Title:

The Effects of Spinal Posture and Pelvic Fixation on Trunk Rotation Range of Motion

Authors:

Trevor Montgomery MHSc (Hons)
Mark Boocock PhD
Wayne Hing PhD

Institute:

Health and Rehabilitation Research Institute
Auckland University of Technology,
New Zealand.

Correspondence Address:

Mark Boocock
Health and Rehabilitation Research Centre
Auckland University of Technology
Private Bag 92006
Auckland 1142
New Zealand
Tel: 64-9-921-9999
Fax: 64-9-921-9620
E-mail: mark.boocock@aut.ac.nz

Word Count:

Abstract: 248

Main Text: 4202

Tables: 1

Figures: 5

Abstract:

Background.

A strong association has been shown between axial trunk rotation and back injuries. Whilst axial rotation of the trunk is important to many vocational tasks and activities of daily living, there is conflicting evidence concerning the influence of spinal postures on trunk rotation.

Methods.

Twenty male participants were assessed using an optoelectronic motion-analysis system to track trunk movement during maximal trunk rotations in different spinal positions within the sagittal plane. The effects of trunk inclination, spinal posture and pelvic fixation on trunk and pelvic rotation were assessed using a repeated-measures multivariate analysis of variance. Test-retest reliability was determined using interclass correlation coefficients and standard error of measurement.

Findings.

Trunk inclination at 45° yielded a 10% (3.2°; $p<0.01$) increase in trunk rotation and a 37% (13.4°; $p<0.001$) decrease in pelvic rotation when compared to standing. When the spine was flexed at an inclination of 45° there was a 6% (2.2°; $p<0.001$) decrease in trunk rotation and a 4% (1.7°; $p<0.05$) increase in pelvic rotation. Extending the spine decreased trunk and pelvic rotation by 2% (1.0°; $p<0.05$) and 17% (6.4°; $p<0.001$), respectively. Fixing the pelvis increased trunk rotation by up to 9% (3.3°; $p<0.001$).

Interpretation.

Flexing the trunk and maintaining a neutral spine maximised trunk rotation ROM. This has implications for educational programmes intended to maximise sporting performance. Within

the clinical setting, unrestricted observation of trunk rotations is considered more appropriate as it may benefit the clinician in determining possible detrimental relative flexibilities that may exist within the body.

Keywords: trunk rotation, spinal posture, trunk inclination, pelvic fixation, thoracolumbar spine

1. Introduction

Axial rotation within the trunk is central to the achievement of many activities of daily living. Evidence from the literature points to a strong association between axial trunk rotation and back problems and when combined with movements such as bending and lifting, trunk rotation has been identified as a contributing factor in more than 60% of industrial and sports-related back injuries (Kumar et al., 2001, Manning et al., 1984).

Approximately 80% of axial trunk rotation occurs within the thoracic spine (Fujii et al., 2008), which has been suggested to stem from the alignment of the facet joints that are ideally orientated to allow rotation (Edmondston et al., 2007, Maiman and Pintar, 1992, White and Panjabi, 1990). Despite the increased rotational capability afforded to the thoracic spine in comparison to the lumbar spine, few studies have investigated the combined range of motion (ROM) of the thoracolumbar region. Of those studies which have investigated thoracolumbar trunk rotation, there is marked variation in the maximum unilateral trunk ROM reported, with values ranging between 41° - 81° (Boden and Oberg, 1998, Edmondston et al., 2007, Fujii et al., 2008, Kumar et al., 1996, Parnianpour et al., 1989, Petersen et al., 1994, Toren, 2001). Such variability in reported trunk rotation ROM may stem from the diversity of measurement devices used to record trunk rotation (e.g. tri-axial electrogoniometry, electromagnetic motion monitors and optoelectronic motion analysis systems) and the differing methodological approaches.

In an attempt to isolate trunk rotation, a number studies have assessed participants in a seated position with the pelvis fixated (Boden and Oberg, 1998, Edmondston et al., 2007, Kumar et al., 1996, Ng et al., 2001, Parnianpour et al., 1989, Toren, 2001, Wessel et al., 1994, Willems et al., 1996). Besides the inherent difficulties of ensuring complete pelvis fixation (e.g.

preventing movement between the subject and the fixation device, and the subject's soft tissue and the bony anatomy beneath), any form of restraint has the potential to increase the ability to generate rotational torques (Boden and Oberg, 1998, Edmondston et al., 2007, Kumar et al., 1996, Toren, 2001). Furthermore, the suitability of extrapolating these findings to non-seated postures may limit their application to many functional tasks.

It has been advocated that maintaining a 'neutral' spine posture during bending and twisting decreases the risk of spinal injury (McGill, 1992). This may be due to the coupling effect of the lumbar facet joints that limit axial rotational range in non-neutral postures. In vitro investigations of the role of extension on axial rotation ROM of the lumbar spine appear to support this concept, with lumbar extension leading to a reduction in axial rotation (Haberl et al., 2004). However, results from in vivo studies appear conflicting (Burnett et al., 2008, Edmondston et al., 2007). The combination of lumbar extension and axial rotation of the trunk has been shown to lead to a decrease in linear torque production of the trunk muscles, suggesting that these muscles work less effectively when the spine is rotated and extended simultaneously (Kumar and Garand, 1992).

Although bending and twisting in a standing posture is commonly seen in a large number of manual vocations, and sport and leisure activities, there appears to be a lack of agreement on the effect of combined postures on trunk rotation ROM. Research has often focused on the lumbar spine and although, the current literature advocates the adoption of a neutral spine posture to maximise the rotary ROM available in the spine, evidence in support of this conjecture is limited. This may be particularly important for vocational tasks and sport activities such as golf, which require maximal axial rotation of the trunk. Thus, the objective of this study was to investigate the combined effects of changes in thoracolumbar spinal

posture on trunk rotation ROM. The influence of pelvic fixation on trunk rotational ROM was also studied.

2. Methods

2.1. Study design

A randomised, repeated measures experimental design was used to investigate the effects of three trunk inclinations (0^o, 22.5^o and 45^o) on maximum active rotation of the trunk and pelvis. At 45^o trunk flexion, the effects of three spinal postures (neutral, flexed and extended) on maximum active rotation of the trunk and pelvis were also studied (Figure 1a-c). Additionally, the effects of pelvic fixation (fixed and free) on maximum active rotational ROM of the trunk and pelvis was also evaluated in all test positions (Figure 1d).

2.2. Subjects

Twenty healthy male participants aged 21 to 43 years volunteered for the study. Their mean (standard deviation (SD)) age, height and weight were 31.4 years (± 8.1 years), 1.77 m (± 0.06 m) and 76.7 kg (± 11.3 kg), respectively. Participants were excluded from the study if they had a neurological condition; previous spinal, thoracic or abdominal surgery; or a history of spinal, pelvic or shoulder pain that restricted activities of daily living and involved one-week vocational absence in the last calendar year, or required treatment of any kind in the last three months. Those participants who were involved in elite asymmetrical sports were also excluded from the study. All participants were provided with written and verbal explanations of the experimental procedures and were required to provide written informed consent. The study was approved by the University ethics committee.

2.3. Trunk and spinal postures

Trunk inclination was measured using an inclinometer (Protech Autotilt, Wedge Innovations, California, USA) attached to a specially constructed chest plate that was secured to the participant's sternum with double-sided adhesive tape and a stretchy Velcro™ band (Figure 1). The inclinometer was zeroed in an upright standing position.

A neutral spine posture involved participants aligning the sacrum, mid-thoracic spine and posterior aspect of the head. To provide proprioceptive feedback to the participant on appropriate postural alignment and prevent inter-segmental spinal flexion occurring when inclining the trunk forward, a length of dowel was held against the sacrum, mid-thoracic spine and head. Trunk inclination was achieved by flexing the trunk about the medial-lateral hip joint axis until the inclinometer measured the desired test angles (22.5^{o} and 45^{o}). The flexed spine posture, required participants to segmentally flex the spine from the head down (i.e. flexion of the cervical spine followed into the thoracic and lumbar spine and sacral regions). Once flexed, they inclined their trunk forward about the hip joint axis until the inclinometer registered 45°. The extended spine posture involved participants segmentally extending the spine from the head down (i.e. initial retraction of the head, cervical extension and progressive thoracolumbosacral extension (Willems et al., 1996)). From this extended position participants inclined their trunk forward about their hip joint axis until the inclinometer registered 45°.

2.4. Familarisation

Prior to the experiment, all participants underwent familiarisation in the experimental procedures. While standing upright, participants were initially taught to rotate their trunk about their spinal axis without distorting the thoracolumbosacral region in other planes. To

encourage segmental rotation from T1 down to the sacrum in a sequential fashion and minimise scapulothoracic motion during rotation, participants placed a length of dowel horizontally behind their shoulders, at approximately the level of T4, and rotated the dowel in a circular motion about their spinal axis. Handles attached anteriorly to the dowel enabled those participants who lacked external rotation at the shoulders to maintain a comfortable position. Once participants were familiar with turning around their spinal axis, they inclined their trunk anteriorly about their hips in the sagittal plane and repeated the rotation movement at a trunk inclination of 45°. Participants also adopted slight knee flexion (1/4 squat position) when rotating their trunk in order to negate the possible effects of hamstring length on restricting trunk rotation. Throughout trunk rotations participants were encouraged to eliminate movements in the other planes of motion, other than about their spinal axis.

2.5. Pelvic fixation

A purpose-built pelvic fixation device was constructed that consisted of adjustable waist belt with four non-stretch adjustable guy ropes anchored to the floor. The waist belt had a rubber inlay designed to minimise slippage and was worn around the pelvis at the level of the pubic symphysis. Each guy rope was adjusted to an appropriate length to allow slight knee flexion (1/4 squat position). Participants were required to 'stand up' within the restraining harness in order to restrict pelvic movement during active trunk rotation (Figure 1d).

2.6. Experimental procedure

Each participant performed maximum left and right trunk rotation in each of the conditions (i.e. three trunk inclinations (0^o, 22.5^o and 45^o) in a neutral spine posture and three spinal postures (neutral, flexed and extended) at 45^o trunk inclination) with and without the pelvis fixated. When undertaking maximum trunk rotation, participants rotated as far as possible in

one direction, paused and then rotated as far as possible in the opposite direction before returning to their start position. Three trials were performed for each condition, with the order of conditions randomised across participants. The direction of rotation was also randomised according to the initial direction of rotation, with all subsequent rotations alternating thereafter. The speed of rotation was controlled using a metronome set at a frequency of 10 Hz in order that the angular velocity of the trunk was below 60°/s. Velocities below this value have been shown to produce minimal torque on the trunk's musculotendinous and ligamentous structures (McGill and Hoodless, 1990). Between trials, participants rested for a minimum of 2 minutes in order to limit the effects of fatigue. Participants who were observed to move out of the spinal posture during rotation were asked to repeat the movement trial. To investigate the repeatability of maximal unilateral trunk rotation, ten participants repeated the experiment on a separate day, at least one week apart.

2.7. Kinematics data

A nine-camera motion analysis system (Qualysis Medical AB, Sweden) sampling at 240Hz was used to record 3D movements of the thorax, pelvis and lower limb segments during trunk rotation. Retro-reflective makers were attached to the skin overlying the 7^{th} cervical spinous process and bilaterally over the acromioclavicular joint line, anterior superior iliac spine, superior aspect of the iliac crest, posterior superior iliac spine, superior tip of the greater trochanter, medial and lateral epicondyles of the distal femur, medial and lateral malleoli of the ankles, lateral aspect of the 5th metatarsophalangeal joint line and the medial aspect of the 1st metatarsophalangeal joint line. A series of cluster markers (Cappozzo et al., 1997) were fixed to the thorax, thighs and shanks using a combination of hypoallergenic tape, stretchy Velcro™ bands and rigid sports strapping tape (Figure 1).

An initial recording of the participant in a standing position was used as a 'static' trial for subsequent biomechanical model of the thorax, pelvis and lower body segments and to provide a measure of the resting sternal angle (0° inclination). In conjunction with the 3D motion capture, a digital video camera (Panasonic, USA) sampling at a rate of 60 Hz provided visual information of the captured motion data. Kinematic data were smoothed using a Butterworth lowpass filter with a cutoff frequency of 12 Hz and subsequently analysed using Visual 3D (C-Motion Inc, USA).

2.8. Biomechanical model

An eight segment, 3D rigid-link dynamic biomechanical model of the thorax, pelvis and right and left lower limbs was constructed in Visual 3D (C-Motion Inc, USA). Body segments were represented as geometric objects (cylinders) and scaled according to each individual (Hanavan, 1964). Orthogonal axes were aligned according to each segment (geometric object) and the position of the thorax and pelvic 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. Angular displacements of the trunk and pelvis were calculated with respect to a global (pelvis with respect to the laboratory) and relative (trunk with respect to the pelvis) co-ordinates reference frame.

2.9. Data analysis

All data was analysed using SPSS v15.0 (SPSS Inc., Chicago) statistical computer software package. Data was tested for normality and a repeated-measures, multivariate analysis of variance (MANOVA) was used to test for main and interaction effects of trunk inclination, spinal posture and pelvic fixation on maximum unilateral trunk and pelvic rotation. Where significant main effects for trunk inclination and spinal posture were identified, post hoc

analysis was performed using Fisher's Least Significant Differences (LSD). Interclass correlation coefficients (ICC) and standard error of measurement (SEM) were calculated for the ten participants who undertook the repeatability study. The statistical significance level was set at $p<0.05$.

3. Results

Maximum unilateral trunk rotation and pelvic rotation for all test conditions are shown in Table 1.

3.1. Test-retest reliability

The SEM and ICC for test-retest reliability of unilateral trunk rotation ROM was 2.1° and 0.815, respectively. The SEM and ICC for unilateral pelvic rotation ROM was 2.4° and 0.977, respectively.

3.2. Trunk Inclination

Trunk inclination had a significant main effect on unilateral trunk ($p<0.001$) and pelvic rotation ROM ($P<0.001$). As trunk inclination increased, there was a significant increase in maximum unilateral trunk rotation, with an average increase of approximately 3% (1.0°) at 22.5° inclination ($P<0.01$) and 10% (3.2°) at 45° inclination ($P<0.01$) compared to a neutral, upright posture (0° inclination) (Figure 2). For unilateral pelvic rotation ROM, as trunk inclination increased, mean unilateral pelvic rotation decreased by 37% (13.4°) when inclining the trunk from 0° to 45° (Figure 3).

3.3. Spinal Posture

Spinal posture had a significant main effect on unilateral trunk ($p<0.01$) and pelvic rotation ROM ($P<0.05$). Flexing and extending the spine led to an average decrease in trunk rotation

ROM of approximately 6% (2.2°) (P<0.001) and 2% (1.0°) (P<0.05), respectively, when compared to a neutral posture (Figure 4). For unilateral pelvic rotation ROM, extending the spine led to an average decrease in pelvic rotation ROM of approximately 17% (6.4°) (P<0.001), whereas flexing the spine led to an average increase of approximately 4% (1.7°) (P<0.05) (Figure 5).

3.4. Pelvic Fixation

Pelvis fixation was found to have significant main effect on unilateral trunk rotation ROM (P<0.001) and unilateral pelvic rotation (P<0.001). Fixing the pelvis led to an average increase in unilateral trunk rotation of approximately 4% (1.6°) (with the spine neutral or flexed) and 9% (3.3°) (with the spine extended) and an average decrease in unilateral pelvic rotation across all test positions of approximately 83% (37°).

3.5 Trunk, spine and pelvic fixation

With the exception of trunk inclination by pelvic fixation (p<0.001), no other significant interaction effects were found for trunk inclination, spinal posture and pelvic fixation.

4. Discussion

4.1. Trunk Inclination

Increases to trunk inclination in the sagittal plane lead 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 reduced.

The contrasting effects of trunk inclination on trunk rotation and pelvic rotation ROM may lie in the 'relative flexibility' of the body (Comerford and Mottram, 2000). 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 may be dictated by the relative flexibilities of the respective body segments. It appears likely 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. The stiffness in the lower body is most likely the result of the trunk inclination 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 '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 was further demonstrated by the interaction effect between trunk inclination and pelvic fixation. In the case of a fixed pelvis, increases in trunk inclination exerted less influence on the ability for the trunk to maximally rotate compared to when the pelvis was unrestricted.

Whilst 'relative flexibility' may provide a possible explanation for these findings, consideration must also be given to the trunk musculature responsible for trunk rotation. If increasing trunk inclination acts to stabilise the lower body, trunk muscles such as the external and internal obliques are likely to contract more effectively from a stable platform and produce more rotational torque, resulting in a greater axial range due to the viscoelastic elements of the thoracolumbar spine being stretched (Gluck et al., 2008). Evidence for this stabilising phenomenon was demonstrated when movement of the pelvis was restricted. This resulted in an increase in mean unilateral trunk rotation of approximately 18% (6°) and a decrease in mean unilateral pelvic rotation of approximately 40% (26°) when moving from

standing to a 45° trunk inclination. 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.

4.2. Spinal Posture

Studies investigating the influence of spinal posture on trunk rotational ROM have often been restricted to measurements of the thoracolumbar spine with participants seated and the pelvis fixed (Edmondston et al., 2007, Kumar et al., 1996, Toren, 2001, Wessel et al., 1994, Willems et al., 1996). These studies have demonstrated conflicting evidence about the extent of spinal flexion or extension on trunk rotation ROM. Segmental flexing of the thoracolumbar spine in the sagittal plane at a trunk inclination of 45° was found to decrease unilateral trunk rotation when compared to a neutral spine posture at the same inclination. Albeit restricted to measurements of lumbar trunk rotation, previous studies have demonstrated reduced axial trunk rotation associated with a flexed spine (Burnett et al., 2008; Gunzburg, 1991; Haberl, 2004). A common feature between these and the current study is that trunk flexion was initiated in a cephalad to caudad direction. In contrast, Hindle and Pearcy (1989) reported increased trunk rotation with a flexed lumbar spine. However, in their study the spine was flexed segmentally from the sacrum upward. Participants were also required to sit with their feet on a stool in order to encourage lumbar flexion. Flexing the thoracolumbar spine in a caudad-cephalad direction and promoting lumbar flexion may negate the natural rotational restriction provided by the orientation of the facet joints in the lumbar spine (Gunzburg et al., 1991, Haberl et al., 2004).

Given that approximately 80% of axial rotation occurs in the thoracic spine (Fujii et al., 2008), it is likely that flexing the spine in a cephalad to caudad direction increases the

stiffness of the posterior soft tissue elements of the spine leading to a decrease in overall axial rotation. Burnett et al. (2008) also reported a greater reduction in lower lumbar axial rotation when flexing the lumbar spine than when extending the lumbar spine. They postulated that the reduced axial rotation for a flexed lumbar spine stemmed from the greater compressive loads on the lumbar spine in flexion.

Maintaining segmental extension of the thoracolumbar spine in the sagittal plane at a trunk inclination of 45° resulted in a decrease in maximal trunk rotation when compared to a neutral spine posture. It may be that the increased activity in the thoracolumbar paraspinal muscles required to maintain the spine in extension acted to restrict axial rotation, in line with the concept that increasing muscle activation can stiffen a joint in a particular direction (MacDonald et al., 2006, McGill, 2007). As Burnett et al. (2007) suggested, compacting the lumbar facet joints in extension may contribute to decreased axial rotation.

4.3. Pelvic Fixation

Maximal trunk rotation increased significantly when the pelvis was fixed. This effect is likely to occur due to the 'relative flexibility' of the body (Comerford and Mottram, 2000). When rotating the trunk with the pelvis unrestricted, rotation occurred both within the trunk and at the pelvis and legs. Fixing the pelvis effectively 'stiffened' the lower body causing the body to take the 'path of least resistance' during rotation allowing more rotation to occur through the trunk. The effects of stiffening and reducing pelvic rotation may also have lead to a more stable platform from which the muscles of the trunk (e.g. external and internal obliques) could exert a rotational torque, resulting in a greater axial range as the viscoelastic elements of the thoracolumbar spine were stretched (Gluck et al., 2008)

Fixing the pelvis did result in a significant reduction in pelvic rotation under all test conditions. The quandary that surrounds trunk rotation findings reported in the literature is deciding whether to assess trunk rotation with the pelvis fixed or restricted and whether this provides findings that are clinically relevant. Evans et al. (2006) argues that testing trunk rotation under restrictive conditions is often both time consuming and complex, and queries the benefit of the outcomes as it does not test the body in a dynamic setting. Furthermore, utilising findings from those studies which have implemented pelvic fixation is often problematic, as pelvic fixation has often been poorly implemented or pelvic motion was not adequately monitored.

Failure to identify the distinct rotational components of the body in a clinical setting could lead to a clinician missing obvious and detrimental relative rotational flexibilities that may exist within the body, prior to 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 on other parts of the body. It would be useful to develop musculoskeletal screening tools that have adequate levels of specificity to identify 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 could be modified to include a second plumb bob that monitors the rotation of the pelvis simultaneously. This would make the test procedure cost effective and clinically achievable, while providing additional information about 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 resulted in less pelvic rotation when the pelvis was unrestrained, than the flexed or neutral postures. 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. Pelvic fixation led to an increase in trunk rotation in all postures.

This study is not without limitations. Placement of the arms in a raised position during trunk rotation may have had an effect on overall trunk rotation ROM via the potential involvement of the latissimus dorsi-thoracolumbar fascia complex, potentially leading to an underestimation of the true maximal unilateral trunk rotation. The use of retro-reflective markers on the skin, particularly over the ASIS, is susceptible to movement artefacts during trunk rotation due to skin displacement and the variability in the anterosuperior pelvic adipose deposition between participants. Furthermore, the method used to restrain pelvic movement was dependent on the participants standing up and maintaining tension within the guy ropes. Whether using the legs to actively fixate the pelvis impacted on the ability to rotate the trunk requires further investigation.

Despite alterations in spine posture and pelvic fixation having a significant effect on trunk rotation ROM, observed changes were small and often of a similar magnitude to the SEM observed for repeated measures of trunk rotation. Whilst every effort was made to ensure that participants maintained both the required trunk inclination and spinal posture when rotating the trunk, it is possible that some participants may have altered their trunk posture during rotation to a more neutral spine posture. Furthermore, when rotating the trunk, participants were not permitted to side flex. This may have limited overall trunk rotation ROM by restricting the 'natural' coupling that is known to occur in the thoracolumbar spine during trunk rotation (Edmondston et al., 2007, Willems et al., 1996).

5. Conclusion

Inclining the spine forward in the sagittal plane restricted rotational movement of the pelvis, but increased trunk rotation by approximately 12%. Adopting an inclined, neutral spine posture that maximises trunk rotation is likely to be beneficial for certain sport activities, such as golf. Whether such postures and the consequent increased ROM reduces the risk of injury during vocational and leisure activities requires further investigation, due to the uncertainty of the association between increased mobility and reduced risk.

Trunk rotation was dependent upon the posture of the spine in the inclined position, with a neutral thoracolumbar spine increasing maximum trunk rotation ROM. In comparison to a flexed or extended thoracolumbar spine, this has the benefit of not placing the spine near the end of its available ROM where greater loads on the facet joint capsules, ligaments and/or discs are likely to occur.

Pelvic fixation resulted in increased trunk rotational ROM compared to an unconstrained pelvis. Caution is needed when utilising trunk rotational measures derived from studies incorporating pelvic fixation, as these are likely to provide overestimations of trunk mobility when considered to unconstrained movement. Within the clinical setting, unrestricted observation of trunk rotations is considered more appropriate as this is likely to benefit the clinician in determining distinct rotational components of the body and possible detrimental relative flexibilities that may exist within the body.

Acknowledgements

The financial support of Auckland University of Technology for this research was greatly appreciated.

References

BODEN, A. & OBERG, K. (1998) Torque resistance of the passive tissues of the trunk at axial rotation. Applied Ergonomics, 29**,** 111-8.

BURNETT, A., O'SULLIVAN, P., ANKARBERG, L., GOODING, M., NELIS, R., OFFERMANN, F. & PERSSON, J. (2008) Lower lumbar spine axial rotation is reduced in end-range sagittal postures when compared to a neutral spine posture. Manual Therapy, 13**,** 300-306.

CAPPOZZO, A., CAPPELLO, A., DELLA CROCE, U. & PENSALFINI, F. (1997) Surface-marker marker cluster design criteria for 3-D bone movement reconstruction. IEEE Transaction on Biomedical Engineering, 44**,** 1165-1174.

COMERFORD, M. J. & MOTTRAM, S. L. (2000) Dysfunction: Focus on Dynamic Stability and Muscle Balance. . Kinetic Control Movement Dysfunction Course Publication.

EDMONDSTON, S. J., AGGERHOLM, M., ELFVING, S., FLORES, N., NG, C., SMITH, R. & NETTO, K. (2007) Influence of posture on the range of axial rotation and coupled lateral flexion of the thoracic spine. Journal of manipulative and physiological therapeutics, 30**,** 193-199.

EVANS, K., REFSHAUGE, K. M. & ADAMS, R. (2006) Measurement of active rotation in standing: reliability of a simple test protocol. Perception and Motor Skills, 103**,** 619-628.

FUJII, R., SAKAURA, H., MUKAI, Y., HOSONO, N., ISHII, T., IWASAKI, M., YOSHIKAWA, H. & SUGAMOTO, K. (2008) Kinematics of the lumbar spine in

trunk rotation: in vivo three-dimensional analysis using magnetic resonance imaging. European Spine Journal, 16**,** 1867-1874.

GLUCK, G. S., BENDO, J. A. & SPIVAK, J. M. (2008) The lumbar spine and low back pain in golf: a literature review of swing biomechanics and injury prevention. Spine Journal, 8**,** 778-788.

GUNZBURG, R., HUTTON, W. & FRASER, R. (1991) Axial rotation of the lumbar spine and the effect of flexion: an in vitro and in vivo biomechanical study. Spine, 16**,** 22-8.

HABERL, H., CRIPTON, P. A., ORR, T. E., BEUTLER, T., FREI, H., LANKSCH, W. R. & NOLTE, L. P. (2004) Kinematic response of lumbar functional spinal units to axial torsion with and without superimposed compression and flexion/extension. European Spine Journal, 13**,** 560-566.

HANAVAN, E. P., JR. (1964) A Mathematical Model of the Human Body. AMRL TR-64-102**,** 1-149.

HINDLE, R. J., PEARCY, M. J., CROSS, A. T., & MILLER, D. H. T. (1990). Three-dimensional kinematics of the human back. Clinical Biomechanics, 5(4), 218-228.

KUMAR, S. & GARAND, D. (1992) Static and dynamic lifting strength at different reach distances in symmetrical and asymmetrical planes. Ergonomics, 35**,** 861-880.

KUMAR, S., NARAYAN, Y., STEIN, R. B. & SNIJDERS, C. (2001) Muscle fatigue in axial rotation of the trunk. International Journal of Industrial Ergonomics, 28**,** 113-26.

KUMAR, S., NARAYAN, Y. & ZEDKA, M. (1996) An electromyographic study of unresisted trunk rotation with normal velocity among healthy subjects. Spine, 21**,** 1500-1512.

MACDONALD, D. A., MOSELEY, G. L. & HODGES, P. W. (2006) The lumbar multifidus: does the evidence support clinical beliefs? Manual Therapy, 11**,** 254-263.

MAIMAN, D. J. & PINTAR, F. A. (1992) Anatomy and clinical biomechanics of the thoracic spine. Clinical Neurosurgery, 38**,** 296-324.

MANNING, D. P., MITCHELL, R. G. & BLANCHFIELD, L. P. (1984) Body movements and events contributing to accidental and non-accidental back injuries. Spine, 9**,** 734-749.

McGILL, S. M. (1992) The influence of lordosis on axial trunk torque and trunk muscle myoelectric activity. Spine, 17**,** 1187-1193.

McGILL, S. M. (2007) Low Back Disorders: Evidence-Based Prevention and Rehabilitation, USA, Human Kinetics.

McGILL, S. M. & HOODLESS, K. (1990) Measured and modelled static and dynamic axial trunk torsion during twisting in males and females. Journal of Biomedical Engineering, 12**,** 403-409.

NG, J. K., KIPPERS, V., RICHARDSON, C. A. & PARNIANPOUR, M. (2001) Range of Motion and Lordosis of the Lumbar Spine: Reliability of Measurement and Normative Values. Spine, 26**,** 53-60.

PARNIANPOUR, M., LI, F., NORDIN, M. & KAHANOVITZ, N. (1989) A database of isoinertial trunk strength tests against three resistance levels in sagittal, frontal and transverse planes in normal male subjects. Spine, 14**,** 409-410.

PETERSEN, C. M., JOHNSON, R. D., SCHUIT, D. & HAYES, K. W. (1994) Intraobserver and interobserver reliability of asymptomatic subjects' thoracolumbar range of motion using the OSI CA 6000 Spine Motion Analyzer. Journal of Orthopaedic and Sports Physical Therapy, 20**,** 207-212.

TOREN, A. (2001) Muscle activity and range of motion during active trunk rotation in a sitting posture. Applied Ergonomics, 32**,** 583-91.

WESSEL, J., FORD, D. & VAN DRIESUM, D. (1994) Torque of trunk flexion and trunk flexion with axial rotation in healthy men and women. Spine, 19**,** 329-334.

WHITE, A. A. & PANJABI, M. M. (1990) Clinical Biomechanics of the Spine, Philadelphia, J.B.Lippincott.

WILLEMS, J. M., JULL, G. A. & NG, J. K. (1996) An in-vivo study of the primary and coupled rotations of the thoracic spine. Clinical Biomechanics, 11**,** 311-6.

Figure legends

Figure 1. Spinal postures at 45° trunk inclination: a) Neutral; b) Flexed; c) Extended; d) Fixated

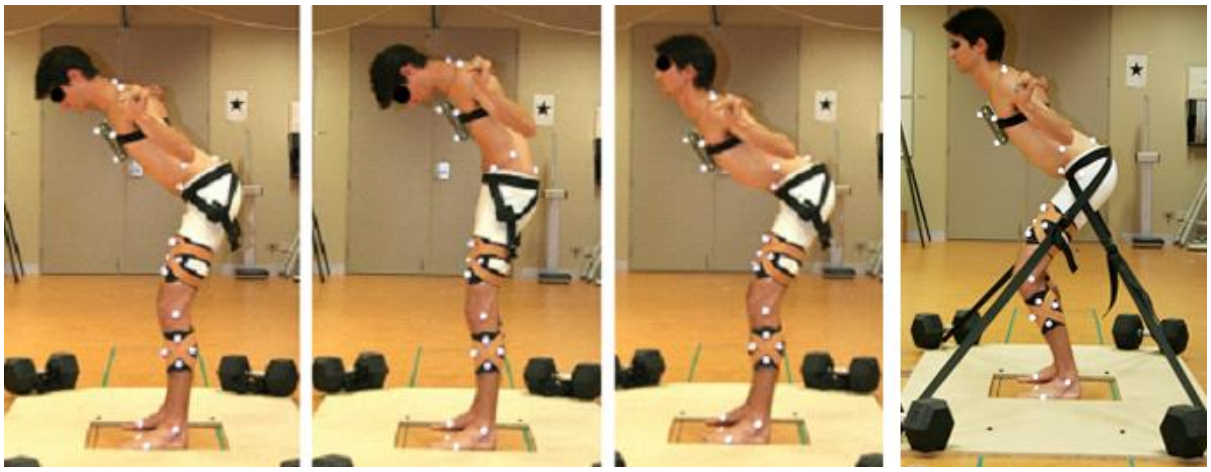
Figure 2. Average maximum unilateral trunk rotation ROM for three trunk inclinations (mean ± standard deviation) * = significant effect (P<0.01)

Figure 3. Average unilateral pelvic rotation ROM for three trunk inclinations (mean ± standard deviation) * = significant effect (P<0.005); ** =significant effect (P<0.001)

Figure 4. Average maximum unilateral trunk rotation ROM for three spinal postures (mean ± standard deviation) * = significant effect (P<0.01); **=significant effect (P<0.05)

Figure 5. Average unilateral pelvic rotation ROM for three spinal postures (mean ± standard deviation) * = significant effect (P<0.05); ** =significant effect (P<0.005)

Figure 1



(a) (b) (c) (d)

Figure 2

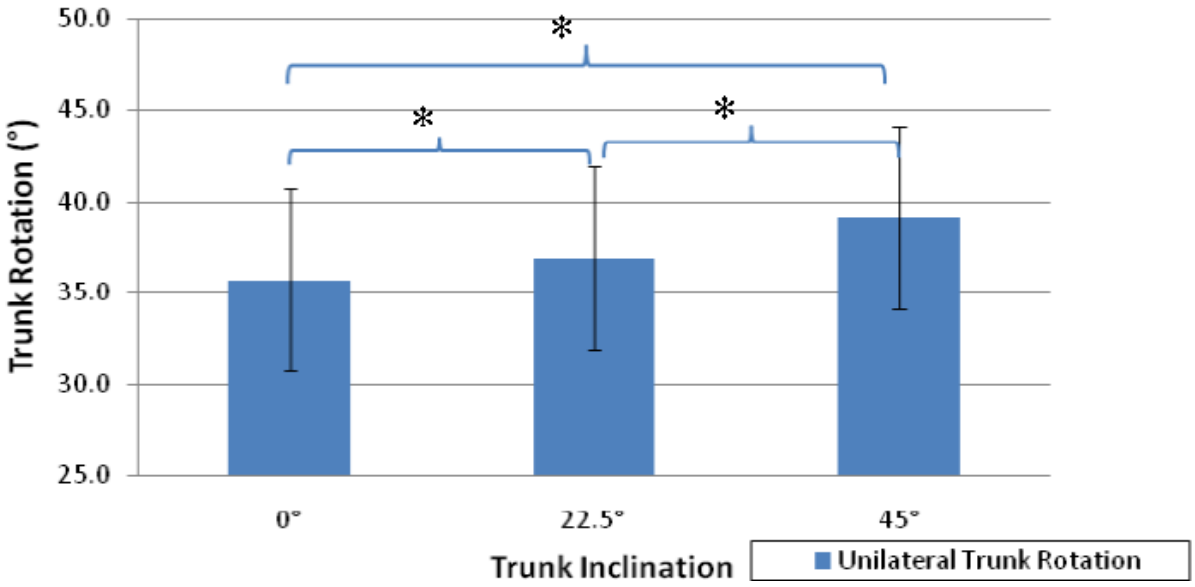

50.0
45.0
40.0
35.0
30.0
25.0
Trunk Rotation (°)
*
*
*
0°
22.5°
45°
Trunk Inclination
Unilateral Trunk Rotation

Figure 3

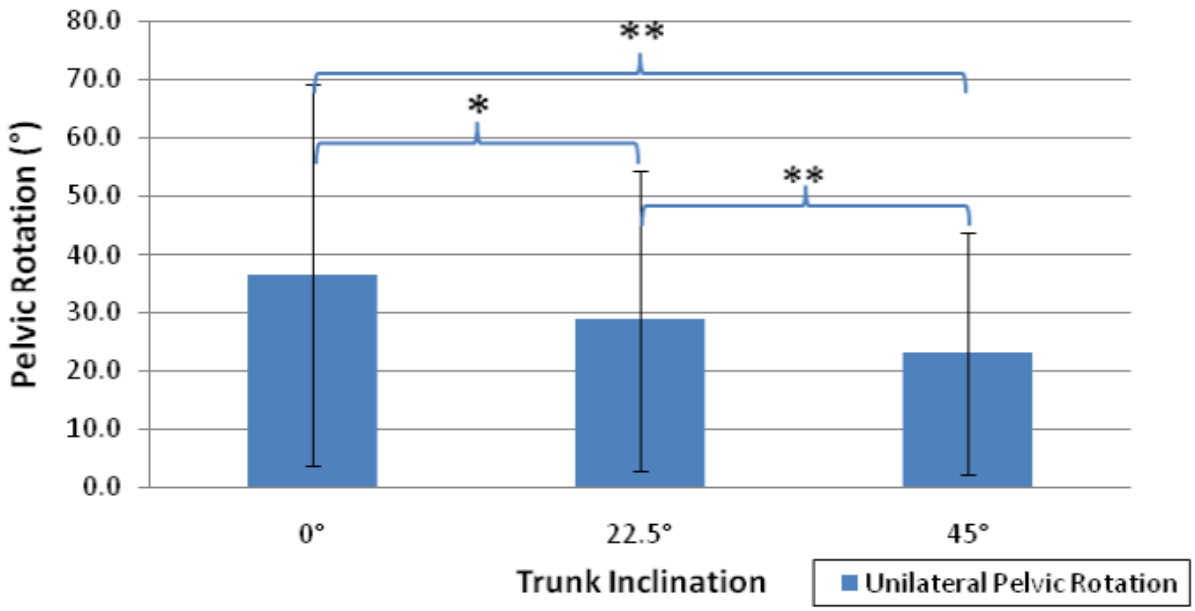

80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Pelvic Rotation (°)
**
*
**
0°
22.5°
45°
Trunk Inclination
Unilateral Pelvic Rotation

Figure 4

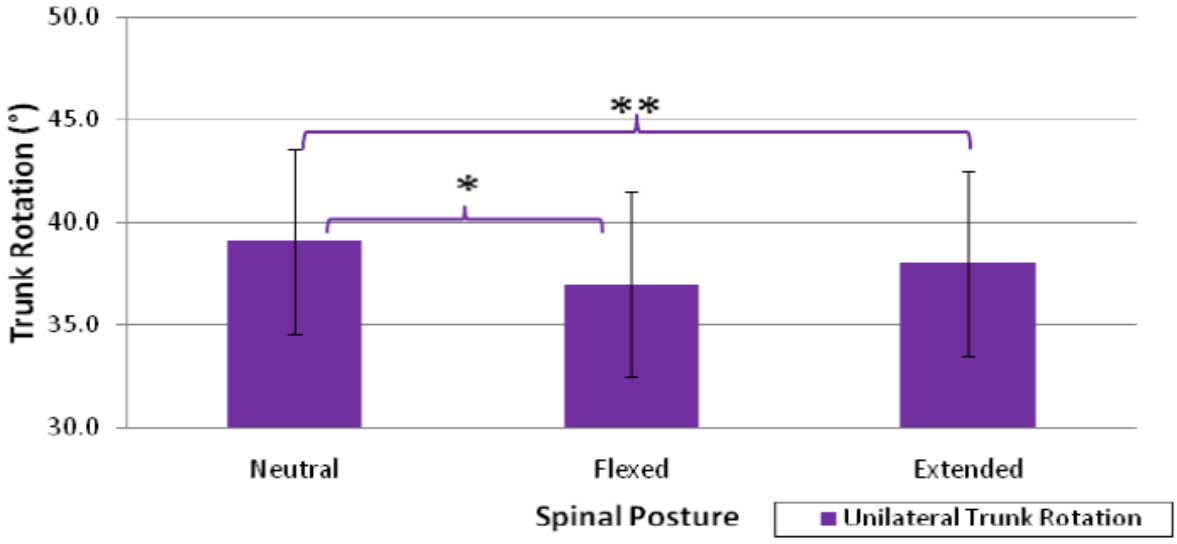
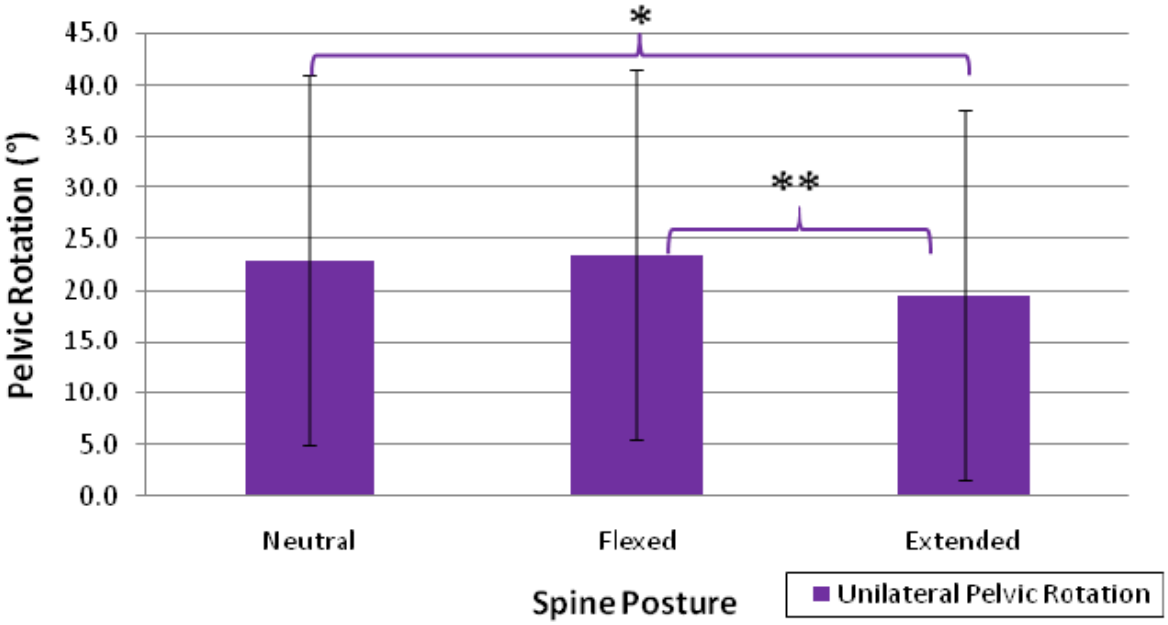

50.0
45.0
40.0
35.0
30.0
Trunk Rotation (°)
**
*
Neutral
Flexed
Extended
Spinal Posture
Unilateral Trunk Rotation

Figure 5


*
**
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Pelvic Rotation (°)
Neutral
Flexed
Extended
Spine Posture
Unilateral Pelvic Rotation

***Potential Reviewers (please suggest at least 2 potential reviewers)**

Suggested Referees include:

A/Prof Stephen Edmondston
Director, Postgraduate Coursework Programs,
School of Physiotherapy,
Curtin University of Technology,
Kent St,
Bentley,
WA 6102,
Australia
Email: S.Edmondston@curtin.edu.au

Dr J D G Troup
Honorary Senior Research Fellow
Aberdeen University Department of Orthopaedic Surgery
Kirkton House
Cairnie
Huntly
Aberdeenshire AB54 4TR
Scotland
Email: johntroup@btinternet.com

Table(s)

Table 1 *Mean (SD, range) ranges of trunk and pelvic rotation (degree) in all test postures with (Fixed) and without (Free) pelvic fixation (n=20)*

	Free		Fixed	
	Trunk Rotation	Pelvic Rotation	Trunk Rotation	Pelvic Rotation
Neutral (0°)	32.4 (4.9, 21.8-41.4)	63.9 (14.9, 28.8-90.8)	39.3 (5.6, 29.0-49.6)	8.9 (3.5, 1.8-21.4)
Neutral (22°)	34.3 (5.3, 24.7-47.6)	49 (19.9, 5.5-88.9)	39.5 (5.0, 29.9-49.4)	8.3 (3.9, 1.8-18.3)
Neutral (45°)	38.2 (5.4, 27.7-54.8)	38.4 (21.9, 5.0-89.7)	39.9 (5.0, 39.9-52.2)	7.6 (3.5, 0.7-17.3)
Flexion (45°)	36.2 (5.3, 17.2-47.4)	40.1 (21.1, 1.1-83.5)	37.6 (4.3, 24.2-47.3)	7.0 (3.7, 0.5-17.7)
Extension (45°)	36.6 (4.1, 25.9-45.8)	32 (18.0, 6.0-79.8)	39.9 (4.9, 27.3-49.5)	6.9 (3.2, 0.8-17.4)