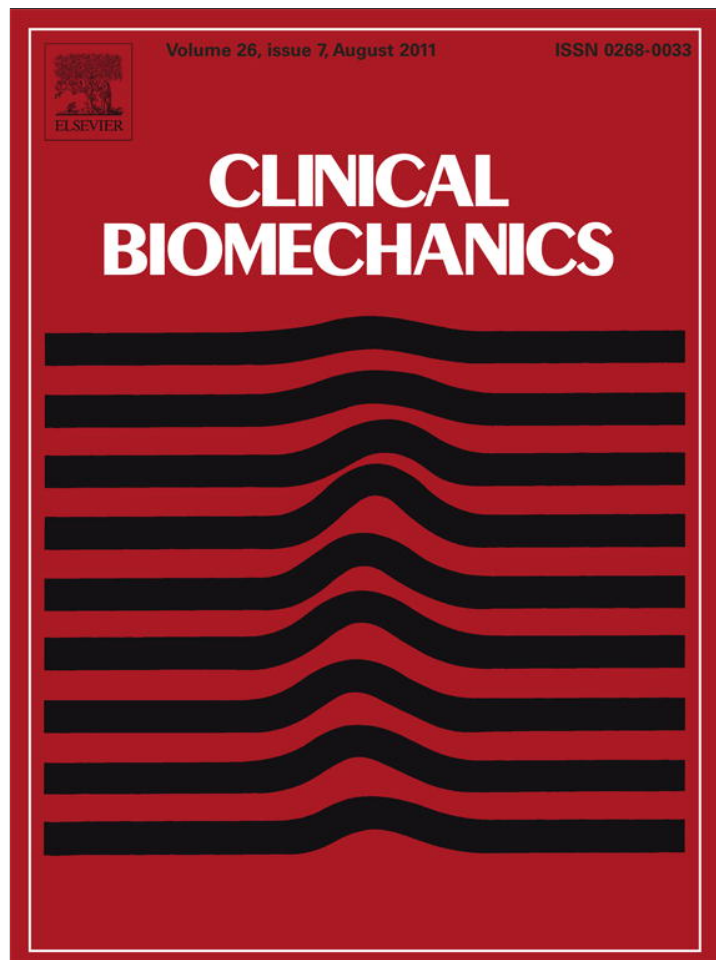


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The effects of spinal posture and pelvic fixation on trunk rotation range of motion

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ABSTRACT

Background: Axial rotation of the trunk is important to many vocational tasks and activities of daily living, and may be associated with back injuries. The influence of spinal postures on trunk rotation appears conflicting. This study investigated the influence of forward trunk inclination, spinal posture and pelvic fixation on maximum 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. A repeated-measures multivariate analysis of variance investigated the effects of forward trunk inclination, spinal posture and pelvic fixation on trunk and pelvic rotation. Test–retest reliability was determined using interclass correlation coefficients and standard error of measurement.

Findings: Forward trunk inclination at 45° yielded a 19% (6.2°; $P < 0.001$) increase in trunk rotation and a 40% (25.5°; $P < 0.001$) decrease in pelvic rotation when compared to standing. When flexing and extending the spine at a forward trunk inclination of 45° there was a 5% (1.9°; $P < 0.01$) and a 4% (1.6°; $P < 0.05$) decrease in trunk rotation. Fixing the pelvis increased the trunk rotation by up to 9% (3.3°; $P < 0.001$).

Interpretation: Inclining the trunk forward and maintaining a neutral spine maximised trunk rotation range of motion (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.

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1. Introduction

Axial rotation within the trunk is central to the achievement of many activities of daily living. Approximately 80% of the axial trunk rotation occurs in 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 of the thoracic spine in comparison to the lumbar spine, few studies have investigated the combined rotational range of motion (RoM) of the thoracolumbar region.

Of those studies which have investigated thoracolumbar trunk rotation, there is a marked variation in the maximum unilateral RoM reported, with values ranging between 41° and 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 methodological approaches and measurement devices used to record trunk rotation (e.g. tri-axial electrogoniometry,

electromagnetic motion monitors and optoelectronic motion analysis systems).

In an attempt to isolate trunk rotation, a number of 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. due to soft tissue movement between the subject and the fixation device), 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). In addition, alterations in posture may impact on the 'relative flexibility' of the system. The concept of relative flexibility has been applied to patients with dysfunction and pain, however such a concept may well apply where deliberately imposed 'restrictions' to one or more body segments result in a desirable increase in 'give' or excessive joint motion of other segments (Comerford and Mottram, 2001).

Spinal posture also appears to influence the ability to rotate the trunk, with in vitro investigations of lumbar extension showing a reduction in axial rotation (Haberl et al., 2004). Combining lumbar extension and axial rotation of the trunk leads to a decrease in the linear torque production of the trunk muscles, suggesting that these muscles work less effectively when the spine is rotated and extended

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simultaneously (Kumar and Garand, 1992). However, the results from in vivo studies of lumbar flexion and extension on trunk rotation appear conflicting (Burnett et al., 2008; Edmondston et al., 2007).

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. Understanding the influence of spinal posture on trunk rotation appears particularly important for the study of 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 forward trunk inclinations (0° , 22.5° and 45°), three spinal postures (neutral, flexed and extended) and pelvic fixation on maximum active rotation of the trunk and pelvis (Fig. 1a–d).

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 (SD 8.1 years), 1.77 m (SD 0.06 m) and 76.7 kg (SD 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

Forward 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 (Fig. 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 the 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. Forward 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° and 45°). 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, participants 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. Familiarisation

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 forward 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.

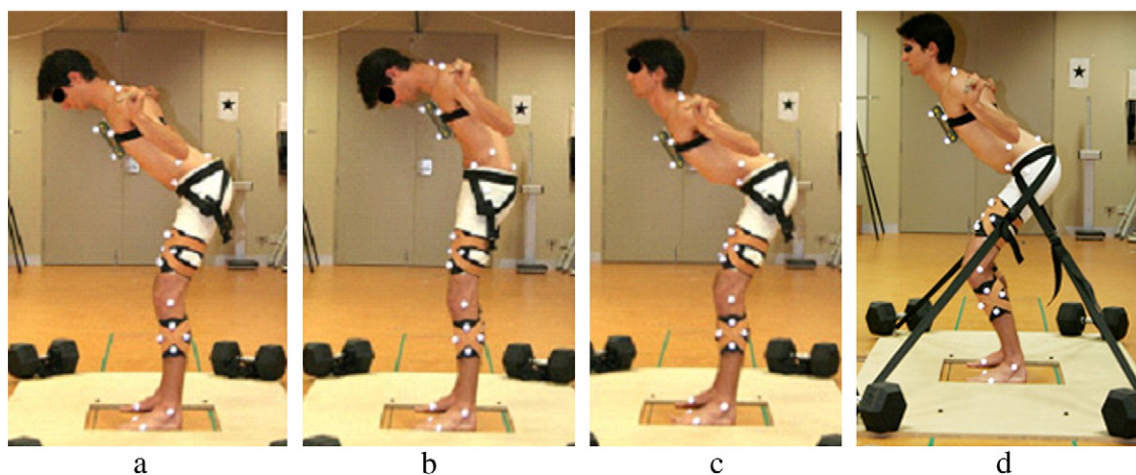


Fig. 1. Spinal postures at a 45° forward trunk inclination: a) neutral; b) flexed; c) extended; d) fixated.

2.5. Pelvic fixation

A purpose-built pelvic fixation device was constructed that consisted of an 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 (Fig. 1d).

2.6. Experimental procedure

Each participant performed maximum left and right trunk rotation in each of the conditions (i.e. three forward trunk inclinations (0° , 22.5° and 45°) in a neutral spine posture and three spinal postures (neutral, flexed and extended) at 45° forward 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 $60^\circ/\text{s}$. 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 min 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 240 Hz was used to record 3D movements of the thorax, pelvis and lower limb segments during trunk rotation. Retro-reflective markers were attached to the skin overlying the 7th cervical spinous process and bilaterally over the acromioclavicular joint line, anterior superior iliac spine (ASIS), 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 (Fig. 1).

An initial recording of the participant in a standing position was used as a 'static' trial for subsequent biomechanical modelling 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. This was used as a post-data collection check to determine whether participants had deviated from the required task. 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 the medial and lateral markers at the ends of each segment, with the longitudinal axis passing through the segment endpoints and the origin being at the proximal end of the pelvis and distal end of the trunk. 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 displacement (unilateral rotation) was rotation occurring about the Z axis of each segment, with zero displacement being the initial position for each posture. Maximum unilateral rotation of the trunk and pelvis was the mean of the absolute angular displacement (maximum) when turning to the left and right. For trunk rotation, angular displacement was measured with respect to the pelvis, whereas angular rotation of the pelvis was with respect to the laboratory co-ordinates reference frame. The sequence of rotation for the Cardian angles was X–Y–Z.

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 repeated-measures, multivariate analysis of variance (MANOVA) was used to test for the main and interaction effects of forward trunk inclination, spinal posture and pelvic fixation on the maximum unilateral trunk and pelvic rotation. Where significant main effects for forward trunk inclination and spinal posture were identified, post hoc analysis was performed using Fisher's Least Significant Differences (LSD). The statistical significance level was set at $P < 0.05$. Interclass correlation coefficients (ICC) and standard error of measurement (SEM) were calculated for the ten participants who undertook the repeatability study.

3. Results

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. Forward trunk inclination

Forward trunk inclination had a significant main effect on the unilateral trunk ($P < 0.001$) and pelvic rotation RoMs ($P < 0.001$). As forward trunk inclination increased, there was a significant increase in the maximum unilateral trunk rotation, with an average increase of approximately 7% (mean = 2.3° , 95th percentile confidence interval (95th CI) = -3.4° – 7.9°) at a 22.5° inclination ($P < 0.01$) and 19% (mean = 6.2° , 95th CI = 1.3° – 11.0°) at a 45° inclination ($P < 0.001$) with the pelvis free to rotate, compared to a neutral, upright posture (0° inclination) (Fig. 2). For the unilateral pelvic rotation RoM, as forward trunk inclination increased, the mean unilateral pelvic rotation decreased by 23% (mean = 14.9° , 95th CI = -9.9° – 39.8°) at a 22.5° inclination ($P < 0.001$) and by 40% (mean = 25.5° , 95th CI = -0.5° – 51.5°) at a 45° inclination ($P < 0.001$) with the pelvis free to rotate, compared to neutral, upright standing (Fig. 3).

3.3. Spinal posture

Spinal posture had a significant main effect on the unilateral trunk ($P < 0.01$) and pelvic rotation RoMs ($P < 0.05$). Flexing and extending the spine led to an average decrease in trunk rotation RoM of approximately 5% (mean = 1.9° , 95th CI = -4.5° – 8.2°) ($P < 0.01$) and 4.2% (mean = 1.6° , 95th CI = -3.3° – 6.5°) ($P < 0.05$), respectively, when

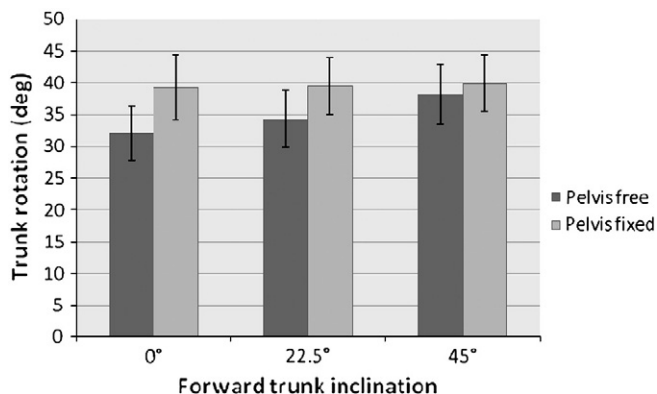


Fig. 2. Means and standard deviations of maximum unilateral trunk rotation RoM for the three forward trunk inclinations with the pelvis free and fixed.

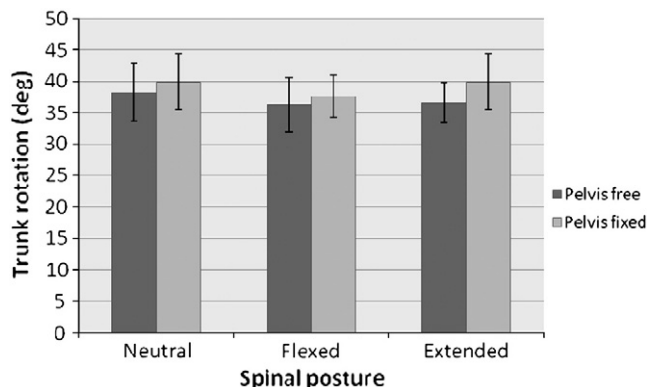


Fig. 4. Means and standard deviations of the maximum unilateral trunk rotation RoM for the three spinal postures with the pelvis free and fixed.

compared to a neutral posture (Fig. 4). For the unilateral pelvic rotation RoM, extending the spine led to an average decrease in the pelvic rotation RoM of approximately 17% (mean = 6.4°, 95th CI = -14°–26.8°) ($P < 0.05$), whereas flexing the spine led to an average increase of approximately 4% (mean = 1.7°, 95th CI = -17.6°–20.9°) (Fig. 5).

3.4. Pelvic fixation

Pelvis fixation was found to have a significant main effect on the unilateral trunk rotation RoM ($P < 0.001$) and unilateral pelvic rotation ($P < 0.001$). Fixing the pelvis led to an average increase in the unilateral trunk rotation of approximately 5% (mean = 1.7°, 95th CI = -4.9°–8.4°) (spine neutral), 4% (mean = 1.3°, 95th CI = -3.5°–6.1°) (spine flexed) and 9% (mean = 3.3°, 95th CI = -2.7°–9.3°) (spine extended) and an average decrease in unilateral pelvic rotation across all test positions of approximately 83% (Figs. 2–5).

3.5. Trunk, spine and pelvic fixation

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

4. Discussion

Increases to forward trunk inclination in the sagittal plane led to a significant increase in the maximum unilateral trunk rotation RoM (19%). Conversely, a forward inclined trunk significantly reduced the maximum unilateral pelvic rotation (40%). This contrasting effect on the trunk and pelvic rotation RoMs may lie in the ‘relative flexibility’

of the respective body segments. As the trunk inclines forward, a ‘stiffening’ of the lower body may occur, decreasing the ability of the pelvis to rotate on the legs. This would be consistent with a shift from one to two independent rotational axes, with the trunk axis having a different orientation to that of the lower body as it is inclined forward.

The concept of relative flexibility has been used to describe patients with dysfunction and pain, who restrict the movement of one or more affected body segments in order to achieve increased ‘give’ or excessive joint motion at other segments (Comerford and Mottram, 2001). This notion of lower body stiffening appeared to be supported by the interaction effect found for forward trunk inclination and pelvic fixation. When the pelvis was fixed, increased forward trunk inclination exerted less influence on the ability of the trunk to maximally rotate compared to an unrestricted pelvis.

Whilst ‘relative flexibility’ may provide a possible explanation for increased trunk rotation in an inclined posture, consideration must also be given to the trunk musculature responsible for trunk rotation. If increasing the forward 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 due to the viscoelastic elements of the thoracolumbar spine being stretched (Gluck et al., 2008). This will result in more rotational torque and greater axial RoM.

The significance of these findings from a clinical perspective is that the body may undertake movement in a manner that is easiest to achieve the goal, not necessarily the most ‘correct’ way to achieve the goal. In standing, more effort may be required to turn using the trunk as opposed to the pelvis. Thus, trunk rotation contributes less to the maximum RoM. In inclined positions, the relative flexibility changes leading to a greater trunk rotation.

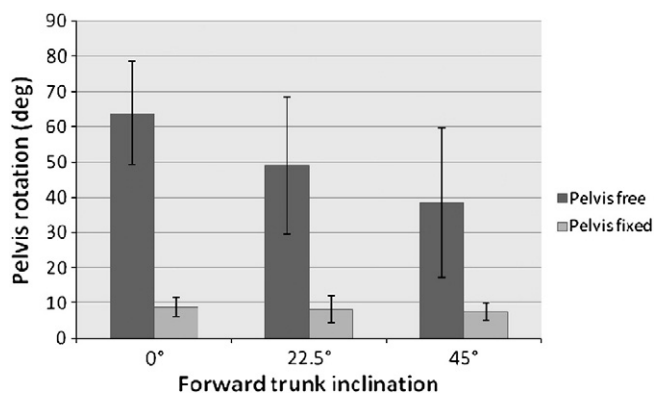


Fig. 3. Means and standard deviations of unilateral pelvic rotation RoM for the three forward trunk inclinations with the pelvis free and fixed.

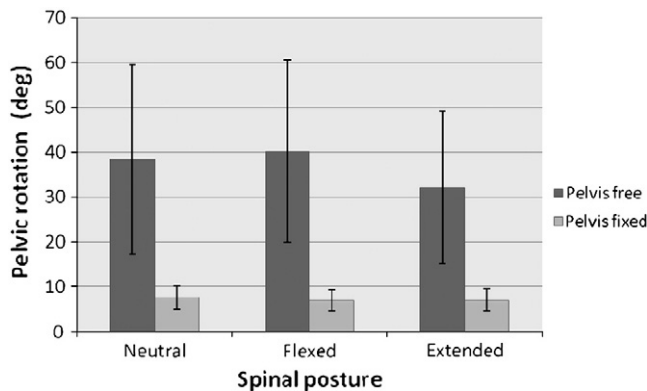


Fig. 5. Means and standard deviations of unilateral pelvic rotation RoM for the three spinal postures with the pelvis free and fixed.

The effect of trunk inclination on trunk rotation has direct relevance to sports activities, such as golf. In the golf swing, the results may explain why the use of shorter length clubs (i.e. 9 iron, pitching wedge) is generally more controlled and more accurate than longer length clubs (i.e. driver) (Pelz, 1999). The shorter irons require the golfer to incline the trunk further forward which 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 thereby decrease error. Conversely, using a longer club (driver) places the trunk in a more upright position and has the potential to allow more pelvic rotation to occur. 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.

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 et al., 1991; Haberl et al., 2004). Findings from this study also showed that in comparison to a neutral spine posture, unilateral trunk rotation decreased when thoracolumbar spine was flexed. The reduction in axial rotation when adopting a flexed spine has been suggested to stem from increased stiffness of the posterior soft tissue elements of the spine and greater compressive loads acting on the intervertebral discs in flexion (Burnett et al., 2008).

The magnitude of reduced trunk rotation associated with a flexed spine posture was smaller than has been reported elsewhere (Edmondston et al., 2007; Willems et al., 1996). Previous studies have primarily measured trunk rotation in a seated posture with the pelvis fixated, which differs from the standing posture adopted in this study. By adopting a seated posture, the thoracolumbar spine is pre-flexed which may have increased myofascial stiffness and decreased functional trunk rotation.

Maintaining segmental extension of the thoracolumbar spine resulted in a decreased trunk rotation when compared to a neutral spine posture. An increase in the activity of the thoracolumbar paraspinal muscles required to maintain the spine in extension may have acted to restrict axial rotation, as increasing muscle activation can stiffen a joint in a particular direction (MacDonald et al., 2006; McGill, 2007). As Burnett et al. (2008) suggested, compacting the lumbar facet joints in extension may contribute to decreased axial rotation.

As discussed previously, fixing the pelvis significantly increased the maximal trunk rotation. From a clinical perspective, the quandary is whether to assess trunk rotation with the pelvis fixed or unrestricted. 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. Using findings from studies which have implemented pelvic fixation is sometimes problematic, as pelvic fixation has often been poorly implemented or pelvic motion was not adequately monitored. Observation of trunk rotations with the pelvis unrestricted is considered more appropriate as this is likely to benefit the clinician in determining relative flexibilities that may exist.

Excessive or restrictive rotation in one area of the body may lead to increased loads on other parts of the body. It would be useful to develop or utilise 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 Selective Functional Movement Assessment (SFMA) may be one such approach (Cook, 2010). Alternatively, 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.

This study is not without limitations. Placement of the arms in a raised position during trunk rotation may have had an effect on the overall trunk rotation RoM via the potential involvement of the latissimus dorsi-thoracolumbar fascia complex, leading to an under-estimation 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.

For the fixed pelvis conditions, small rotational movements of the pelvis were observed (an average of 7.7° across the fixed pelvic conditions). Some of this pelvic rotation may have stemmed from skin and marker movement, or slight movement of the belt. Every effort was made to minimise potential 'slippage' between the belt and the subject by lining the belt with a rubberized material and tightening the harness around the subject's pelvis. 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 only rotated about their trunk, it is possible that some additional lateral flexion occurred during rotation increasing 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 trunk forward in the sagittal plane restricted rotational movement of the pelvis (40%), but increased trunk rotation by approximately 19% at a forward trunk inclination of 45° when compared to upright standing. Trunk rotation was dependent upon the posture of the spine in the inclined position, with a neutral thoracolumbar spine increasing the maximum trunk rotation RoM. Adopting an inclined, neutral spine posture that maximises trunk rotation and stabilises the pelvis is likely to be beneficial for certain sport activities, such as golf.

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 compared to unconstrained movement.

Conflict of interest statement

There were no commercial relationships involved in this research that could constitute a conflict of interest.

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