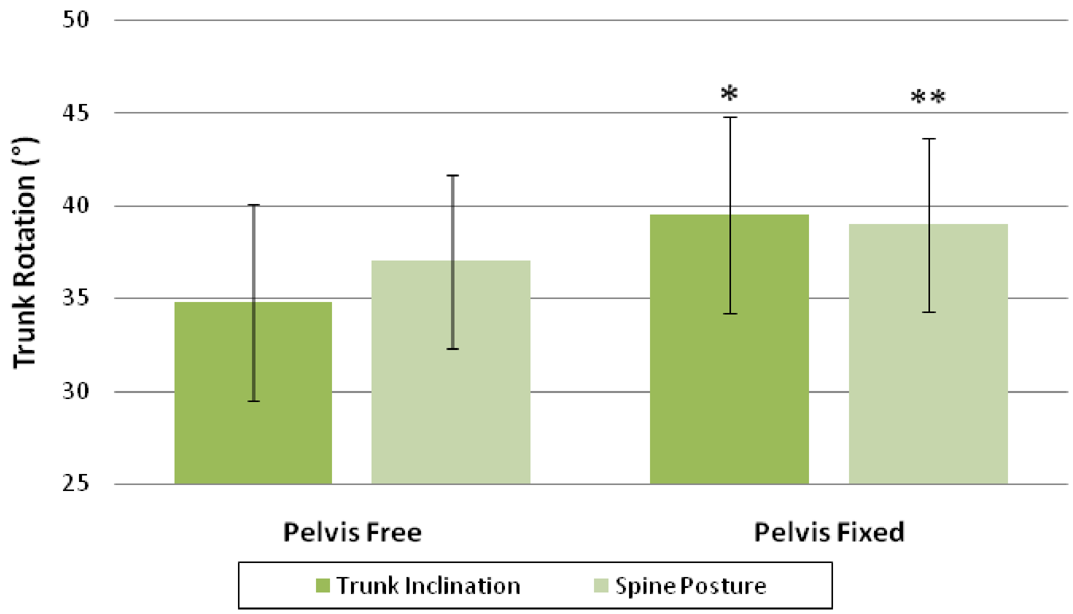
Figure 4.11 Average AP displacement of the COP during trunk rotation for three spinal postures (mean ± standard deviation)

4.3.3 **Pelvic Fixation**

Pelvic fixation was found to have had a significant main effect ($p<0.001$) on all four dependent variables, (trunk rotation, pelvic rotation, lateral and AP displacement of the COP). The descriptive statistics are presented in Tables 4.8, 4.9 and 4.12.

4.3.3.1 ***Trunk Rotation***

Figure 4.12 displays the results of the *post hoc* analysis of the significant effect of pelvic fixation on trunk rotation, showing that a significant difference in maximum unilateral trunk rotation ROM existed when fixing the pelvis and altering both trunk inclination ($p<0.001$) and spinal posture ($p<0.005$). Participants yielded an average of 3.6° more trunk rotation when the pelvis was fixed across all test positions.



* = significant effect ($p<0.001$); **= significant effect ($p<0.005$)

Figure 4.12 *Post hoc* analysis of the effect of pelvic fixation on maximum unilateral trunk rotation ROM (mean ± standard deviation)

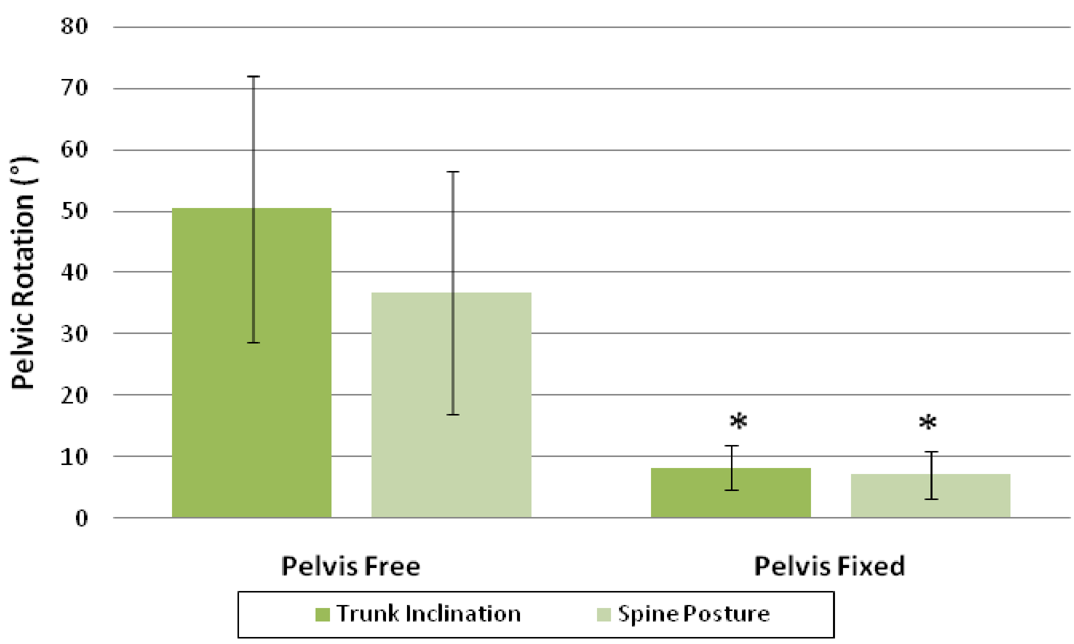
Table 4.12 The effect of pelvic fixation on average maximum values of unilateral trunk rotation ROM, pelvic rotation ROM, lateral and AP displacement of COP with alterations in trunk inclination and spinal postures (mean ± standard deviation)

Pelvic Fixation	Trunk Inclination	Spinal Posture
Pelvis Free - Unilateral Trunk Rotation (°)	34.8 (5.7)	37.0 (4.8)
Pelvis Fixed - Unilateral Trunk Rotation (°)	39.5 (5.2)	39.0 (4.6)
Pelvis Free - Unilateral Pelvic Rotation (°)	50.4 (21.5)	36.8 (19.9)
Pelvis Fixed - Unilateral Pelvic Rotation (°)	8.3 (3.5)	7.2 (2.8)
Pelvis Free - Right Lateral Displacement of COP (m)	0.038 (0.019)	0.041 (0.023)
Pelvis Fixed - Right Lateral Displacement of COP (m)	0.020 (0.011)	0.022 (0.012)
Pelvis Free - Left Lateral Displacement of COP (m)	-0.036 (0.025)	-0.038 (0.022)
Pelvis Fixed - Left Lateral Displacement of COP (m)	-0.019 (0.010)	-0.020 (0.010)
Pelvis Free - Anterior Displacement of COP (m)	-0.041 (0.015)	-0.041 (0.017)
Pelvis Fixed - Anterior Displacement of COP (m)	-0.018 (0.012)	-0.015 (0.010)
Pelvis Free - Posterior Displacement of COP (m)	0.014 (0.008)	0.016 (0.013)
Pelvis Fixed - Posterior Displacement of COP (m)	0.011 (0.012)	0.017 (0.017)

Anterior and left lateral displacements of the COP are represented by negative integers (-)

4.3.3.2 ***Pelvic Rotation***

As was expected, pelvic fixation had a significant main effect ($p<0.001$) on unilateral pelvic rotation during active trunk rotation, with participants yielding an average of 36.9° less pelvic rotation when the pelvis was fixed across all test positions. Figure 4.13 displays the results of the *post hoc* analysis, showing that a significant decrease in pelvic rotation ROM occurred when fixing the pelvis and altering both trunk inclination ($p<0.001$) and the spinal posture ($p<0.001$).



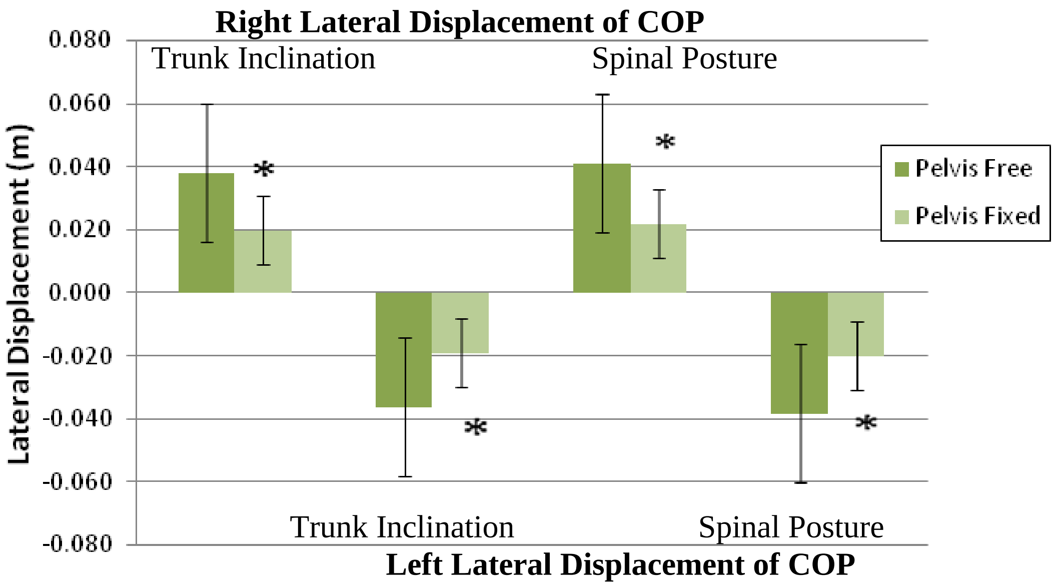
* = significant effect ($p<0.001$)

Figure 4.13 *Post hoc* analysis of the effect of pelvic fixation on unilateral pelvic rotation ROM during trunk rotation (mean ± standard deviation)

During alterations in trunk inclination, fixing the pelvis restricted mean rotational ROM to 8.3° (max=21.4; min=1.8°), where as an unrestricted pelvis allowed a mean rotational ROM of 50.0° (max=90.8°; min=5.5°). With mean values of 63.9°, 49.0° and 38.4° (calculated from Table 4.8) for trunk inclinations of 0°, 22.5° and 45° respectively, it appears that a restriction of pelvic rotation occurs as trunk inclination increases. During alterations in spinal posture, fixing the pelvis restricted its mean rotational ROM to 7.2° (max=14.4; min=1.1°), where as an unrestricted pelvis allowed it to rotate an average of 36.8° (min=3.2°; max=86.5°). With mean values of 38.4°, 40.1° and 32.1° (calculated from Table 4.9) for neutral, flexed and extended spinal postures respectively, it appears that trunk inclination to 45° is likely to create a natural restriction to pelvic rotation rather than the shape of the spine.

*4.3.3.3 **Lateral Displacement of the COP***

Figure 4.14 displays the results of the *post hoc* analysis of the significant effect of pelvic fixation on lateral displacement of the COP, showing that a significant difference in left and right lateral displacement of the COP existed when fixing the pelvis and altering both trunk inclination (p<0.001) and spinal posture (p<0.001).



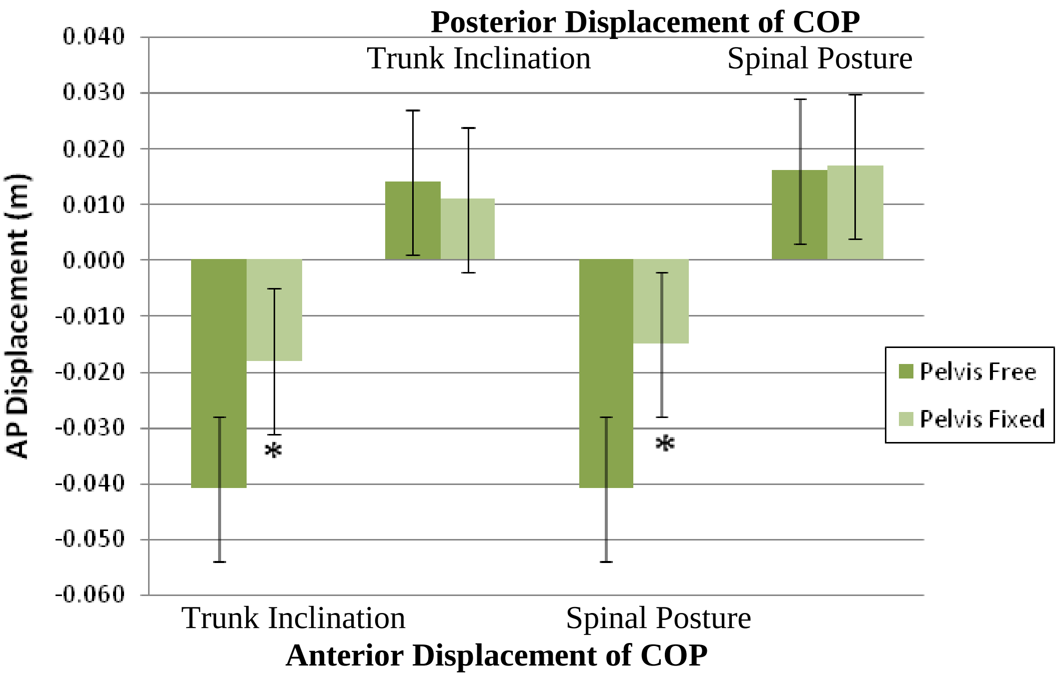
* = significant effect (p<0.001); left lateral displacement of COP is represented by –ve integers

Figure 4.14 Effect of pelvic fixation on lateral displacement of the COP during trunk rotation (mean ± standard deviation)

*4.3.3.4 **AP Displacement of the COP***

Figure 4.15 displays the results of the *post hoc* analysis of the significant effect of pelvic fixation on AP displacement of the COP, showing that a significant difference in anterior and posterior displacement of the COP existed when fixing the pelvis and altering both trunk inclination ($p<0.001$) and spinal posture ($p<0.001$).

The average anterior and posterior displacements of the COP decreased when the pelvis was fixed (see Table 4.12).



* = significant effect ($p<0.001$); Anterior displacement of COP is represented by -ve integers

Figure 4.15 Effect of pelvic fixation on AP displacement of the COP during trunk rotation (mean ± standard deviation)

4.3.4 ***Direction of Turn***

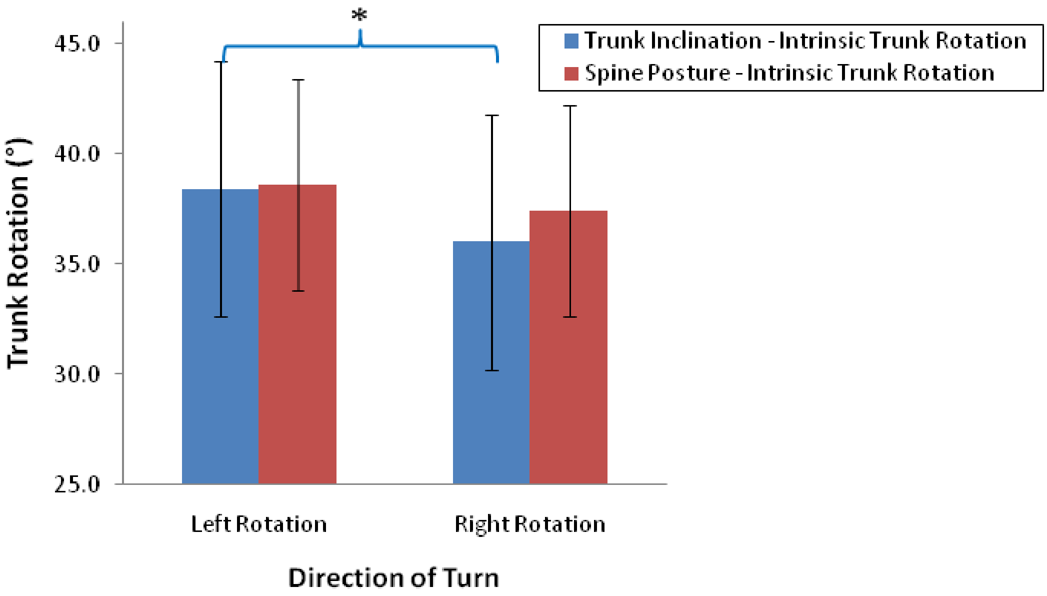
4.3.4.1 ***Trunk Rotation***

Direction of turn had a significant main effect ($p<0.01$) on maximum unilateral trunk rotation. *Post hoc* analysis showed that significant differences ($p<0.01$) existed between left and right rotation with alterations in trunk inclination only (turning to the left average 2.4° more trunk rotation than turning to the right) (see Figure 4.16).

Table 4.13 Average values for the effect of direction of turn on maximum unilateral trunk rotation ROM, pelvic rotation ROM, lateral and AP displacement of COP with alterations in trunk inclination and spinal postures

Direction of Turn	Left Rotation			Right Rotation		
	Mean ± SD	Max	Min	Mean ± SD	Max	Min
Trunk Inclination – Unilateral Trunk Rotation (°)	38.4 (5.7)	49.4	25.4	36.0 (5.9)	50.7	24.7
Spinal Posture – Unilateral Trunk Rotation (°)	38.6 (4.8)	48.2	26.3	37.4 (4.8)	50.7	27.5
Trunk Inclination - Unilateral Pelvic Rotation (°)	29.1 (26.1)	90.8	2.4	29.6(26.3)	88.9	1.8
Spinal Posture - Unilateral Pelvic Rotation (°)	22.0 (20.3)	86.5	1.4	22.0 (20.8)	78.0	1.1
Trunk Inclination – Right Lat Displacement of COP (m)	- -	-	-	0.029 (0.018)	0.114	0.007
Trunk Inclination - Left Lat Displacement of COP (m)	-0.027 (0.021)	-0.109	-0.001	- -	-	-
Spinal Posture - Right Lat Displacement of COP (m)	- -	-	-	0.031(0.020)	0.114	0.005
Spinal Posture - Left Lat Displacement of COP (m)	-0.029 (0.019)	-0.110	-0.001	- -	-	-

SD = Standard Deviation; Max = Maximum; Min = Minimum; left lateral displacement of the COP is represented by negative integers (-)



* = significant effect (p<0.001)

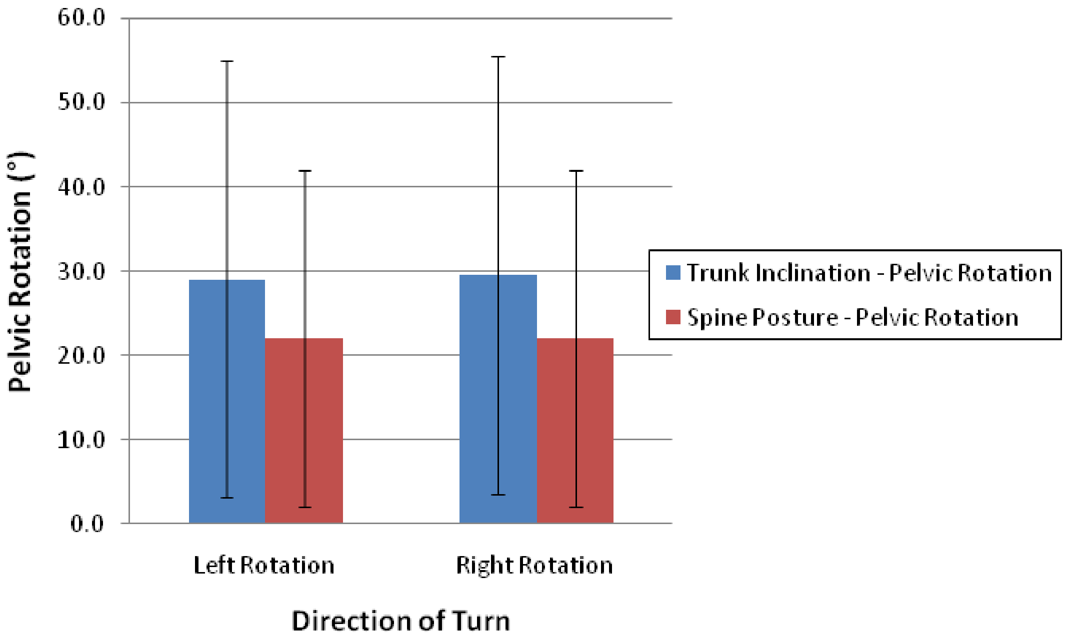
Figure 4.16 The effect of direction of turn on maximum unilateral trunk rotation (mean ± standard deviation)

Direction of turn had no effect ($p>0.05$) on trunk rotation whilst undertaking active trunk rotation in the in the three spinal postures

There was an interaction effect ($p<0.05$) for spinal posture and direction of turn on trunk rotation ROM.

4.3.4.2 ***Pelvic Rotation***

Direction of turn had a non significant main effect (p>0.05) on pelvic rotation ROM (see Figure 4.17).



NB: no significant effect (p>0.05)

Figure 4.17 The effect of direction of turn on unilateral pelvic rotation (mean ± standard deviation)

4.3.4.3 ***Lateral Displacement of COP***

Direction of turn had a non significant main effect (p>0.05) on lateral movement of the COP whilst undertaking active trunk rotation. Trunk rotation to the left resulted in left lateral displacement, whilst right rotation resulted in right lateral displacement (see Table 4.13).

4.3.4.4 ***AP Displacement of COP***

Direction of turn had a non significant main effect (p>0.05) on AP displacement of the COP.

CHAPTER FIVE

Discussion

5.1. Introduction

The purpose of this study was to investigate the effects of trunk inclination, spinal posture, pelvic fixation and direction of turn during maximal trunk rotation. Of particular interest was whether these variables affected the rotational ranges of the trunk and pelvis, and the displacement of the trunk COP in the sagittal or coronal planes.

The following chapter begins by presenting the findings of this study and comparing them to the current body of knowledge regarding trunk rotation. This will be followed by a discussion on the possible implications that the results of this study have on sports and vocations that undertake trunk rotation forward in the sagittal plane. The chapter will conclude with a discussion of the possible limitations of the current study.

5.2. Trunk Rotation Repeatability

Substantial to *almost perfect* test-retest reliability (see Tables 4.1–4.3), provided evidence to suggest that healthy participants are capable of replicating maximal trunk rotation for the selected sagittal plane postures used in this study. The design of the study utilised methodological procedures not previously used in trunk rotation studies; in particular the fixation of the pelvis and the position of the arms during trunk rotation. The number of participants included in the reliability study is in line with previous studies (Edmondston et al., 2007; Smith et al., 1985).

5.3. Trunk Inclination

The results show that increasing trunk inclination forward in the sagittal plane leads to a significant increase in maximum trunk rotation ROM. Conversely, as participants rotated their trunks in more inclined positions, the rotation that occurred at the pelvis was significantly less. There appear to be no methodologically comparable studies within the literature that have investigated the effects of alterations in forward trunk inclination on either trunk or pelvic rotation in standing. Despite this, the results warrant closer examination as to the potential benefits that extrapolation of these results might provide in both industrial and sporting arenas.

The contrasting effects of trunk inclination on trunk rotation and pelvic rotation ROM may lie in the 'relative flexibility' of the whole system (Comerford & Mottram, 2000). With respect to the study findings, trunk rotation in an unrestricted neutral standing posture resulted in rotational movement occurring in both the trunk and the lower body (as measured by pelvic rotation). The amount of rotation that occurred in the trunk and the lower body was dictated by the relative flexibilities of the respective body segments. It appears that trunk inclination caused the lower body to 'stiffen' and decreased the ability of the pelvis to rotate on the legs during active trunk rotation (see Figure 4.5). The stiffness in the lower body is most likely the result of the trunk inclination movement creating two rotational axes for the body, with the trunk axis in the inclined plane having a different orientation to that of the vertical lower body axis. If the lower body is now 'relatively stiffer' than the trunk, in the forwardly inclined position, the 'more flexible' trunk can rotate further than in a neutral standing posture with an unrestricted pelvis. This effect can be clearly seen in Figure 4.3 which demonstrates a significant increase in maximum trunk rotation ROM as trunk inclination angle increases forward from a neutral standing posture. The net effect of trunk inclination on trunk rotation is similar to that seen when rotating the trunk with the pelvis fixed in standing (see Figure 4.12), demonstrating that trunk inclination has a 'stabilising effect' on the pelvis and lower body.

Whilst 'relative flexibility' offers a plausible explanation for the study findings, consideration must be given to the trunk musculature responsible for trunk rotation. If increasing trunk inclination acts to stabilise the lower body, trunk muscles like the external and internal obliques are theoretically able to contract more effectively from a stable platform and produce more rotational torque, resulting in a greater axial range as the viscoelastic elements of the thoracolumbar spine are stretched (Gluck et al., 2007). Figure 4.4 demonstrates that 45° of trunk inclination with an unrestricted pelvis produces a mean maximal rotational ROM of the trunk very similar to all three of the trunk inclination positions when the pelvis is fixed. This indicates that forward trunk inclination appears to stiffen or stabilise the lower body and restrict the ability for the pelvis to turn in space. Further confirmation of this stabilising phenomenon was demonstrated by a decrease in mean unrestricted unilateral pelvic rotation of approximately 26° when moving from standing to a 45° trunk inclination position. In reality, the interplay of relative flexibility and torque production is likely to be responsible for the significant increase in maximum trunk rotation when the trunk was inclined forward.

With regard to the impact of trunk inclination on displacement of the COP during active trunk rotation, the results show that increases in trunk inclination lead to significantly more lateral displacement of the COP than when the trunk is rotated in a neutral standing posture. Again, no comparable data could be found in the current body of literature to support or refute this finding. Whilst the impact of trunk inclination on lateral displacement of the COP was found to be significant, the reasons behind this remain unclear. The mean increase in lateral displacement of the COP during trunk rotation in an inclined position was approximately 6mm. It is difficult to establish whether such a small increase has any clinical significance but suggests increased instability associated with rotational movements occurring in a forwardly inclined posture. Conversely, analysis of the data showed that trunk inclination had no significant impact on anterior or posterior movement of the COP during trunk rotation.

This may suggest that in the study group population, the control of the COP position in the sagittal plane is relatively efficient; however, repeating this experiment in a balance-impaired population (e.g. the elderly) may yield different results.

5.4. Spinal Posture

5.4.1. **Flexion**

The results of this study showed that segmentally flexing the thoracolumbar spine forward in the sagittal plane to a trunk inclination of 45° leads to a significant decrease in unilateral trunk rotation when compared to a neutral spine posture at the same inclination. This finding is congruent with the findings of a number of other studies investigating trunk rotation ROM in a flexed spinal posture (Burnett et al., 2007; Gunzburg et al., 1991; Haberl et al., 2004). For those studies that demonstrated a reduction of trunk rotation when the spine was flexed, trunk flexion was initiated in a cephalad to caudad direction. Similarly, this study flexed the spine segmentally from T1 down to the sacrum until the trunk segment had reached a 45° inclination. Given that data reported by Fujii et al. (2007) has shown that approximately 85 % of axial rotation occurs in the thoracic spine, taking up the ‘play’ in the soft tissue structures of the thoracic spine with flexion should theoretically lead to a decrease in overall axial rotation. Findings from our study, using this methodological strategy of flexing the spine, are consistent with this theory. In contrast, Hindle and Pearcy (1989) flexed the spine segmentally from the sacrum upward by getting the subjects to sit and put their feet up to encourage lumbar flexion. Flexing the thoracolumbar spine segmentally, in a caudad-cephalad direction, may allow greater trunk rotation, provided that the degree of lumbar flexion negates the natural rotational restriction provided by the orientation of the facet joints in the lumbar spine (Gunzburg et al., 1991; Haberl et al., 2004). It is possible that the contrasting increase in trunk rotation range reported by Hindle and Pearcy (1989) occurred as a result of the test positions they used (i.e. sitting with feet up on a another stool), which principally flexed the lumbar spine to a point that allowed greater than normal lumbar axial rotation to occur. This methodology has the potential to expose the lumbar spine to injury. If on the other hand, the lumbar spine was minimally involved in segmental spinal flexion in a cephalad-caudad direction to a 45° inclination, a decrease in axial torque that occurs with an overall decrease in trunk rotation could minimise the injury risk to the lumbar spine. However, as flexion movements between the individual lumbar segments were not measured during our study, it is not possible to determine the flexion contribution of the lumbar spine when we segmentally flexed the thorax forward to a 45° trunk inclination.

5.4.2. **Extension**

The results of this study demonstrate that maintaining segmental extension of the thoracolumbar spine in the sagittal plane at a trunk inclination of 45° led to a significant decrease in maximal trunk rotation when compared to a neutral spine posture. We suggest that the increased activity in the thoracolumbar paraspinal muscles required to maintain the spine in extension, acted in some way to restrict axial rotation, in line with the concept that increasing muscle activation can stiffen a joint in a particular directions (MacDonald, Moseley, & Hodges, 2006; McGill, 2007). Additionally, impaction of the lumbar facet joints in extension may have contributed to this loss of axial range, as was found in a previous study (Burnett et al., 2007).

Whilst extending the thoracolumbar spine at a 45° trunk inclination also led to a significant decrease in pelvic rotation, compared to both the neutral and flexed spine postures, the mechanisms behind this result are unclear. Whilst this extension-related sagittal plane posture leads to an overall decrease in total body rotation by virtue of its effect on both pelvic and trunk rotation ROM, questions should be raised as to whether it would offer more protection to the spine than performing axial rotation in a neutral spinal posture. Whether the rotation-related loss of axial rotation due to thoracolumbar extension allows the same level of muscular torque production as simply not rotating the trunk as far through the available range, as was shown by Kumar and Garand (1992), is yet to be determined. Until this is established it is difficult to speculate as to the advantages this particular spinal posture could offer to lifting and loading vocations.

5.4.3. **Neutral**

The results of this study demonstrated that a neutral spine demonstrated significantly more trunk rotation than in either the flexed or extended spine postures. These findings are consistent with those of Burnett et al. (2007). These researchers found a greater reduction in lower lumbar axial rotation in lumbar flexion than in lumbar extension, possibly reflecting the relative increase in stiffness of the posterior soft tissue elements of the spine, as opposed to the proposal by Burnett et al. (2007) of greater compressive loading forces occurring on the spine in flexed postures as a reason for this difference.

Further findings of our study indicated that alterations in spinal posture had no significant effect on either AP or lateral displacement of the COP during trunk rotation with the trunk inclined to 45°. With trunk inclination having a significant impact on lateral displacement of the COP, these findings support trunk inclination as being the predominant factor in determining stability of the COP.

5.5. Pelvic Fixation

The results of the investigation into the effect of pelvic fixation on trunk motion showed that fixing the pelvis leads to a significant change in maximal trunk rotation, pelvic rotation and displacement of the COP. Despite the fact that no comparable data could be found in the literature investigating the effects of pelvis fixation on trunk motion in either standing or sitting postures, the findings appear worthy of discussion.

Maximal trunk rotation increased significantly when the pelvis was fixed. This effect is likely to occur for reasons similar to those offered in Section 5.3 to explain how increases in trunk inclination led to increases in trunk rotation ROM. As expected, fixing the pelvis caused a significant reduction in pelvic rotation under all test conditions. The quandary that surrounds trunk rotation findings reported in the literature is deciding whether testing trunk rotation with the pelvis fixed or restricted provides results that are clinically relevant. Evans et al. (2006) presents the argument that testing trunk rotation under restrictive conditions is often both time consuming and complex and queries the benefit of the outcomes as it is not testing the whole system in a dynamic setting. A review of the literature indeed questions the validity of the findings as pelvic fixation was either implemented poorly or pelvic motion was not adequately monitored (see Section 2.5.2). It is reasonable to argue that not identifying the distinct rotational components of the body in a clinical setting could lead to a clinician missing obvious and detrimental relative flexibilities that may exist within the whole system, before the onset of related symptoms such as pain. Excessive or restrictive rotational motion in one area of the body is likely to lead to increased loads being placed on other parts of the body, as commonly seen in the golf swing. It would be useful to develop musculoskeletal screening tools that have adequate levels of specificity to identify these potential rotational anomalies that relate to relative flexibility or in more severe cases, gross instability. The simple plumb bob technique (Evans et al., 2006), used to measure overall body rotation (as described in Chapter Two) could be modified to include a second plumb bob that monitors the rotation of the pelvis simultaneously. This would still make the test procedure cost effective and clinically achievable but provide additional information to the relative rotational flexibilities occurring within the body.

With regard to the interaction between spinal posture and pelvic fixation, our study showed that the extended spine posture demonstrated significantly less pelvic rotation when the pelvis was unrestrained, than the flexed or neutral postures (see section 4.3.3.2). Conversely, flexing the spine at 45° of trunk inclination with an unrestricted pelvis, allowed the most amount of pelvic rotation, and the least amount of trunk rotation of any of the spinal postures. Additionally, fixing the pelvis minimised the effect that trunk inclination had on trunk rotation ROM, demonstrating that any form of pelvic fixation will lead to an increase in trunk rotation range.

Furthermore, our study showed that fixing the pelvis caused a 47 % decrease in lateral displacement of the COP in both directions with alterations in both trunk inclination and spinal posture. While fixing the pelvis led to a 60 % decrease in AP displacement of the COP across all test positions, the reduction only occurred anteriorly. We postulate that the biomechanical lever system of the ankle-foot complex, where the foot protrudes anteriorly from the ankle joint, is capable of resisting greater translation of the COP anteriorly than posteriorly before overbalancing occurs. This mechanism would allow greater variability in anterior displacement of COP when undertaking tasks such as trunk rotation when the pelvis is unrestrained (as seen in Figure 4.7 and 4.11) and may explain why fixing the pelvis leads to a significant reduction in anterior COP displacement only.

5.6. Direction of Turn

There was no significant effect of direction of turn on pelvic rotation ROM or displacement of the COP under all test conditions; however, there was a significant impact of direction of turn on trunk rotation ROM with alterations in the trunk inclination. Interestingly, there was significantly less trunk rotation to the right than the left. Anthropometric data indicated that 15 of the 20 participants were right-handed and participant screening revealed no obvious rotational deformities. Most comparable studies in the literature pooled and averaged their directional data, making comparisons difficult (see Table 2.1). In only one study, with 22 of the 24 subjects reported to be right-handed, there were similar findings of consistently greater left rotation than right (Evans et al., 2006).

In contrast, Kumar et al. (1996) reported direction-specific data and demonstrated slightly higher mean thoracolumbar rotation to the right than to the left, while Edmondston et al. (2007) also presented data for average thoracic rotation that demonstrated greater right rotational ranges compared to the left. It appears that neither reported on the statistical significance of directional bias. The reasoning behind the impact of directional bias on trunk rotation ROM remains unclear. Evans et al. (2006) cite an earlier paper that presents a 'driver's side' hypothesis (H. Lee, Nicholson, & Adams, 2004), to explain directional bias in cervical spine ROM studies across different countries. This hypothesis is based on studies which demonstrate that people who drive cars which have the steering wheel located on the right have a greater cervical rotation ROM to the left, most likely due to the need to achieve maximum end-of-range left cervical rotation to reverse the car (H. Lee et al., 2004). Whilst this hypothesis seems plausible, it is not only difficult to determine whether this hypothesis is applicable to our research findings, but is also outside the scope of this study.

5.7. Trunk Rotation

The overall mean unilateral trunk rotation in a neutral standing posture was 35.7°, irrespective of direction of turn, and demonstrated consistent ranges between the study participants and across the experimental conditions. This increased to 39.1° when rotating the trunk with a neutral spine inclined forward to 45°. Whilst this is consistent with *X-factor*s of 32-38° reported in golf-specific studies (McLean, 1992; McTeigue et al., 1994), this value falls considerably short of the approximately 54-81.° ranges that previous papers (Boden & Oberg, 1998; Fujii et al., 2007; Kumar et al., 1996; Parnianpour et al., 1989; Smith et al., 1985; Toren, 2001) have reported for unilateral axial rotation of the trunk in an upright position. Even Willems et al. (1996) reported an average ROM for the thoracic portion of the trunk that is approximately 20% greater than the axial rotation ROM we reported for the entire trunk region. There appears to be only one recent paper by Edmondston et al. (2007) which found a mean unilateral trunk rotation value (40.9°) similar to our findings. Of interest were the methodological similarities between this study and ours, particularly the investigation into the effects of sagittal plane posture on trunk rotational range, the use of optoelectronic equipment to measure trunk rotation and the position of the arms during testing. Additionally, it would be interesting to determine whether the mid-thorax position of the cluster marker set used in the study by Edmondston et al. (2007) (see Figure 2.6) yields similar results to the sternal cluster marker set used in our study.

The contrasting ROM values reported across trunk rotation studies demonstrate that methodological criteria play an important role in the quantification of trunk rotation ROM. The first methodological criterion considered important is the position of the arms during trunk rotation. In the study by Kumar et al. (1996), subjects had their arms folded across their lower abdomen, placing the glenohumeral joints in slight flexion and approximately 75° of internal rotation (see Figure 2.3). In experiments by both Boden and Oberg (1998) and Toren (2001), subjects held the anterior aspect of a shoulder frame that was fixed to their upper trunk, putting the glenohumeral joints into approximately 30° abduction and 60° external rotation from the horizontal (see Figure 2.4). The thoracic coupling study by Willems et al. (1996) tested subjects with arms folded across the chest, placing the glenohumeral joints in what appears to be slight flexion, adduction and approximately 70-80° internal rotation (see Figure 2.5). In the well-constructed MRI study by Fujii et al. (2007), trunk rotation was tested in supine, with the arms in this experiment positioned at rest beside the trunk, placing the glenohumeral joints in anatomical neutral. Although it appears that the earlier study by

Parnianpour et al. (1989) measured axial rotation of the subjects in standing, there was no specific mention of arm position during testing.

By comparison, both the current study and that of Edmondston et al. (2007) had the arms positioned in full external rotation of the glenohumeral joints and some degree of relative abduction (see Figure 2.6 and Figure 3.14). It is possible that this arm position may have had an impact on the ability to rotate the thoracolumbosacral spine, via the anatomical attachments of the latissimus dorsi muscle. Latissimus dorsi originates from the spinous processes of T6-T12, the thoracolumbar fascia (with attachments to the transverse and spinous processes of the lumbar vertebra, the sacrum), the iliac crest and the lower 3-4 ribs and attaches superolaterally to the floor of the bicipital groove of the humerus (Moore, 1992). The role of latissimus dorsi is to extend, adduct and internally rotate the humerus (Moore, 1992). By positioning the shoulder joints in full external rotation and between 40-90° of abduction (i.e. holding a piece of dowel behind the scapulas or placing the hands on the shoulders) it may partly pre-tension the latissimus dorsi-thoracolumbar fascia complex, and potentially limit the rotational range achievable from the thoracic and lumbar regions. Thus, restriction to the axial movement of the thoracolumbosacral spine via this large myofascial complex may explain the significant differences in trunk rotation ROM seen between both our study and that of Edmondston et al. (2007), compared with earlier work. Furthermore, the latissimus dorsi muscle has been shown to produce the highest EMG activity during isometric trunk axial rotation in males (Kumar, Narayan, & Garand, 2001; McGill, 1991), and lengthening it may impact on the torque production capabilities of the trunk. As torque production is known to decrease as trunk axial rotation ROM increases (Kumar & Garand, 1992) it raises the question that if a lengthened latissimus dorsi muscle contributes to a loss of torque production, it may, in part, contribute to the overall rotational deficits seen in both ours and Edmondston et al. (2007) studies.

Although it has been suggested that tension in the scalenes, trapezius, rhomboids and pectoral muscles may impact on the ability of the thoracic spine to rotate (Willems et al., 1996), the arm position used in this experiment would be unlikely to cause these muscles to be a factor in our present findings.

The second methodological criterion that differed across the studies were the systems used to measure axial rotation ROM. As mentioned earlier, Kumar et al. (1996) used an axial rotation tester with an inbuilt high-speed potentiometer; Boden and Oberg (1998) and Toren (2001) used an optoelectronic system to monitor the relative positions of retro-reflective markers fixed on a shoulder and pelvic frame; Fujii et al. (2007) used MRI and Parnianpour et al. (1989) used a isokinetic dynamometer, to measure trunk rotation of their respective subjects. Conversely, Edmondston et al. (2007) used an optoelectronic system to monitor the movement of retro-reflective markers attached to bony prominences of the subjects themselves. Likewise, this study used on optoelectronic system to monitor the movement of retro-reflective tracking marker sets positioned on specific anatomic locations (i.e. sternum, pelvis) to specifically measure the position of the trunk relative to the pelvis, providing a distinct point of difference in the measurement of trunk rotation compared to earlier studies.

Although earlier studies endeavoured to minimise the rotational movement of the pelvis by testing subjects in a seated position with the pelvis and/or legs fixed (Boden & Oberg, 1998; Edmondston et al., 2007; Kumar et al., 1996; Toren, 2001; Wessel et al., 1994; Willems et al., 1996), few acknowledged the potential for the pelvis to move within their respective fixation systems (Boden & Oberg, 1998; Toren, 2001; Wessel et al., 1994). Even with the use of a pelvic fixation device in this experiment, participants still averaged approximately 8° of unilateral pelvic rotation during active trunk rotation.

Neglecting to monitor rotation of the pelvis during trunk axial rotation introduces the possibility that the trunk ROM values reported in earlier experiments potentially overestimate the axial rotation ROM that actually occurs within the trunk. As soft tissue artifact error accompanies any type of pelvic fixation system (Boden & Oberg, 1998), it must also be considered as an additional source of error in studies that include pelvic fixation in their methodologies.

A third methodological difference across the studies was the positions in which subjects were tested. Of the seven previous studies mentioned, all but two investigated trunk rotation in sitting. Whilst two of the studies provided occupational-based reasoning behind this decision (investigating trunk rotation in tractor drivers and office workers (Boden & Oberg, 1998; Toren, 2001)), the others appeared to be dictated by either testing methodology or the fact that measurement of trunk axial rotation ROM was secondary to the primary focus of strength-related aspects of trunk biomechanics (Kumar et al., 1996; Kumar & Panjabi, 1995). It is hypothesised that sitting may allow subjects to generate more internal rotary torque with their trunk rotator muscles than in standing, particularly as sitting appears to provide a more stable platform for the pelvis and legs and may act to fixate the pelvis. As previously discussed this may serve to increase torque production and lead to greater active trunk rotation ROM values, as the increased torque could stretch the myofascial and ligamentous components of the spine at end range. In contrast, the pelvic fixation device used in this experiment required the participants to actively fixate their pelvis by tensioning the device with a continued upward thrust of their legs. Whilst this muscle activation may have impacted on trunk ROM, the average difference in mean trunk rotation was still significantly greater ($p<0.001$) when the pelvis was fixed (mean=39.1°, SD=4.9°) than when the pelvis was free (mean=35.7°, SD=5.3°), suggesting that this fixation technique had little impact on the overall result. Whilst the MRI study was the only study that tested axial rotation in supine, the test represents only the passive ROM of trunk rotation (Fujii et al., 2007).

Another consideration when investigating trunk rotation ROM is the effect that breathing has on the internal mobility of the trunk. It has been suggested that the ability for the ribcage to deform during axial rotation could impact on the overall axial range that can be achieved (Boden & Oberg, 1998; Toren, 2001). Although breathing has the ability to alter the stiffness of the ribcage, none of the trunk axial rotation studies found in the literature allowed for its effect in their trunk rotation ROM studies. Of the few studies that have investigated the effects of breathing on spinal stability (Cholewicki, Juluru, Radebold, Panjabi, & McGill, 1999; Hodges, Eriksson, Shirley, & Gandevia, 2005; McGill, Seguin, & Bennett, 1994), the focus has been on the use of inspiration to decrease trunk ROM. Of particular note is the decrease in trunk axial rotation ROM with breath-holding (McGill et al., 1994). Whilst rotational sports such as golf and tennis anecdotally encourage expiration to maximise trunk ROM, further research needs to be undertaken before the findings of previous research can be confidently extrapolated in this way.

It would appear that differences in exclusion criteria, method of measurement, method of pelvic fixation and differences in the biomechanics of the experimental technique (i.e. arm position) may account for the large variation in average trunk rotation ROM values reported across the studies.

5.8. Centre of Pressure Displacement

The results of the current study showed that whilst the COP shifts both forward and backward during trunk rotation, the magnitude of the forward shift of the COP was approximately twice that of backward shift. The lack of significant difference in translation of the COP between the trunk inclination and spinal posture testing positions indicates that the neuromuscular mechanisms involved in maintaining balance of the body during bending and twisting are relatively efficient. As it is well known that balance responses decrease with advancing age, further investigation into age-related effects on anterior COP displacement during bending and twisting may add to the current body of knowledge investigating balance in the elderly.

By contrast, in lateral displacement, maximal lateral displacement of the COP correlated well with the maximum ipsilateral trunk rotation in either direction. This finding shows similarities to the findings of a golf-specific research papers which found that the weight or centre of mass shifted onto the right foot at the top of the back-swing in right-handed golfers (Barrentine, Fleisig, Johnson, & Woolley, 1994; Burden et al., 1998), indicating a shift in the COP in the same direction as the trunk rotation.

It was interesting to find that maximum anterior shift of the COP was at least twice that of the posterior shift with alterations in both trunk inclination (see Figure 4.7) and spinal posture (see Figure 4.11). Furthermore, the occurrence of the maximum COP shift during trunk rotation varied widely between and across the study participants. These findings indicate that maximal AP shift is not linked to maximum trunk rotation, but rather suggests that the body's equilibrium systems are continually working to maintain a more central position of the COP during trunk rotation. As mentioned earlier, it would appear that the body tolerates a greater shift in the COP anteriorly than posteriorly during trunk rotation. It would be useful to compare these findings to studies investigating balance and stability when rotating the trunk in standing or in a positive inclination.

5.9. Implications for the Real World

The findings of this study could be used as a platform to build a greater knowledge base on the effects of trunk inclination as it pertains to the trunk rotational requirements for sporting participation such as in golf, and vocations involving manual materials handling tasks. When applying these trunk inclination findings to the accuracy required in the golf swing, the results may partly explain why the use of shorter length clubs (i.e.

9 iron, pitching wedge) is generally more controlled and more accurate than the use of longer length clubs (i.e. driver) (Leadbetter, 2002). The shorter irons require the golfer to incline the trunk further forward which, as this study has shown, restricts the ability of the lower body to rotate. Removing excess pelvic motion in the golf swing may help to simplify the sensorimotor processing required to execute the shot and as a consequence of this, decrease the error within the shot and increase the repeatability between shots. Conversely, using a driver forces the trunk into a more upright position and, as we have shown, will allow more pelvic rotation to occur in the golf swing. The more moving parts in the golf swing, the more central neural processing has to occur in order to execute the shot accurately, leaving greater room for error in the shot.

Regarding driving distance, the effects of trunk inclination on trunk rotation also present somewhat of a paradox to golfers. Whilst the longer clubs are used for distance where more trunk rotation or *X-factor* would be advantageous (Costis & Midland, 2006), the longer clubs place the trunk in a more upright position. This destabilises the lower body and effectively decreases the ability for the trunk to rotate. The decrease in *X-factor* will most likely translate to a shorter driving distance. To combat this paradox, other strategies should be considered to help stabilise the lower body during the swing, such as a strength-conditioning programme for the legs; this may encourage a reduction in axial rotation of the pelvis and a concurrent increase in *X-factor* which, in turn, will increase the axial torque generated within the trunk and help to maximise the driving distance (Lephart et al., 2007).

This study also demonstrates that segmental flexion of the trunk from T1 down leads to a significant decrease in axial rotation ROM when inclined at a trunk inclination of 45°, a movement pattern that has the potential to be detrimental to golf performance. For example, to maximise driving distance in golf, it has been shown to be advantageous to produce maximum *X-factor* in the backswing. Furthermore, to maximise repeatability in the golf swing, it is advantageous to minimise the number of moving body parts and the number of movement compensation strategies. If the findings from this study are extrapolated to golf, setting up with a flexed spinal posture or increased thoracic kyphosis reduces the ability to rotate the trunk and may force the golfer to produce compensation strategies in other areas of the body in an effort to achieve a ‘full backswing’. This will have an opposing effect on the two strategies the golfer is trying to achieve – maximum trunk rotation with minimal extra body movements or compensation strategies. These compensation strategies may be in the form of increased pelvic rotation or lower body movement, increased scapula motion, increased arm lift or, the most common fault – an increase in contralateral trunk side flexion. Excessive contralateral side flexion during trunk rotation in the golf swing is known in the industry as ‘crunch factor’ and is one of the most recognised biomechanical faults leading to low back injury in golfers (Gluck et al., 2007).

In this study, placing the thoracolumbar spine in an extended position while the trunk was inclined forward led to a decrease in trunk rotation ROM. With regard to golf, a common coaching strategy amongst teaching professionals that encourages a ‘better golf posture’ is to have the golfer ‘stick their buttocks out’ and imagine they are sitting on a shooting stick or spectator-sports-stick (Hogan, 1985), a position that increases lumbar lordosis. Unfortunately, any potential gains in trunk rotation range that may occur with the stabilising effect that thoracolumbar extension (by way of an increased lumbar lordosis) has on the lower body are likely to be negated by this increase in lumbar extension.

Where trunk rotation ROM in a forwardly inclined trunk position is the main requirement for the vocational or sporting task at hand (i.e. golf), maintaining a neutral spine posture (i.e. the waiter’s bow) appears to be the most appropriate. The rotational restriction that occurs when the spine is flexed or extended in a forwardly inclined position can lead to undesirable movement compensations (Gluck et al., 2007). These compensations, like excessive trunk side flexion during the golf swing are far more detrimental on the spine than single plane movement alone. Whilst the presentation of data and discussion on coupled motions is outside the scope of this present study, it is acknowledged trunk rotation does not occur in isolation and that the movement couple of rotation-lateral flexion, particularly in the thoracic spine, is common (Edmondston et al., 2007; Willems et al., 1996).

In relation to golf, it would appear from the findings of this study that a neutral spine, in an inclined position, is the most biomechanically advantageous, allowing the greatest trunk rotation ROM to occur whilst providing adequate restriction to lower body rotation. Conversely, adopting a flexed posture at set up in a golf swing appears to be the least conducive position to achieve good biomechanics as it will restrict trunk rotation and allows excessive pelvic rotation. As mentioned earlier, restricting the ability of the pelvis to rotate in sports such as golf allows the creation of greater trunk rotation, as demonstrated by the results of this study. Interestingly, one of the techniques golf coaches commonly use to restrict pelvic rotational involvement during the golf swing is to encourage clients to hit golf balls while holding a large ball between their knees (Leadbetter, 2002). This coaching technique can effectively reduce pelvic rotation and, in theory, should allow greater trunk rotation to occur much like the forwardly inclined, neutral spine posture appears to do in this study.

From a vocational perspective, if increased lumbar flexion allows excessive axial rotation and predisposes the lumbar discs to injury, teaching those whose vocations require flexion-rotation (such as manual materials handling tasks), to flex the spine segmentally from T1 down before rotating may theoretically decrease the stress placed on the lumbar spine discs. However, whilst this theory may limit the torsional load on the lumbar intervertebral discs, operating the thoracic spine articulations near the end of their available ranges may lead to more thoracic-related injuries. It seems apparent that performing axial rotation whilst the trunk is flexed, irrespective of the region of the trunk the flexion occurs in, has the potential to increase the risk of spinal injury. The findings of this study support the recommendations by McGill (2007) that teaching bending strategies whilst maintaining a neutral spine (i.e. the waiter's bow), may lead to a reduction in flexion-rotation related injuries that currently plagues industries involved in manual material handling.

5.10. Limitations of the Study

Whilst efforts were made to address limitations of previous trunk rotation studies outlined in the literature review, it must be acknowledged that this study possesses its own limitations. It has been acknowledged earlier that the placement of the arms during trunk rotation may have an important effect on overall trunk rotation ROM (see section 5.7), via the potential involvement of the latissimus dorsi-thoracolumbar fascia complex. While the arm placement was consistent throughout the experiment, the position may have led to an underestimation of the true maximal unilateral trunk rotation ROM.

Another potential limitation to the study is the use of optoelectronic motion capture systems to measure trunk rotation ROM, with particular regard to placement of retro-reflective markers. Whether the cluster marker set placed on the sternum via a sternal plate gives a true representation of the trunk rotation ROM needs further investigation. As trunk rotation is a measure of the difference in angular displacement between the most proximal and distal aspects of the trunk (i.e. T1 to pelvis), devising an alternative cluster marker set, which is attached more proximally to the trunk segment, may provide a more accurate measure of trunk rotation. Furthermore, our pilot study indicated that retro-reflective markers placed on the ASIS bilaterally produced a substantial amount of soft tissue artifact error during trunk rotation due to variability in the anterosuperior pelvic adipose deposition between participants. Whilst attempts were made to reduce the effects arising from potential skin movement artifacts, it was not possible to measure the extent to which these artifacts may have influenced measurements of trunk and/or pelvic rotation.

This study was limited to male participants due to difficulties involved with the placement and attachment of the sternal plate. Therefore caution is needed when extrapolating the findings of this study to the female population.

Whether the pelvic fixation technique used in this study can be described as a limitation is worthy of debate. Fixing the pelvis when rotating the trunk in a 45° trunk inclination with a neutral spine posture, produced an average maximum trunk rotation ROM only 1.8° more than an unrestrained pelvis in the same test position (see Figure 4.4). Whether using the legs to actively fixate the pelvis impacts on the ability for the trunk to rotate requires further investigation.

Whilst attempts were made to control the angular velocity at which the participants rotated during this study to less than 20° per second, there is a possibility that some participants rotated faster than others, which could facilitate greater stretch on the viscoelastic structures of the trunk and potentially skew the ROM results. Furthermore, because angular velocity was limited in this study we were unable to measure the *'supramaximal' rotation* ROM or *X-factor stretch* that occurs when the viscoelastic structures of the spine are stretched when rotating the trunk at angular velocities up to 60° per second, such as those found in the back swings of professional golfers (Gluck et al., 2007; Hume et al., 2005; Novosel & Garrity, 2004).

Further sources of error in the study may arise from whether the use of the 'sternal angle' as the definitive measure for trunk inclination angle was appropriate to use to measure the position of the altered spinal postures (i.e. flexion and extension) and whether participants were able to maintain the trunk inclination angle or the spinal posture whilst performing the trunk rotation movement. Moreover, it is important to question whether visual observation was sufficient to not only accurately identify that participants had adopted each of the required start positions, but if it could also adequately monitor for excessive movement out of the test positions during trunk rotation, both of which may potentially introduce variability to the study.

Finally, it is recognised that attempting to eliminate trunk side flexion during trunk rotation may have affected the overall trunk rotation ROM, due to the potential impact of this particular methodological restriction on the 'natural' coupling that is known to occur in the thoracolumbar spine during trunk rotation (Edmondston et al., 2007; Willems et al., 1996). Whether allowing the 'natural' trunk rotation–side flexion coupling to occur would alter maximum trunk rotation ROM should be further investigated.

CHAPTER SIX

Conclusion and Recommendations

6.1. Conclusion

The effects of spinal posture on trunk rotation have received considerable attention within the literature over the last 20 years. By comparison, there appears to be a scarcity of information regarding the effects of both trunk inclination and pelvic fixation on trunk rotation. Results of this study showed that alterations in both trunk inclination and spinal posture had a significant effect on trunk and pelvic rotation ROM. Furthermore, fixing the pelvis also had a significant effect on trunk and pelvic rotation ROM.

The findings of this study suggest that the most advantageous position to adopt when rotating a trunk that is positioned forward in the sagittal plane is that of a neutral thoracolumbar spine. Whilst this posture leads to an increase in trunk rotation ROM, it does so without placing the spine near the end of its available combined ranges where greater loads on the facet joint capsules, ligaments and discs are likely to occur. Furthermore, this particular posture encourages a natural stabilisation of the lower body. Rotating the trunk in this position appears to meet the unique set of biomechanical requirements for the sport of golf and may help to reduce the risk of injury in manual material handling tasks.

The study findings also suggest that the least advantageous position to adopt when rotating the trunk, when it is inclined forward in the sagittal plane, is that of a flexed thoracolumbar spine. This position leads to a reduction in trunk rotation ROM, encourages greater pelvic and lower body rotation, reduces torque production of the trunk and may place the posterior spinal elements in a position that could increase their risk of injury. As segmental flexion has been shown to reduce overall trunk rotation

ROM, it would seem inappropriate for vocations or sports that require maximum rotational ranges in varying degrees of trunk inclination to utilise this style of combined spinal motion. As the literature suggests, the combination of flexion and rotation of the spine in manual material handling tasks appears to have a high correlation with the onset of low back pain (Allread et al., 2000; Marras et al., 1995; Marras et al., 1993). This flexed spinal posture is also one of the most common set-up faults in the golf swing, which leads to poor swing mechanics and is likely to increase the risk of spinal injury.

An important application of our results to the sport of golf is that by adopting a neutral spine when addressing the ball, a golfer will have the potential to produce maximum trunk rotation, whilst simultaneously increasing stability in their lower body. Likewise for industries heavily involved in manual material handling tasks that require repetitive bending and twisting, teaching workers how to bend and rotate whilst maintaining a neutral thoracolumbar spine could decrease the risk of developing a low back pathology.

As axial rotation within the trunk is an essential component in many of the physical tasks that we encounter in our daily lives, the importance of continuing research in this area is strikingly apparent. Only when we fully appreciate the potential benefits of this primary movement, will we be able to develop educational programmes and training strategies that minimise the impact of axial rotation on the development of spinal injuries and maximise the potential that it offers to vocational and sporting performance.

6.2. Recommendations

The findings of this current study suggest several areas for future research:

i. Although the majority of studies investigating trunk rotation ROM have measured rotation with a fixed pelvis in sitting, few have accurately accounted for the error that can occur if the pelvis moves within the fixation device. To ascertain a more accurate measure of trunk rotation, further studies quantifying and comparing the maximum trunk rotation ROM that occurs in sitting, standing and a 45° trunk inclination with a neutral spine posture are needed.

ii. Whilst alterations in spinal posture have been shown to have a significant effect on trunk rotation ROM, the reasons behind this is unclear. Although it is acknowledged that the length of spinal tissues is likely to play a role in the restriction to trunk rotation in flexed and extended spinal postures in a trunk inclined forward to 45°, the role that trunk muscles may play in this restriction has yet to be fully explored.

iii. Investigate whether segmental trunk flexion from T1 down is more advantageous in occupations that require small amplitude trunk rotations (<30°) at a trunk inclination equal to or less than 45°, rather than allowing the flexion to originate from the lumbar spine. Whether the protection that this style of bending and rotating affords the lower back has equally detrimental effect on the upper thoracic, neck and shoulder structures should be determined.

iv. Whilst gender participation was noted in most axial rotation ROM studies, gender-specific ROM data was not extrapolated in the majority of the studies indicating that further research into the relative trunk flexibility between men and women should be undertaken.

v. Increases in axial rotation have been shown to impact on torque production capabilities of the trunk musculature, with women producing consistently less torque in flexion-rotation and extension-rotation than men (Kumar & Garand, 1992; Kumar & Narayan, 2001; Smith et al., 1985; Toren, 2001). The role of gender-related trunk flexibility on torque production needs to be further investigated.

vi. As *X-factor* appears to correlate with greater distance in golf (Gluck et al., 2007; Hume et al., 2005), it is a worthy subject of further research. Investigating whether additional trunk rotation ROM or *X-factor* may be gained from rotating the trunk at higher speeds in the backswing, than those used in this present study, appears warranted. This would need to be assessed in conjunction with a study of golf swing movement patterns, as increases in rotational speed may introduce unwanted variability into the backswing and downswing movement patterns and potentially have a negative impact on golf performance.

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Appendices

Appendix i

Adults over 18 years of age wanted for trunk rotation study

Twenty five participants are required for 2 sessions of up to 120 minutes each. Participants need to have had no back, pelvic or shoulder pain that has stopped them from doing their normal daily activities, caused them to have 1 week or more off work in the last year, or required treatment within the last 3 months. Participants need to have no neurological conditions, no history of back and abdominal surgery and have not competed in an asymmetrical sport at an elite level. Surface markers will be placed on the trunk, pelvis and legs so that trunk rotation movements can be accurately measured using a 3-dimensional camera system. This study will provide a platform to develop training programmes to assist at-risk people who undertake sport or job-related bending and twisting. If you feel you could help with this study please contact Trevor at t.montgomery@golfworks.co.nz or phone Mark Boocock 09 921 9999 x7167.

Appendix ii

Participant Information Sheet

Date Information Sheet Produced:

28/07/2006

Project Title

The effects of trunk flexion on spinal rotational movement patterns.

You are invited to take part in the following study that is being undertaken by the School of Physiotherapy, Auckland University of Technology. This information sheet explains the study to you, and you can then decide whether you would like to be involved. It is entirely your choice, and if you do agree to take part, you are free to withdraw from the study at any time without having to give a reason. If you do not understand any aspect of the study described below, please ask for clarification. You do not have to decide immediately about participating in the study. However, if the full numbers of subjects are selected before your decision is made, you will not be included in the study.

This study will be undertaken at the Physical Rehabilitation Research Centre, Auckland University of Technology, Akoranga Drive, North Shore.

What is the purpose of this research?

Back strains often occur in sports and jobs where people are bending and twisting at the same time. Measuring how people turn their spines when bending over is useful to figure out how these injuries may occur. To accurately measure how people rotate their spines, light weight reflective markers are placed on the trunk, pelvis and legs at known locations on the body using adhesive tape. A camera system is then used to track these markers. This movement data, together with the measurement of forces acting under the feet will give a comprehensive description of how a person rotates when they bend and can be used to identify potential problems with the way sports and jobs that involve this type of combined movement of the spine are taught and undertaken. The information gathered will help in developing rehabilitation strategies, exercise programmes and education for people who injure their backs whilst bending and twisting.

How are people asked to be part of this research?

This study will involve 25 volunteers who:

- are aged over 18 years old;
- have met the criteria on the screening questionnaire (see attached); and
- are able to stand for 45-60 minutes, are able to turn and bend repeatedly with suitable rests periods.

What happens in this research?

This study will involve **two** testing sessions carried out at the Auckland University of Technology Physical Rehabilitation Research Centre in a research laboratory that is appropriately screened to ensure the full privacy of all participants. The duration of each session will be approximately 120 minutes.

Participant setup:
1. You will be asked to stand while makers are placed on the skin overlying bony landmarks of the pelvis and trunk. Markers will be attached with hypoallergenic tape and stretchy Velco™ bands. You will remain standing throughout the study.

2. You will be taught to flex your trunk forward at the hips using a piece of dowel as a reference against the back to prevent trunk flexion, as shown in Figure 1 (approximately 15 minutes to complete).

Figure 1.

Collection: You will be asked to stand in the middle of the capture area on a force platform (a device that accurately measures the forces you exert on the ground) for 10 seconds while data is recorded with the cameras. After a short rest you will be asked to rotate your trunk while you are bent forward at 3 different angles. These movements will be performed with the hips restrained against a support frame using Velcro™ straps, and with the hips free to move. Three good trials for each different test position will be collected and kept for analysis (up to 80 minutes).

Marker removal: The markers will be removed with Remove™, a wipe which dissolves the glue and makes the removal of the markers more comfortable for you (approximately 5 minutes).

The testing session will be repeated 1 week later.

What are the discomforts and risks?

You perform each of the movements and therefore, the risk of acquiring an injury will be minimised. All care will be taken to ensure that you do not sustain an injury from this project. If you feel that this has happened then it is your responsibility to let the researchers know as soon as possible so appropriate care can be administered. The researchers are postgraduate-trained physiotherapists who will be able to assist you if an injury does arise.

There is a possibility that you may have some minor skin irritation due to the tape used for attaching the markers. The tape may also pull slightly on the skin during removal.

How will these discomforts and risks be alleviated?

All participants will be screened using a questionnaire (see attached) to ensure that they are at the lowest possible risk of developing an injury.

To reduce the skin irritations, hypoallergenic tape is used. Adhesive remover will also be used to dissolve the glue during the removal of the markers to minimise discomfort. If you have a history of skin allergies please advise the researchers.

What are the benefits?

While there is no direct benefit for you to participate in this research it will provide us with information required to help people prevent back injuries during sports or jobs that involve bending and twisting.

What compensation is available for injury or negligence?

Compensation is available through the Accident Compensation Corporation (ACC) within its normal limitations.

How will my privacy be protected?

- No material that could personally identify you will be used in any reports on this study unless your personal approval is given for the dissemination of results to specific persons. All subjects will be assigned a number and only the principal researchers of this study will have access to your name. All subject records will be held securely in the Physical Rehabilitation Research Centre (PRRC) at AUT for 6 years, after which it will be destroyed. Anonymous data will be used to form a database on the effect that trunk position has on trunk rotation.

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If you wish to have a copy of the results of this research, you are entitled to this on request to Dr Mark Boocock. These will be available after the study is completed and published.

What are the costs of participating in this research?

This research will take two sessions of approximately 60 minutes each, 1 week apart.

How do I agree to participate in this research?

If you agree to participate in the study, please complete the attached consent form and screening questionnaire.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Mark Boocock, *mark.boocock@aut.ac.nz* , 09 921 9999 ext 7167.

Other contacts regarding this project are Dr Wayne Hing, wayne.hing@aut.ac.nz, 09 921 9999 ext 7800 and Trevor Montgomery, trevor.montgomery@golfworks.co.nz, Golf Works Ltd 09 525 2898 (Work).

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz* , 09 921 9999 ext 8044.

***To be approved* by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.**

Appendix iii

Screening Questionnaire

Date Information Sheet Produced:
23/06/2006

Project Title
The effects of trunk flexion on spinal rotational movement patterns.

Dear participant,
This questionnaire is designed to identify whether it is appropriate and safe for you to participate in this research project. Please answer the questionnaire to the best of your ability. If you have any questions please do not hesitate to raise these with the researchers – Trevor Montgomery, Dr Mark Boocock or Dr Wayne Hing.

	Please Circle
1. Have you experienced neck, back, rib cage, pelvis or shoulder pain that has: -	
• Restricted activities of daily living for 1 week or more (i.e. bed mobility, walking, bending and dressing)?	Yes / No
• Required more than a 1-week absence from your normal vocation/job in the last year?	Yes / No
• Required treatment of any kind (i.e. physiotherapy/chiropractic/osteopathy/massage therapy) within the last 3 months?	Yes / No
2. Are you aware of any injury-related or congenital deformities of your spine (i.e. spondylolisthesis, spina bifida, pars defects, scoliosis, Scheuermann's disease)? If yes – please specify…………………………….	Yes / No
3. Do you suffer from any neurological conditions that you are aware of (i.e. Parkinsons Disease, Huntingtons Disease, Muscular Dystrophy, Multiple Sclerosis) If Yes – please specify…………………………….	Yes / No
4. Have you ever undergone spinal, thoracic or abdominal surgery (i.e. spinal fusion, discectomy, appendectomy, inguinal hernia repair)? If Yes – please specify…………………………….	Yes / No
5. Have you competed in an asymmetrical sport at an elite level for 6 months or more? If Yes – please specify………………..……........	Yes / No

Name:……………………………………………………….. Date:……………………

Researcher Use Only
Identification Number:…………………………..…. Participant Approved: Yes / No

Appendix iv

Consent to Participation in Research

This form is to be completed in conjunction with, and after reference to, the AUTEC Guidelines

Title of Project: **The effects of sagittal plane postures on trunk rotation range of motion**

Project Supervisor: **Dr Mark Boocock**

Researcher: **Dr Mark Boocock, Dr Wayne Hing, Trevor Montgomery**

- I have read and understood the information provided about this research project (Information Sheet dated 23/06/06)
- I have had an opportunity to ask questions and to have them answered.
- I understand that my participation is entirely voluntary and that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I understand that if I do not meet the criteria on the screening questionnaire I will not be eligible to participate in this research project.
- I give permission for the researcher to use the information gathered as part of the research study. I understand that my individual details and results will remain anonymous and that the collated results of participants in the study that I am participating in may be published.
- I understand that participant data will be held securely in the Physical Rehabilitation Research Centre (PRRC) at AUT for 6 years, after which time it will be destroyed. Anonymous data will be used to form a database on the effect that trunk position has on trunk rotation.
- I agree to take part in this research.

I (full name): ………………………………………… agree to participate in this research project.

Signature:……………………………………………………………………………………………

Participant Contact Details (if appropriate):

……………………………………………………………………………………………………

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……………………………………………………………………………………………………

Date:

To be approved **by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.**

Note: The Participant should retain a copy of this form.