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van Dieen, J.H.; Nussbaum, M.A.

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6

Trunk

Jaap H. Van Dieën and Maury A. Nussbaum

CONTENTS

Introduction

Low back pain (LBP) is the most prevalent work-related health problem in the industrialized world. The lifetime prevalence is estimated at more than 70% in the general population and as high as 90% in populations exposed to heavy physical loads at work, such as concrete reinforcement workers and nurses. Although most low back complaints recede in about a month, regardless of treatment, recurrence is very common (about 85%), and about 4% of cases become chronic. About 50% of LBP cases result in days lost from work (Van der Hoogen et al. 1997). The direct medical costs and especially

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the indirect costs, such as workers' compensation and production losses, associated with these complaints are enormous.

Trunk postures are of ergonomic concern chiefly because adverse trunk postures have been shown to be associated with LBP (Hales and Bernard 1996, Burdorf and Sorock 1997, Kuiper et al. 1999). In part because of the limited success of LBP treatment, much emphasis has been placed on ergonomic measures to prevent its first time occurrence (Linton and Van Tulder 2001). Improving workplace design such that unfavorable trunk postures are avoided appears a promising avenue in this respect.

6.1 Definitions and Measurement

In general, posture can be defined as the orientation of body segments in space and in relation to each other. This definition assumes body segments to be rigid links, whose orientation with respect to a neighboring segment is determined by rotations about three axes in one joint. With respect to the trunk, this assumption is clearly not correct. The trunk contains multiple joints, with the total rotations determining the orientation of the trunk as whole. In many applications, however, trunk posture can be described as if the trunk were a rigid segment. To this end, the orientation of the upper part of the trunk with respect to the pelvis needs to be determined. Reflecting the fact that the motions causing this orientation are in reality not pure rotations, they are here called forward/backward bending, lateral bending, and twisting in accordance with ISO 11226 (ISO 2000) (Figure 6.1).

The effects of a trunk posture are not only determined by these angles between segments, but also by the orientation of the trunk with respect to the gravitational field (Figure 6.2). The angles with respect to the gravitational axis system will be referred to as forward inclination and sideward

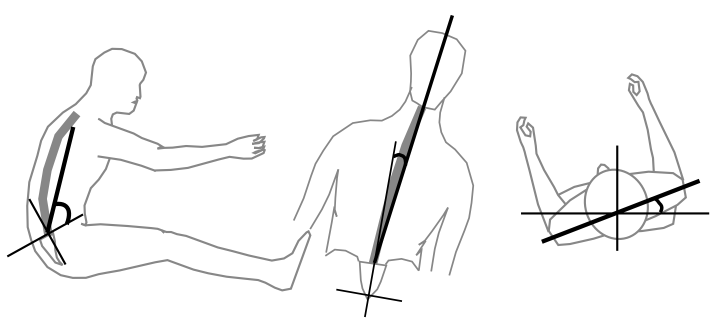

FIGURE 6.1
Forward bending, lateral bending, and torsion or twisting. These classifications of trunk posture are defined in terms of the angle between the trunk and the pelvis and determine the configuration of the spine. Note that the pelvic orientation may be different from vertical.

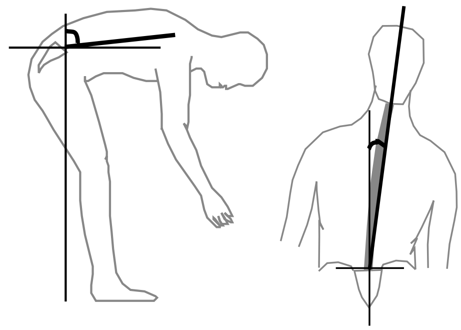

FIGURE 6.2
Forward inclination and sideward inclination. These classifications of trunk posture are defined in terms of the angle between the trunk and the horizontal and determine the effect of gravity acting on the upper body.

inclination. Note that flexion and lateral flexion are used in the literature as synonymous with both forward and sideward inclination and of bending and lateral bending. The third degree of freedom in the gravitational system is irrelevant in terms of the effects of posture on an individual. However, when rotating the trunk around a vertical axis while standing and keeping the feet fixed, individuals also rotate the pelvis in the hip joints. Therefore, the overall rotation of the trunk is not equal to twisting.

It is important to note that the above definitions can be unambiguously used only for postures or movements in a primary plane or about a primary axis. The usual way of describing the three-dimensional orientation of a segment is through decomposition of the orientation in three angles about three orthogonal axes, the so-called Euler angles. However, a posture that involves rotations about more than one axis is not uniquely described by three Euler angles. The order in which rotations are performed also determines the resulting posture, or inversely the order of decomposition determines the Euler angles obtained for a certain posture. This is illustrated in Figure 6.3.

In an asymmetric posture, joint rotation about an axis is easily misinterpreted. Consider the following example. The thorax is rotated forward to 90° and subsequently rotated about a horizontal midsagittal axis. The latter movement would be considered lateral bending, with respect to the pelvis axis system (according to the definition given above). With the trunk bent forward less than 90°, the same excursion would be a combination of twisting and lateral bending. However, the effect of the latter excursion on the configuration of the trunk is the same as in twisting when standing upright. This illustrates that, although trunk postures can be clearly defined with respect to a pelvis axis system, the resulting postural angles do not always allow an intuitive interpretation.

A more intuitive description of postures can be obtained by describing the main movement component (usually bending) in the pelvis axis system and the other two components in an axis system connected to the trunk

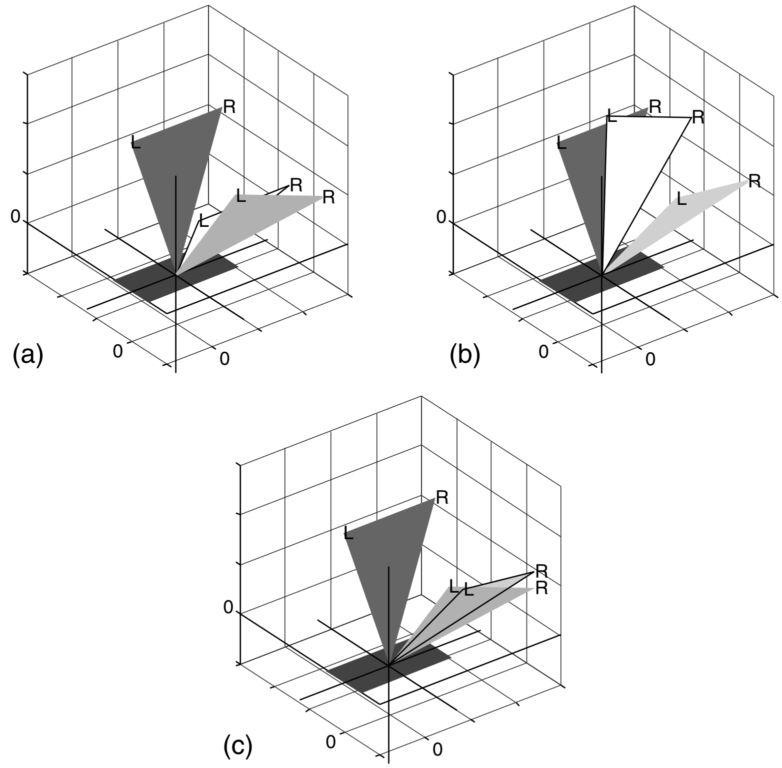

FIGURE 6.3
The black horizontal plane represents the pelvis, the dark gray triangle represents the trunk in an upright posture. (A) The trunk is first rotated forward 40° (white) and then sideward 20° (light gray). (B) The trunk is first sideward rotated 20° (white) and then forward rotated 40° (light gray). (C) Both final postures, which are not identical. The two primary rotations (20° sideward and 40° forward rotation) thus do not uniquely describe a posture.

(Van Dieën et al. 1998, Gagnon et al. 2000). Measurements of the trunk and pelvis orientations allow for conversions between such axis systems, but classifications based on visual observation may become highly ambiguous because the order of rotations and the axis system used to define angles are usually not made explicit. Consequences of such errors in relation to the evaluation of lifting postures have been discussed by Dempsey and Fathallah (1999). It should also be noted that in the current literature no consensus exists on the axis system to be used to describe trunk posture and loading, which can explain some disparities between studies (Kingma et al. 1999, Plamondon et al. 1999, Gagnon et al. 2000, Van Dieën and Kingma 2001).

Determination of trunk posture requires identification of the position of bony landmarks on the upper trunk or thorax and on the pelvis. Such position identification is often done implicitly, for example, in visual observation of postures. In these cases soft tissue deformation may hamper adequate characterization. An example of this is the impression of a lumbar lordosis in power lifters during lifting, which is actually caused by the prominent contracting gluteus muscle (Cholewicki and McGill 1992). Explicit identification of landmarks is commonly performed using automated video analysis systems along with markers that are usually attached over bony landmarks. On the pelvis a number of bony prominences can be used to this end. On the trunk a marker on the shoulder is often used. Given the considerable range of motion of the shoulder girdle with respect to the thorax, a marker fixed to the thorax is preferable.

Three general methods for determining trunk postures can be differentiated: self-report, observation, and objective measurement. In terms of applicability in ergonomics the three methods have been mentioned here in descending order. Self-reports can be easily administered at relatively low cost, whereas objective measurements require expensive equipment and acquisition of data is time-consuming. Observation can be considered intermediate. In terms of measurement accuracy and validity they have been mentioned in ascending order (Van der Beek and Frings-Dresen 1998). It has been shown that substantial discrepancies between the results of these methods do occur (Burdorf and Laan 1991, Burdorf et al. 1992, Van der Beek et al. 1994, De Looze et al. 1994). Subjective reports of postures are typically obtained using questionnaires and diaries. The results obtained with self-reports, however, are of questionable accuracy and validity (Van der Beek and Frings-Dresen 1998, Li and Buckle 1999). Consequently, observational methods, either direct or video based, have become increasingly popular (Van der Beek and Frings-Dresen 1998, Li and Buckle 1999).

A wide variety of observational methods have become available (for a recent review see Li and Buckle 1999). Nevertheless, the validity of classifications of trunk posture on the basis of observation has been questioned. The validity certainly appears low when subjects change posture relatively frequently (De Looze et al. 1994), due to limitations in the information processing capacity of the observer. Multimoment or time-sampled observations are less demanding for the observer than real-time observations, and consequently the validity of posture classifications is better for these methods (Van der Beek and Frings-Dresen 1998). In addition, validity generally increases when fewer distinct classifications of posture are used, although De Looze et al. (1994) did not find significant differences in validity when classifying trunk forward inclination in 15° or 20° intervals. In addition, the use of coarse categories (e.g., pooling twisting and lateral bending) can in part solve the problem noted above of describing trunk postures in three dimensions, although at the cost of a loss of information. Recently, Paquet et al. (2001) investigated the validity of an observation method based on time sampling with five categories for trunk posture. They found good correspondence to a reference method for the percentage of time spent in a neutral trunk posture, mild forward inclination (>20° and <45°) and extreme trunk forward inclination (>45°). The percentage time in asymmetric postures (sideward inclination or twisting >20°), however, was significantly underestimated. Direct observation has advantages over video-based observation in terms of costs and possibly accuracy, since camera angles may affect classifications (Punnett and Keyserling 1987). On the other hand, video-based observation allows repeated measurements and the use of stills can improve accuracy.

Quantitative measurements of trunk posture can be obtained using several available technologies. Optical methods, such as automated video or film analysis, in principle allow highly accurate three-dimensional determination of trunk posture from marker positions. For laboratory-based measurements, this methodology generally is the first choice; yet applicability outside the laboratory is usually limited. Problems arise in practice because markers can be highly obtrusive, fields of view of cameras are limited, and markers become obscured by objects or body parts.

Several other measurement systems have been developed as alternatives to optical methods (for an overview, see Li and Buckle 1999). Most frequently used are those based on goniometers (e.g., Snijders and Van Riel 1987, Marras et al. 1992). Goniometer-based systems, however, provide only relative rotations of the trunk and pelvis, and do not indicate trunk orientation with respect to the gravitational field. Applicability of electromagnetic tracking devices, which can be used as goniometers (McGill et al. 1997), is severely limited by disturbances caused by metal objects in proximity to the sensors. Recently, inertial sensing (accelerometers, gyroscopes) methods that allow accurate quantification of trunk postures have become available (Baten et al. 1997). Inertial sensing methods can indicate both trunk/pelvis angles and trunk orientation with respect to the vertical. These methods suffer from integration drift, which hampers long-term recording. Goniometric and inertial sensing methods are promising for field use, although the need to attach sensors to the back will continue to limit applicability in some work situations (for example, in seated work). In general, a careful selection of measurement methods is required to fit the aims of the recording and the environment in which recordings are to be made.

6.2 Trunk Anatomy

Although the causes of most cases of LBP are undiagnosed, there is sufficient evidence that the lumbar spinal column and associated soft tissues play an important role in the etiology of the complaint. To understand how trunk posture relates to stress on low back tissues, and ultimately to damage, some understanding of the anatomy of the spine and surrounding musculature is needed.

The spine consists of bony structures called vertebrae, 5 in the lumbar part, 12 in the thoracic part, and 7 in the cervical part. Orientations of the individual lumbar and thoracic vertebrae determine the overall posture of the trunk. In upright stance, the lumbar vertebrae form a curve, concave posteriorly,

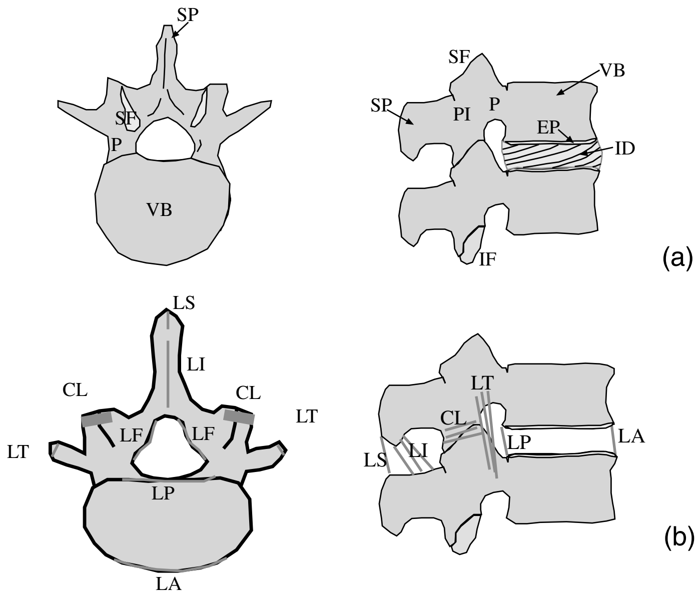

FIGURE 6.4
Schematic overview of motion segment anatomy. The morphology depicted is typical for the lumbar spine; thoracic vertebrae have a slightly different appearance. (a) Bony and cartilaginous structures of the motion segment. VB = vertebral body; SP = spinous process (i.e., the part of the vertebra that can be felt under the skin); SF = superior facet; IF = inferior facet; EP = end plate; ID = intervertebral disc; PI = pars interarticularis; P = pedicle. (b) Ligaments of the motion segment. LS = supraspinous ligament; LI = interspinous ligament; CL = capsular ligaments; LT = transverse ligaments; LP = posterior ligament; LA = anterior ligament; LF = ligamentum flavum.

called lordosis. The thoracic spine forms a convex curve or kyphosis. Although these curves are often referred to as natural, it should be kept in mind that their presence is specific for the standing posture. In trunk forward inclination the lumbar lordosis decreases or disappears, as in the case in sitting and especially slouched sitting. Given the sitting posture typically observed in primates, it can be questioned whether this posture should be considered unnatural.

The general anatomy of motion segments, the fundamental building blocks of the spine, is illustrated in Figure 6.4. A motion segment consists of two vertebrae, connected by pads of soft tissue called intervertebral discs and by a number of fibrous straps called ligaments. These connections allow for a considerable range of motion between two vertebrae. Motions are guided and restricted by two joints on the posterior side of the vertebrae called facet joints or zygapophysial joints. In the lumbar spine, these joints limit torsion and forward shearing of the superior vertebra, as a consequence of the nearly vertical orientation of the joint surfaces at a 45° angle to the frontal plane. The posterior bony parts of the vertebrae also limit extension. The lumbar

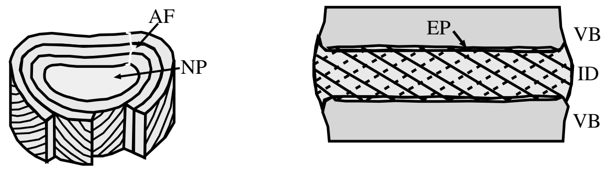

FIGURE 6.5
Schematic illustration of intervertebral disc anatomy. ID = intervertebral disc; VB = vertebral body; EP = end plate; AF = annulus fibrosus; NP = nucleus pulposus.

spine is therefore most flexible in forward and lateral bending. In the lower thoracic spine the facet joints are oriented in the frontal plane, while at higher levels they are more horizontal (and completely horizontal in the cervical spine). As a consequence, the thoracic spine has more mobility in twisting. Although facet joint orientation would allow substantial lateral bending, the range of thoracic movement is limited due to the ribs.

The ligaments have strongly nonlinear material characteristics. In the spine, they therefore resist motions of the vertebrae mainly toward the limits of the range of motion. Posterior ligaments (supraspinous and interspinous ligaments) resist bending, whereas the anterior ligament resists extension. The transverse ligaments resist lateral bending and the capsular ligaments limit torsion.

The intervertebral disc deserves special attention in relation to LBP, because damage to this structure appears to be an important source of pain (Adams and Dolan 1997, Van Dieën et al. 1999). Each disc consists of a gel-like center called the nucleus pulposus that is contained by a ring of fibrous tissue layers, the annulus fibrosus. Discs are bordered on the top and bottom by two plates consisting of bone and cartilage called the end plates (Figure 6.4 and Figure 6.5). The nucleus pulposus has a water content of around 80%, which gives it roughly hydrostatic properties. It therefore distributes forces acting along the axis of the spine evenly over the end plates and also tensions the annulus fibrosus. Fibers in the annulus fibrosus are oriented at an angle of about 60° to the long axis of the spine, and alternate from +60° to –60° between different layers. The annulus is thereby able to resist the hoop stresses caused by the hydrostatic pressure in the nucleus pulposus and also to resist bending and twisting motions of the spine.

The muscles surrounding the spine are illustrated in Figure 6.6. Their main functions can be gleaned from their location with respect to the vertebrae. Muscles posterior to the center of the vertebrae act primarily as trunk extensors. Among these muscles the most important is the erector spinae, a large muscle mass comprising the iliocostalis and longissimus, which in turn comprise many small muscle fascicles that run approximately parallel to the spine. When active unilaterally, the erector spinae mass acts to bend the trunk laterally or to resist a force that would bend the trunk to the opposite side. Other muscles lateral to the center of the vertebrae, especially the oblique abdominal muscles, perform a similar function. The oblique abdominal

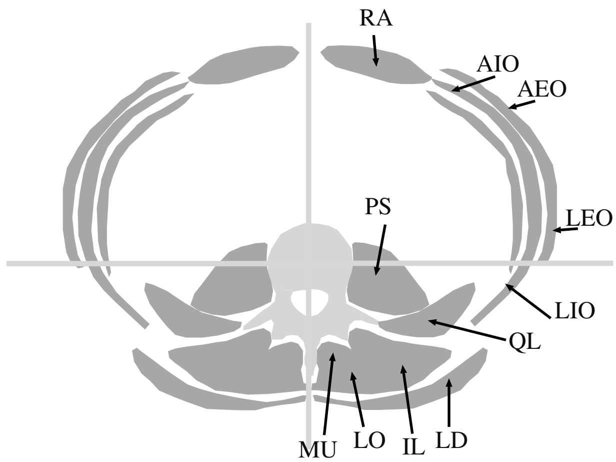

FIGURE 6.6
Schematic overview of the lumbar muscles in a transverse cross-section of the trunk. RA = rectus abdominus; AIO = anterior internal oblique; LIO = lateral internal oblique; AEO = anterior external oblique; LEO = lateral external oblique; MU = multifidus; LO = longissimus; IL = iliocostalis; LD = latissimus dorsi; PS = psoas; QL = quadratus lumborum.

muscles also serve to twist the trunk along its long axis and, when assisted by the rectus abdominus muscle (and usually by gravity), can bend the trunk forward. Because these muscles contribute to moments about more than one axis, in order to obtain a moment about only one axis other resulting moments have to be exerted by other muscles. For example, when the oblique abdominal muscles are recruited to cause pure trunk twisting, the forward and lateral bending components have to be compensated for by the erector spinae.

6.3 Effects of Trunk Posture

The adverse health effects of certain postures are thought to be mainly of mechanical origin. A conceptual model of how maintaining a posture may result in LBP is illustrated in Figure 6.7. Trunk posture is defined, as described above, in terms of the orientation of the trunk in the gravitational field (segment angles) and in terms of thorax orientation with respect to the pelvis (joint angles). Segment angles determine the moment acting about the lumbar spine as a consequence of gravity acting on the upper body, whereas joint angles determine the strain of muscles and other tissues. Tensile strain of tissues and the resulting tissue stress can directly cause tissue damage and discomfort. In addition, the forces produced by stretched structures will produce a moment.

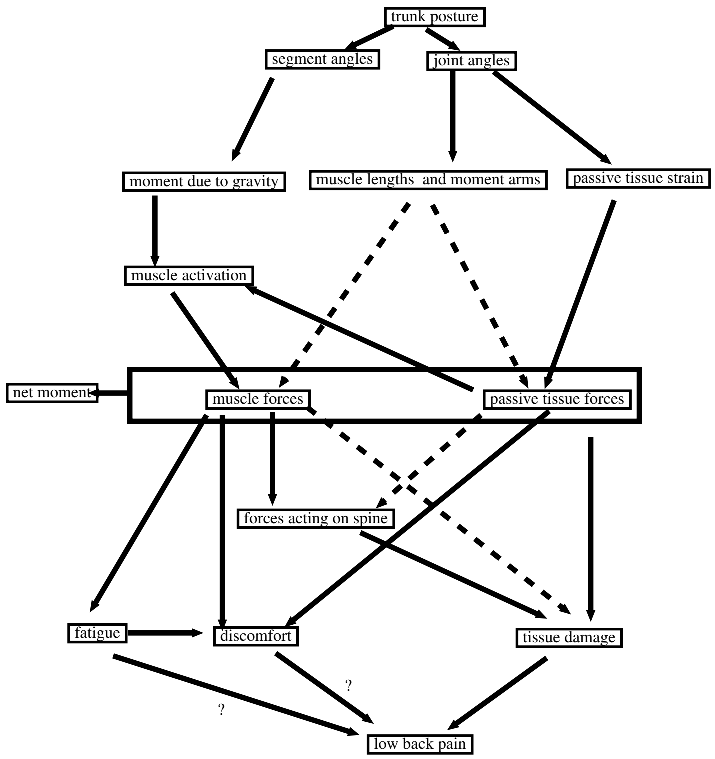

FIGURE 6.7
Conceptual model of the relationship between trunk posture and LBP (for explanation see text). Relationships indicated with dashed lines are not specifically addressed in this chapter.

To maintain a given posture, an individual must equilibrate the sum of this moment, the moment caused by gravity, and the moments due to muscle forces (i.e., their sum equals zero). Muscle moments and passive tissue moments may have the same sign or may counteract each other; their sum is designated the net moment. Moment equilibrium is achieved through modulating muscle activation. In addition to the level of activation of the muscle, the moment it produces depends on its moment arm and length, which are in turn determined by the joint angles. The latter aspect will not be extensively dealt with here. Muscle activation can lead to muscle fatigue, which may contribute to discomfort and potentially to LBP. Muscle and passive tissue forces determine the shear and compression forces acting on the spine, which can cause damage and ultimately LBP. It is uncertain whether direct relationships exist between fatigue and discomfort on the one hand and LBP on the other, but of course these may be relevant outcomes in their own right. Several feedback loops are in reality present but have been omitted from the model. For example, fatigue will affect postures adopted and will affect the distribution or pattern of muscle recruitment.

6.3.1 Trunk Postures and Mechanical Load

The following sections review which structures are loaded most in several trunk postures. In addition, these address the question of whether the level of these loads is high enough to cause clinically relevant damage. Mechanical loads on the low back are only in part determined by postures. External forces acting on the body, for example, when lifting, can contribute substantially. The following discussion refers to the effects of posture exclusively, ignoring other contributions. Moreover, mechanical loads are determined by the three-dimensional posture, because excursions about different axes interact (e.g., Van Dieën 1996, Marras et al. 1998). Nevertheless, for the sake of clarity, effects of bending (or forward inclination), lateral bending (or sideward inclination), and twisting are discussed separately.

6.3.1.1 Tensile Tissue Strain

Tissues in the trunk are generally slack in the neutral upright postures, and any non-neutral posture imposes strain on some tissues. Tensile tissue strain can cause discomfort or damage when it exceeds threshold values or when it is maintained for a prolonged time (Harms-Ringdahl et al. 1983), although information regarding these thresholds and time periods is incomplete.

6.3.1.1.1 Forward Bending

The range of motion of the trunk in the lumbar area in forward bending was reported to be about 55°, or slightly less than 10° of bending per motion segment in one study (Adams and Hutton 1982). Another study (Peach et al. 1998) reported a range of motion of 70°. Age differences may account for these disparate results, as the latter study dealt with college-age subjects. In the thoracic area only limited bending occurs. When the lumbar spine bends forward, passive tissues posterior to the axis of rotation, which is approximately in the center of the intervertebral disc (Pearcy et al. 1984), generate an extension moment as shown in Figure 6.8 (Dolan and Adams 1993). This passive moment is sufficient to carry most of the upper body weight in (near) maximum bending of the spine as is evidenced by the absence of lumbar muscle activity in these postures (the flexion–relaxation phenomenon; Kippers and Parker 1984, McGill and Kippers 1994), although some activity of distant muscles may contribute (Toussaint et al. 1995).

Most of the passive forces will be contributed by passive elongation of muscles and fascia, as the spine with its ligaments and the intervertebral discs can only provide up to 25% of the total passive moment (Adams and Dolan 1991). The exact contribution of passive muscle forces to the extension moment is not known, but in fully bent postures the bellies of the lumbar extensor muscle slips are strained to 1.2 to 1.6 times their length in the upright posture (Macintosh et al. 1993). The relative contribution of the different structures in the spine has been studied in some detail. It appears that the distribution over ligaments and the intervertebral disc depends on

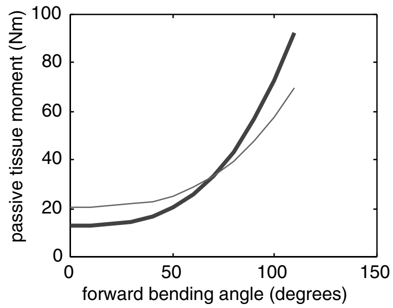

FIGURE 6.8
Passive extension moment as a function of bending angle in males (thin line) and females (thick line), based on regression equations provided by Dolan and Adams (1993).

the bending angle (Adams et al. 1980). The intervertebral disc makes a relatively high contribution in moderate bending, whereas at the end of the range of motion the supraspinous and interspinous ligaments make a larger contribution to the total passive moment. These ligaments are strained to about 1.2 times their rest length at 5° of bending (Panjabi et al. 1982), which is about half the range of motion of a segment.

The supraspinous and interspinous ligaments are also the first to fail when hyperflexion occurs (Adams et al. 1980, 1994). In hyperflexion the posterior part of the disc can also be damaged, leading to herniation of the nucleus pulposus (Adams et al. 1980). It appears, however, that hyperflexion occurs only at about 10° over the *in vivo* range of motion, providing a margin of safety for the spinous tissues (Adams and Hutton 1986). Consequently, it would not seem likely that trunk bending causes tissue strains sufficient to cause damage. With sustained or repeated bending, however, creep will occur (Twomey and Taylor 1982, McGill and Brown 1992, Adams and Dolan 1996). This gradual increase in strain may be a cause of damage to the posterior annulus (Adams and Hutton 1985, Green et al. 1993), and possibly to the posterior and interspinous ligaments (Solomonow et al. 2001).

6.3.1.1.2 Lateral Bending

The range of lumbar trunk motion in lateral bending is about 30° in young subjects and about 20° in subjects older than 65 years (McGill et al. 1999). As in forward bending, passive tissues generate substantial resistive moments (McGill et al 1994) as shown in Figure 6.9.

Little is known about the contributions of various tissues to passive lateral bending moment. Some studies suggest that the disc contributes only a little (Krismer et al. 2000). The transverse ligaments are strained the most (Panjabi et al. 1982), but their stiffness is unknown. To the authors' knowledge no evidence has been provided that excessive tissue strain in lateral bending can cause clinically relevant damage.

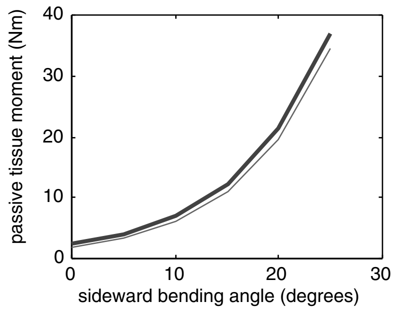

FIGURE 6.9
Passive lateral moment as a function of lateral bending angle in males (thin line) and females (thick line), based on regression equations provided by McGill et al. (1994).

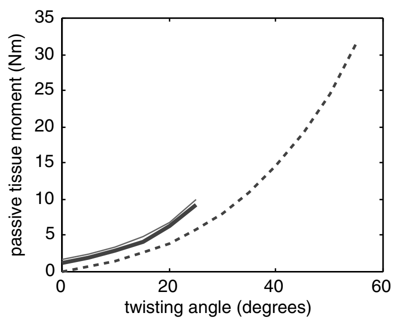

FIGURE 6.10
Passive moment as a function of twisting angle measured between pelvis and sternum (solid lines) and between pelvis and shoulders (dashed lines) in males (thin line) and females (thick line), based on regression equations provided by McGill et al. (1994) and Bodén and Öberg (1998).

6.3.1.1.3 Twisting

The twisting range of motion in the lumbar area is limited to about 15° and is not strongly dependent on age (McGill et al. 1999). Because of the considerable twisting mobility in the thoracic area, the range of motion is higher when measured at the level of the shoulders (about 60°; Bodén and Öberg 1998), in line with the definition in Section 6.1, Figure 6.1, or when measured at the level of the sternum (McGill et al. 1994). Passive tissue resistance to twisting is considerable, as shown in Figure 6.10 (McGill et al. 1994, Bodén and Öberg 1998).

In twisted trunk postures, muscle strains will be low as a result of the small moment arms of most muscles about the twisting axis (McGill and Hoodless 1990). In contrast, strains in ligaments of the spine, especially the capsular ligaments, are considerable (Farfan et al. 1970, Panjabi et al. 1982). The intervertebral disc also contributes, due to strain in a portion of the annulus fibers (Haher et al. 1989). Primary resistance to torsion is produced by compression of the facet joint on one side (Adams and Hutton 1981).

There has been considerable debate about whether tissue strains in twisted postures can cause clinically important damage to the spine. Farfan and coworkers (Farfan et al. 1970) have suggested that torsion may cause damage to the annulus fibrosus and as such may be a cause of back pain and disc degeneration. Their arguments have been contested by Adams and Hutton (1981), who showed that the compressed facet joint would probably be the first to fail in torsion, and that extremely high twisting angles would be required to produce disc damage. Tensile strains in the disc that result from twisting depend on the exact location of the axis of rotation, and this axis may be incorrectly imposed in *in vitro* biomechanical experiments (Haher et al. 1989). In addition, it has been shown that frequently repeated twisting can induce damage to the annulus fibrosus even when the angular excursion is small (Liu et al. 1985).

6.3.1.2 Net Moments

Moments required to maintain a certain trunk posture are partially determined by passive tissue resistance. For example, when sitting with a twisted spine, the passive resistance described above would tend to de-rotate the spine, and muscle activity is consequently required to maintain this posture. In many postures, upper body weight contributes substantially and to a much greater degree than the effects of passive tissue resistance. The angle of the trunk with respect to the field of gravity therefore must be identified to obtain meaningful information on mechanical loading. Orientations of the trunk with respect to gravity in the sagittal and frontal planes were defined earlier as forward and sideward inclination, respectively. In forward or sideward inclined postures gravity produces substantial moments about the joints in the lumbar spine. While the moment arms of gravity are close to zero in an upright stance, they increase as a sinusoid of the angle of forward or sideward inclination. As discussed above, these moments are partially counteracted by passive tissues due to bending. Except for extreme postures, muscle forces generate a substantial portion of the counteractive moment. Therefore, moments resulting from gravity are equilibrated by the net effect of all muscles and passive tissues producing moments about the joint considered. Net moments are often used as an indicator of mechanical load, as they reflect the combined load on all these tissues.

Because the net moment is produced by an unknown combination of muscle and passive tissue forces, setting standards with respect to injury thresholds is not possible at this level of analysis. An indication of how load magnitude relates to the capacity of the musculoskeletal system can be obtained by comparison of the net moments during a task with some measure of force or moment generating capacity (i.e., strength). This capacity is most often obtained in isometric maximum voluntary force/moment tests in standardized postures (Garg and Chaffin 1975, Chaffin and Erig 1991,

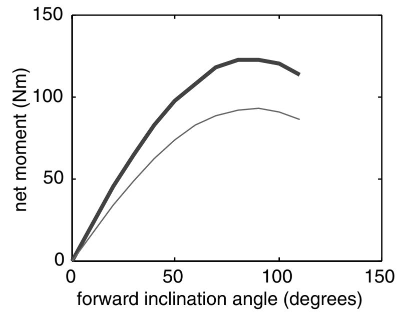

FIGURE 6.11
Net moments on the low back as a function of forward trunk inclination angle for an average male (thin line) and female (thick line).

Gravel et al. 1997). It should be kept in mind that posture in itself will affect strength as a consequence of changes to muscle lengths and moment arms.

It is notable that there can be situations wherein tissues concurrently produce moments about a joint that are opposite in sign, yielding a zero net moment, although considerable mechanical load is still present. In most cases, there is some activity of muscles on the side of a joint opposite to where muscle force is required to produce the moment, probably to guarantee sufficient stability of the joint position. This type of muscle activity is often termed antagonism, and has been shown to occur for several trunk postures and movements (e.g., De Looze et al. 1999).

6.3.1.2.1 Forward Inclination

The net moment on the low back was described earlier as increasing with trunk inclination as a linear function of the sine of the inclination angle. Figure 6.11 gives the net moment as a function of the angle of inclination, estimated for a 50th percentile male and female using a linked segment model (Chaffin and Andersson 1991). Kumar (1996) determined that maximum voluntary extension moments in the upright position averaged 321 Nm for males and 185 Nm for females. The passive tissue moments (Figure 6.8) have the same sign as the moments produced by the extensor muscles. Nevertheless, considerable muscular effort will be required to maintain forward inclined postures, especially in moderate to high levels of forward bending, because the passive moments are typically insufficient to equilibrate gravitational loads.

6.3.1.2.2 Sideward Inclination

As was the case in forward inclination, the net moment in sideward inclination will increase as a linear function of the sine of the inclination angle. Estimates of net moments as a function of bending angle were again made using a linked segment model (Chaffin and Andersson 1991), and are shown in Figure 6.12. Males can on average produce lateral flexion moments of

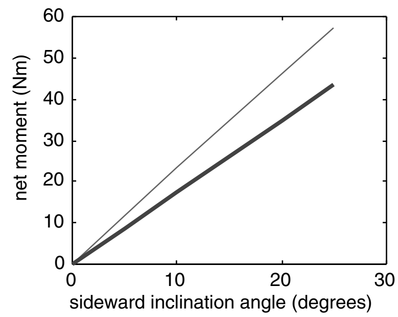

FIGURE 6.12
Net moments on the low back as a function of sideward trunk inclination angle for an average male (thin line) and female (thick line) subject.

164 Nm; females can produce 109 Nm (Kumar 1996). The passive tissue moments (Figure 6.9) counteract a large portion of the gravitational moment and hence assist the moments produced by the muscles. Consequently, only limited muscular effort is required to maintain laterally flexed postures.

6.3.1.2.3 Twisting

Net moments in twisted postures are zero. Maintaining a twisted posture requires muscular effort, because the passive tissue moment and muscular moment are opposite in direction. The muscular moment required to maintain a twisted posture can therefore be estimated from the twisting angle and is illustrated in Figure 6.10. Using the regression line determined by Bodén and Öberg (1998), which fits the earlier definition of twisting, the moment required to maintain a twisting angle of about 50° is estimated at 25 Nm (for males). In males, average maximum twisting strength is 80 Nm (44 Nm for females). Using these numbers as a reference, maintaining a 50° twisted posture would require about 30% of an average male's strength, indicating that keeping such a posture for a prolonged period would be quite a strenuous activity.

6.3.1.3 Muscle Activation

Measurements of muscle activation through electromyography (EMG) are often used as indicators of back load. An underlying assumption is that a straightforward (linear) relationship exists between muscle force and EMG. Unfortunately this is not the case, because the relationship between muscle force and activation (or EMG record) is strongly affected by muscle length and, although less relevant in the context of posture assessment, muscle velocity. This limitation is especially important in trunk extensor muscles, which operate over large length ranges and can produce substantial moments even in the absence of activation (as discussed in Section 6.3.1.1.1).

Nevertheless, if careful calibration procedures are used, trunk muscle EMG measurements can provide an indication of moments acting about the lumbar spine (Van Dieën and Visser 1999, Kingma et al. 2001). Measures of muscle activation can also provide information on how muscles work together, or coordinate, to equilibrate gravitational and passive tissue moments. One important aspect of such coordination is antagonistic muscle activity (opposing the required moment), the presence of which will increase the development of fatigue and the forces acting on the spine.

6.3.1.3.1 Forward Inclination

In forward inclination, the gravitational moment is resisted mainly by the erector spinae muscles. Andersson et al. (1977a) measured erector spinae EMG in several flexed postures, while subjects had their pelvises strapped to a reference frame. In this situation bending angles and inclination angles (as defined above) were equal, but the results cannot be generalized quantitatively to forward inclination in freely adopted postures. Up to about 50° of forward inclination, erector spinae activation increases in both the lumbar and thoracic regions. EMG amplitudes as a function of forward inclination angle can be well described by a linear function of the sine of the angle of inclination. With a further increase in forward inclination, erector spinae muscle activation levels eventually decrease (Kippers and Parker 1984), because of the increasing passive tissue contribution to the moment required (the flexion–relaxation phenomenon, which is illustrated in Figure 6.8). Only minimal antagonistic cocontraction of abdominal muscles is present in unloaded forward inclination (De Looze et al. 1999, 2000).

6.3.1.3.2 Sideward Inclination

Limited data are available on muscle activation when maintaining sideward inclined postures. Lateral bending moments in upright postures, however, are produced mainly by activation of the contralateral latissimus dorsi and erector spinae muscles along with the (lateral parts of the) external oblique abdominal muscles. A small level of coactivation of the muscles on the ipsilateral side has been found (Lavender et al. 1992a,b, Van Dieën and Kingma 1999). These findings on muscle activity can probably be generalized to sideward inclined postures, although activity levels will be relatively low given the substantial passive moment contribution.

6.3.1.3.3 Twisting

Torén (2001) studied muscle activation in twisted postures. Although the normalization procedure used does not allow for quantitative interpretation, the data show that contralateral external oblique and ipsilateral erector spinae muscles likely play a primary role in counteracting the passive tissue moment. This is also consistent with data on twisting moments produced in a neutral posture (Pope et al. 1986, McGill 1991). It can be assumed that the role of the erector spinae muscle is mainly to counteract the bending and lateral bending moments caused by activity of the external oblique. In twisting efforts substantial cocontraction of all trunk muscles is found (Pope et al. 1986, McGill 1991).

6.3.1.4 Spinal Forces and Intra-Discal Pressure

Compression and shear forces acting on the spine cannot be measured directly. Researchers therefore rely on model-based estimates. An indication of compression forces can be obtained from measurements of intra-discal pressure. This is an invasive technique, which is not suitable for routine use. Deformations of the disc occurring in non-neutral postures will also affect the relationship between compression force and intra-discal pressure (Schultz et al. 1979). Model predictions of compression force have been reported to be well correlated with intra-discal pressure measures (Schultz et al. 1982). In addition, different models converge to similar predictions (Hughes et al. 1994, Van Dieën et al. 2000), and models predict directly measurable variables (e.g., moments) fairly well (Granata and Marras 1993, Cholewicki et al. 1995, Nussbaum and Chaffin 1998, Van Dieën et al. 2000). On the basis of these observations, model-based predictions of spine compression are considered sufficiently accurate for comparative use. Predictions of shear forces, in contrast, tend to be very different between models, perhaps not surprisingly given the strong dependency of the predictions on modeling assumptions (Nussbaum et al. 1995, Van Dieën and De Looze 1999). The following discussion is therefore limited to compression forces.

Compression force estimates could in theory be compared to data on the strength of spinal motion segments to derive threshold limit values for trunk posture. Compression strengths of human spinal motion segments range from about 2 to 10 kN (Hansson et al. 1980, Brinckmann et al. 1989). Given limited information on validity of compression predictions, and the fact that motion segment strength data are based on *in vitro* testing, this comparative approach seems unwarranted. Furthermore, the estimates made below show that spine compression resulting only from postural loads is not likely to exceed the compression strength of the spine.

Compression forces were estimated from the net moments in different postures presented earlier (Section 6.3.1.2), using an optimization model described by Van Dieën (Van Dieën 1997, Van Dieën and Kingma 1999, Van Dieën et al. 2000). Monotonic increases of compression with increasing postural deviations are seen in all planes of motion (Figure 6.13). Maximal compression forces are estimated in forward inclination, due to the large net moments occurring in that posture. Results from measurements of intra-discal pressure are available for forward inclination only, but are consistent with these model predictions (Andersson et al. 1977b, Sato et al. 1999, Wilke et al. 1999). From the graphs it is clear that only in forward inclination do compression forces reach levels exceeding 2 kN. However, the compression estimates are based on an average male. Compression strength of the vertebral column of the average male will be around 6.3 kN (Jäger 2001). This

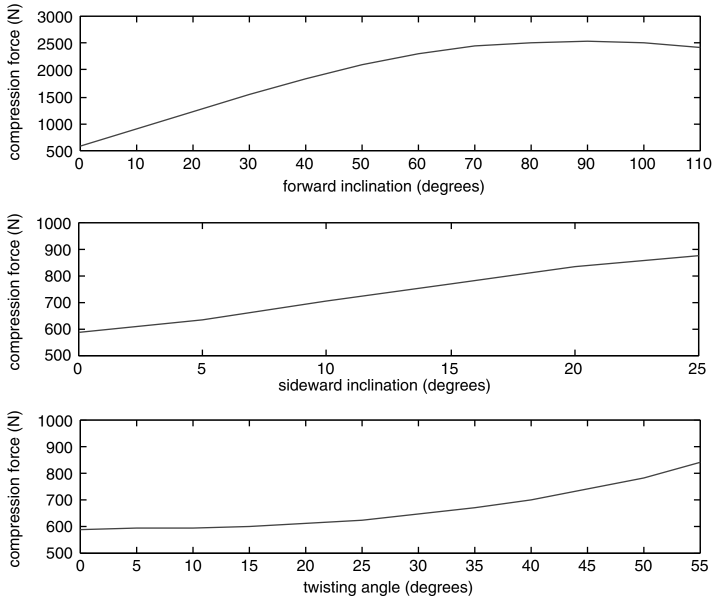

FIGURE 6.13
Estimated spine compression forces (N) in an average male as a function of trunk forward inclination (upper panel), sideward inclination (middle panel), and twisting (lower panel).

strength is lower in some other groups, especially older females, but in these groups compression forces will usually also be lower due to a lower body mass (although shorter muscle lever arms may offset this effect). In the working population in general, spinal compression strength is assumed to be above 3 kN (Waters et al. 1993, Van Dieën and Toussaint 1997, Jäger and Luttmann 1997). However, frequently repeated compression at initially submaximal levels may eventually cause fractures of the vertebral end plates (Hansson et al. 1987; Brinckmann et al. 1988). It is therefore conceivable that frequent forward inclination causes damage even in this population.

6.3.2 Trunk Postures and Discomfort

Subjective perceptions of discomfort resulting from the adoption or maintenance of a specific trunk posture can be measured using one of several existing scales. Among the more commonly used are the various numerical scales (Borg 1970, 1982, Corlett and Bishop 1976), the body mapping of Corlett and Bishop (1976), or a visual analogue scale (e.g., Ulin et al. 1990).

Studies on the relationship between trunk postures and discomfort have mainly focused on the seated condition. A review of seating research is given in Chapter 7; in this section, the presentation centers on deviations from the upright posture. In contrast to the extensive work on seating, relatively few investigations have examined discomfort in the standing posture. Existing studies can be broadly classified by whether subjective responses were determined when non-neutral trunk postures were held for brief or for more prolonged periods

Discomfort resulting from short-term deviated trunk postures was assessed by Genaidy and Karwowski (1993) and Genaidy et al. (1995). Subjects flexed, extended, laterally bent, and rotated their trunks away from the neutral posture to half or the full range of motion (ROM), and held these positions for 30 or 60 s. Perceived levels of joint discomfort were rated on a 10-point scale (modified from the Corlett and Bishop, 1976, scale), where 0 = none, 5 = moderate, and 10 = extreme. Using a ranking system for assessment of postural deviations corresponding to these discomfort ratings, somewhat inconsistent results were found in terms of relative levels of discomfort resulting from the different postures. More specifically, the studies differed in terms of the rates of discomfort onset associated with each of the deviated postures.

In a more extensive study of this type, Kee and Karwowski (2001) had subjects adopt fixed percentages of their trunk ROM (0, 25, 50, 75, and 100%) that were held for 60 s. The discomfort experienced was quantified using a free modulus method, allowing subjects to freely choose their own range of numbers to reflect discomfort ranging from none to maximal. From these ratings, normalized values were obtained as a function of each individual's minimum and maximum discomfort rating. Increases in discomfort were roughly linear as a function of increasing postural deviation, although with larger increases toward the limit of ROM. Relative discomfort ratings from the different trunk postures were also inconsistent with the earlier work of Genaidy and colleagues noted above (Genaidy et al. 1995). The discrepancies in these studies suggest either that the onset of discomfort associated with deviated trunk postures may not be adequately assessed using short-term trials or that the results may be highly sensitive to the specific procedures and methods employed. While clearly demonstrating that discomfort occurs, the studies provide no clear indication regarding the relative effects of different types of trunk deviation.

Discomfort resulting from more prolonged maintenance of a posture has been investigated during several simulated work activities. Corlett and Manenica (1980) reported results from a study in which subjects performed a tapping task in several postures (with varied working heights and horizontal distances). Higher levels of initial discomfort were found in tasks requiring any forward inclination of the trunk, and in all tasks involving trunk bending a majority of subjects reported back pain at the limit of endurance. Subjects performed a manual tracking task in the study of Boussenna et al. (1982) with the task height at 25, 50, 75, and 100% of shoulder height to their limit of endurance. With increasing trunk inclination, subjects reported a higher level of overall discomfort, using the scales of Corlett and Bishop (1976), and higher final ratings of mid-back and low back discomfort. Similar results were found when subjects performed screw driving tasks for

1 to 2 h at different heights (Ulin et al. 1990); at lower locations, requiring more trunk inclination, higher levels of perceived exertion and discomfort were reported.

Miedema et al. (1997) summarized the results of seven earlier studies (including the first two noted in the previous paragraph), all of which examined static holding in a variety of postures without external loads. Maximal holding times (MHTs) were determined as the duration that the static postures could be held continuously, starting from a rested state. Changes in arm postures were confounded with changes in trunk postures, and thus it is very difficult to specify a clear MHT vs. posture relationship from their data. Nonetheless, postures requiring more forward trunk inclination were generally associated with lower MHTs.

Sudarsan and colleagues (Sudarsan et al. 2001a) have recently reported preliminary results on posture-induced discomfort during static and dynamic forward trunk inclinations and the effects of personal factors (age, gender, and back disability status) and task factors (inclination angle and work–rest cycle). Tasks were performed until subjects reached their maximum pain tolerance or to a limit of 600 s. Subjects with LBP reported generally higher levels of discomfort, particularly during the dynamic tasks. Reported discomfort was also higher for larger duty cycles (80% vs. 60% work), i.e., when the time spent in the inclined posture per cycle increased. Discomfort increased with increasing trunk inclination angle, although the relationship appeared nonlinear, with smaller changes seen at the higher angles.

Divergences in discomfort-based rankings of trunk motions reported suggest that such differences may be minimal or sensitive to specific testing conditions. Studies of longer-term exertions have been limited to forward trunk inclination, but indicate consistently that discomfort increases with increasing angles of postural deviation. As a whole, these studies suggest a monotonic relationship between postural deviation and discomfort. The specific form of the relationship is not clear, however, nor whether the relationship is consistent for different postural deviations (e.g., forward inclination vs. twisting). At present, the evidence does indicate that discomfort related to trunk posture can be minimized by reducing the extent of trunk deviations from the neutral posture.

6.3.3 Trunk Postures and Fatigue

Localized fatigue is a continuous and accumulative process that results from muscular contraction, and can be measured using a wide variety of both subjective (e.g., discomfort) and objective (e.g., strength, EMG) tools. It is important to differentiate the fatigue process, which is ongoing, from endurance, which is a terminal event in which muscle capacity fails to maintain task demands. Given the current complexity involved in objectively monitoring localized fatigue, and disagreement regarding the best methods to quantify fatigue, endurance has been the primary measure of muscular responses to postural deviations. Well-known relationships between endurance time and relative effort level (e.g., percentage of maximum voluntary exertion, or MVE) have been reported for static exertions (Rohmert 1973), while much less is known for intermittent and/or dynamic activities. Furthermore, the use of these relationships to predict fatigue status has been debated both in terms of the accuracy (Van Dieën and Oude Vrielink 1994) and validity (Mathiassen and Winkel 1992).

A small number of studies have determined the effects of different trunk postures on endurance time, which can be interpreted as an indirect indicator of localized fatigue. In Corlett and Manenica (1980), subjects performed a tapping task in several postures with varied working heights and horizontal distances. A tenfold decrease in endurance time was reported between tasks requiring an upright vs. a horizontal trunk. Endurance times decreased substantially with any forward inclination, although only minimal differences were found among several postures requiring 45° to 90° of forward inclination. Similar results were found by Boussenna et al. (1982) and Sudarsan et al. (2001b) regarding a nonlinear decrease in endurance with increasing static forward trunk inclination. Sudarsan et al. (2001b) also observed that endurance times in inclined postures were reduced in individuals with ongoing back pain.

Other studies, while not directly assessing endurance, have either determined the effects of posture on muscle activity or monitored signs of muscle fatigue more specifically. Dolan et al. (1988) showed that lumbar muscle activity was elevated, relative to relaxed standing, in several commonly adopted postures that all resulted in trunk bending (e.g., standing slumped, standing with one leg raised). It can be inferred that these non-neutral postures would also result in more rapid development of muscle fatigue. Asymmetric trunk exertions, particularly involving twisting, have been shown to result in decreased strength (McGill 1992, Van Dieën 1996), higher EMG activity (see Section 6.3.1.3), and more frequent EMG-based signs of muscle fatigue (Kim and Chung 1995, Van Dieën 1996, O'Brien and Potvin 1997).

These reported findings on fatigue and endurance can be adequately explained based on known mechanical and physiological relationships. As the trunk deviates from an upright, neutral posture, increasing muscular activity in the low back is required to equilibrate the increasing spine moments resulting from gravitational loads (as discussed in Section 6.3.1.2). As the moment arms for body segment masses respond as a sine function of the deviation angle, this accounts for the observed nonlinearities in endurance times summarized above. In non-neutral postures, changes in muscle moment arm and muscle length may affect the capacity for moment generation. For a given load, this yields a muscle contraction at another fraction of capacity (%MVE). Because endurance and exertion level (as %MVE) are inversely related, an additional factor may thus contribute to decreased endurance with trunk deviations. The correspondence between the results summarized here and those in the previous section suggests that discomfort related to trunk deviations may be caused in large part by the sequelae of localized fatigue.

In addition to gravitational loads, increasing postural deviations result in passive tissue deformation (of muscles, ligaments, and intervertebral discs, as mentioned in Section 6.3.1.1), which can either contribute to load equilibration (as in forward trunk inclination) or yield additional torques that must be equilibrated (as in trunk twisting). Even small deviations, with small associated muscle forces, may lead to fatigue, because localized blood flow, one factor responsible for fatigue development, is already impaired at very low levels of static muscle contraction. McGill et al. (2000) demonstrated that contractions as low as 2% of MVE resulted in compromised blood flow to the erector spinae muscle mass.

Although fairly limited, the existing evidence indicates that fatigue increases and endurance decreases in a monotonic fashion with increasing deviation from an upright trunk posture. The specific form of the relationship, particularly for deviations in different planes, requires further investigation.

6.3.4 Trunk Postures and Low Back Pain

In a large cross-sectional study on male construction workers, Holmström et al. (1992) studied the relationship between LBP and trunk flexion as assessed by questionnaires. Given the research methodology, flexion probably referred to bending and forward inclination. A significant dependence was seen between the prevalence of LBP and the duration for which flexed postures were adopted. An exposure response relationship between the time spent in stooped postures and LBP risk was also found. Such cross-sectional studies, however, must be interpreted with caution, because they cannot prove causality. The validity of questionnaire-based assessments of posture is also limited (as already noted in Section 6.1).

Two case-control studies on workers in automobile assembly reported high odds ratios for non-neutral trunk postures (Punnett et al. 1991, Norman et al. 1998). Both used video-based observation of postures. Norman et al. found an increased risk for LBP with increased average and peak forward inclination, but not with sideward inclination or twisting angles (with angles defined as in Section 6.1). Punnett et al. studied the time spent in mild flexion (>20°, <45°), severe flexion (>45°), lateral flexion (>20°), and twisting (>20°). Although it was not explicitly stated, it appears that the flexion and lateral flexion angles were defined with respect to the vertical thus referring to inclination, and twisting was defined with respect to the pelvis (as in Section 6.1). They found a significantly higher risk of LBP with increasing time spent in non-neutral trunk postures. In addition, an exposure–response relationship was found for the time spent in non-neutral postures, with an eightfold increase in the risk when the time increased from 0 to 100% of the work cycle.

Finally, two prospective cohort studies on trunk posture and LBP have been conducted (Riihimäki 1985, Hoogendoorn et al. 2000). Riihimäki studied the occurrence of sciatica (LBP with pain radiating to the legs) in a 3-year follow-up of a cohort consisting of over 2000 workers. Postures were assessed using questionnaires. Both twisting and flexion appeared to be associated with an increased risk of sciatica. Hoogendoorn et al. used video-based observations on a cohort of 861 workers, who were followed for 3 years. Postures were classified as neutral (<30° deviation), mild flexion (30° to 60°), extreme flexion (60° to 90°), very extreme flexion (>90°), and twisting (>30°). Again, the frame of reference for these angles was not explicitly stated, but it appears that definitions are such that flexion refers to forward inclination and twisting is defined consistent with the definition given in this chapter (Section 6.1). Low but significant increases in risk of sciatica were found with exposure to non-neutral postures. When flexed postures over 60° were adopted for more than 5% of the work time, the risk increased by 50%. When twisted postures were adopted for more than 10% of the work time, the risk increased by 30%. There were also some indications of an exposure–response relationship, with the risk increasing with longer exposure.

The studies reviewed all show that non-neutral trunk postures constitute a risk factor for LBP. This risk is also consistently shown to increase with increased duration of exposure. Results from the different studies, however, are divergent to a degree that precludes definitive quantitative conclusions. In addition, the data do not allow for sufficient differentiation between postural deviations in different planes or to different angular magnitudes.

6.4 General Evaluation Criteria

The epidemiological data reviewed clearly support the hypothesis that the risk of LBP is related to exposure to non-neutral postures. In addition, exposure–response relationships have been found. This would suggest that setting threshold limit values for exposure to non-neutral postures might help to prevent LBP. However, the large disparities between studies and the arbitrary cutoff points used do not allow this at present.

The short-term effects of trunk posture that have been reviewed (mechanical load, discomfort, and fatigue) might alternatively be used to derive threshold values. For example, assuming that compression-induced damage to the spine is a cause of LBP, the relationship between postural angles and spine compression combined with data on compression strength could be used to this end (Van Dieën et al. 1999). Unfortunately, the etiology of LBP is to a large extent unknown, and as a consequence the selection of short-term effect variables remains somewhat arbitrary. To address the ongoing need for threshold values for use by practitioners, ISO standard 11226 (ISO 2000) has presented data relevant to trunk postures for protection from health risks associated with prolonged (>4 s) static working postures. This standard recommends that asymmetrical trunk postures be avoided, as should trunk inclinations of >60° from vertical. Less deviated trunk postures are deemed acceptable when there is external support. Finally, maximum acceptable holding times are provided for postures between 20° and 60° where there is no external support. These specific recommendations are to be viewed as tentative, as they are mainly based on a limited number of experimental studies of discomfort and fatigue caused by static working postures. It is not clear how effective the recommendations will be in preventing discomfort and fatigue, and certainly not to what extent they will prevent musculoskeletal injury.

Considering the data provided above, it seems unlikely that postural load alone will cause immediate injury. Tissue strains, net moments, and compression forces appear well within the capacity of most individuals. Prolonged submaximal loading of tissues in sustained postures, however, will lead to creep effects (e.g. McGill and Brown 1992). In animal experiments it has been shown that these creep effects may cause muscular cramps, which could lead to pain. Furthermore, reflex control of back muscles appeared affected by creep of spinal ligaments, which might lead to an increased vulnerability to mechanical injury lasting for hours after the exposure (Solomonow et al. 1998).

Static postures may further affect nutrition of the intervertebral disc negatively, whereas movement may promote nutrition (Holm and Nachemson 1983, Van Deursen et al. 2001a,b). However, there is no strong evidence that static postures per se lead to LBP. Most of the data suggest only that non-neutral postures are related to LBP (Burdorf and Sorock 1997, Hoogendoorn et al. 1999, 2000). It may be that the impairment of disc nutrition is stronger when a relatively high intra-discal pressure is maintained for a long time, as would be the case in sustained exposure to non-neutral postures. Finally, non-neutral postures have been shown to require prolonged muscle activity at substantial levels, which does cause muscular fatigue when postures are sustained. Fatigue has been suggested to lead to back pain either directly, as a cause of myalgic pain (Jørgensen 1997), or indirectly, as a of cause mechanical overloading due to reduced motor control (Sparto et al. 1997, Van Dieën et al. 1998).

An alternative approach to setting threshold values would be to define these in terms of the level of a short-term effect variable. They would then have to be based on the relationships between short-term effect variables and LBP risk instead of the relationship between posture and LBP. This might have an advantage in that several important interacting exposure variables are reflected, at the level of such short-term effects. In addition, several short-term effects are important in their own right, such as fatigue and discomfort. When considering threshold values for posture, these would need to be defined in terms of postural angle in combination with duration, duty cycle, and frequency. The latter variables are only beginning to be addressed. In addition, interactions of postural deviations about three axes and interactions with external forces would need to be taken into account. Short-term effect variables might show the integrated effect of all of these exposure variables and their interactions. An encouraging step in this direction is the model developed by Norman et al. (1998), which relates LBP risk to a combination of integrated and peak forces acting on the spine.

On the basis of the present review, we conclude that the state of knowledge of the relationship between posture and short-term effects and between short-term effects and LBP precludes determination of threshold limit values. All the data suggest, however, that negative effects of posture increase more or less monotonically with postural deviation although mostly in a nonlinear way. Finally, the data and methods regarding short-term effect variables provide a means for comparative evaluation of postures in practice and may be used to develop tentative guidelines.

Summary

Adverse trunk postures cause fatigue and discomfort and can cause LBP. The chapter reviews the measurement of trunk posture and its effects on physical loading and health. Trunk postures need to be defined in terms of the orientation of the trunk with respect to the gravitational field (forward or sideward inclined) and in terms of the shape of the trunk (forward bend, sideward bend, or twisted). Measuring trunk postures in these five dimensions is a challenging task. Visual observation can yield valid results only when a fairly coarse categorization of postures is used and when time-sampled observations are made, due to limitations on the information processing capacity of the observer. Interpretation problems often arise when trunk postures involve rotations of the trunk about more than one axis. Objective measurement can provide adequate data at high sampling frequencies, but these techniques are cumbersome and may interfere with task performance. Recent technological developments will make objective measurement of trunk posture in the field possible.

The effects of trunk postures on the musculoskeletal system depend on interactions of the five dimensions in which posture is defined and on interactions with any forces exerted on the environment, for example, when holding an object. In general, non-neutral trunk postures cause more mechanical load, more muscle fatigue, more discomfort, and more health risk. Short-term effects increase monotonously when looking at any one dimension at a time. This suggests that the same may hold for health risks.

The state of knowledge precludes determination of threshold limit values. However, data regarding the short-term effects of adopting certain postures can provide a means for comparative evaluation of postures in practice and may be used to develop tentative guidelines.

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