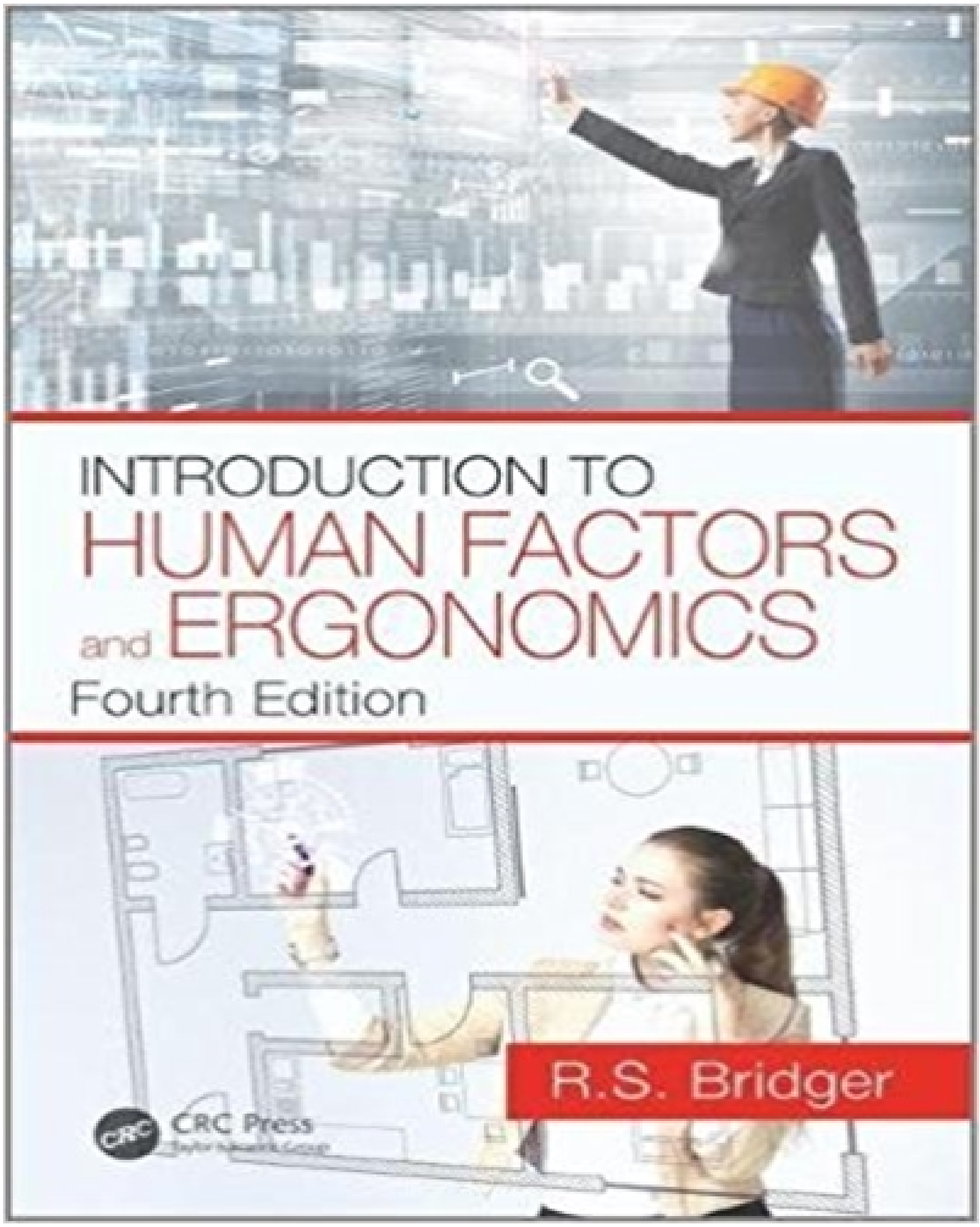
Solutions for Introduction to Human Factors and Ergonomics 4th Edition by Bridger



Solutions

CHAPTER 2. BODY MECHANICS AT WORK. RISK ASSESSMENT AND DESIGN

1. What is a 'good' posture? How would you decide?

One way to approach this is from first principles. If posture is the 'average orientation of the body over time' then we have to consider the loading patterns on the body as a consequence of adopting the posture while doing the task. Thus, a consideration of anatomical principles in relation to internal and external force generation is essential. If we take an ergonomic approach then a good working posture is process of adaptation to the task demands in the most resource efficient way. People may trade-off biomechanical demands for physiological cost savings, therefore the task may be mechanically demanding with low physiological load.

In practice, a good working posture is one which minimises the load on the body while carrying out the task, while ensuring that operators can exert the required forces and carry out task-related movements efficiently. From an ergonomic perspective, a good posture depends on an appropriate arrangement of the workspace and work objects to maximise efficiency.

2. Are biomechanical models for estimating spinal compression too simplistic?

Probably. The main drawback is that the effects of fatigue on the tissues themselves such that the threshold for injury is not the same at the end of the task as it was at the beginning. In this chapter, we have only reviewed static models although dynamic modelling is possible with access to a force platform, accelerometers and so on. Best to see the models in Chapter 2 as 'first approximations' which are useful for estimating the benefits of workspace improvements for lowering spinal compression, rather than as absolute assessments of loading and therefore of risk. They are of obvious use when making cost-benefit arguments for ergonomic improvements to working conditions. This is because budget holders nearly always require evidence before they will approve additional allocations of funds.

3. Would it be possible to 're-engineer' the human body when designing lifelike robots?

Yes. If the intention was to build robots that were as lifelike as possible then it would be possible to re-engineer the human body, particularly, the skeleton. In humans the main areas of weakness are the lumbar and cervical spines and the knee and hip joints. These might all be re-engineered, either by making the components stronger or by developing alternative ways of achieving the function. A more general question concerns how lifelike the robots should be and why?

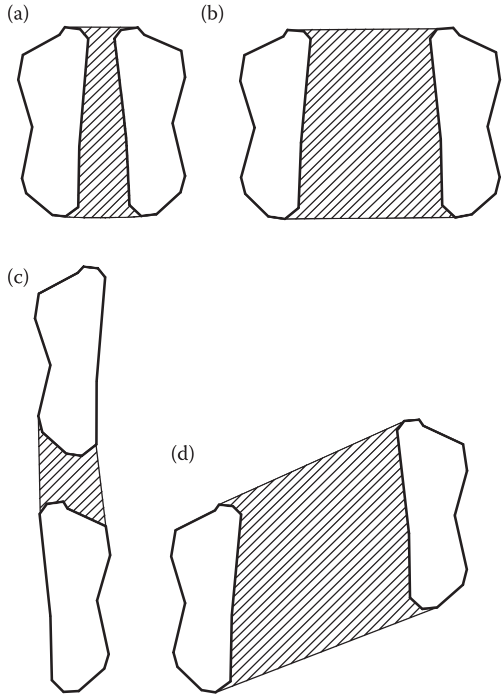


FIGURE 2.1 Stability of the body parts depends on the shape of the base of support described by the position of the feet: (a) unstable, (b) fairly stable in all directions, (c) stable anteroposteriorly, and (d) laterally stable.

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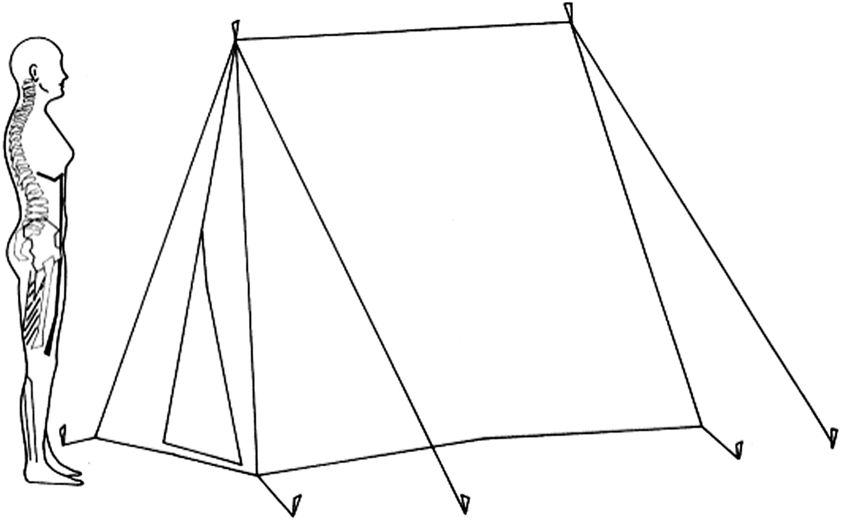

FIGURE 2.2 Tent analogy. The skeleton is the tent pole, the muscles are the guy ropes, and the soft tissues are the canvas.

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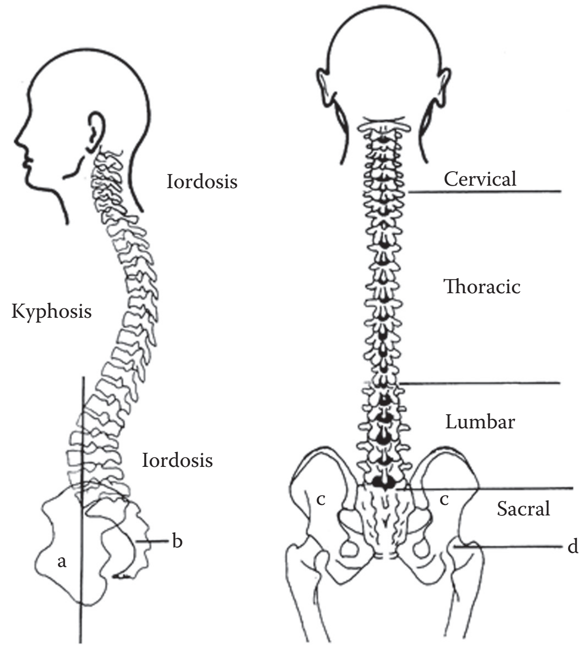

FIGURE 2.3 The lumbar, thoracic, and cervical spines and the pelvis (a) and sacrum (b). The weight of the upper body is transmitted through the lumbar spine, the iliac bones of the pelvis (c) to the hip joints (d) and legs.

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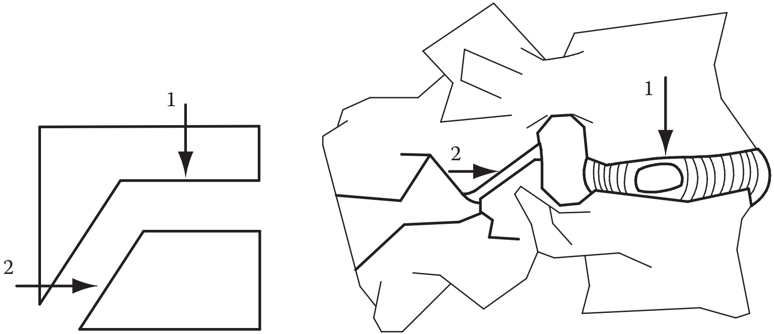

FIGURE 2.4 Function of (1) intervertebral disk and (2) facet joints. The disk resists the compressive load and the facets resist the intervertebral shear force. (From Kapandji, I.A. 1982. *The Physiology of the Joints*. Vols. 1–3. Churchill Livingstone, Longman Group, Edinburgh, UK. With permission.)

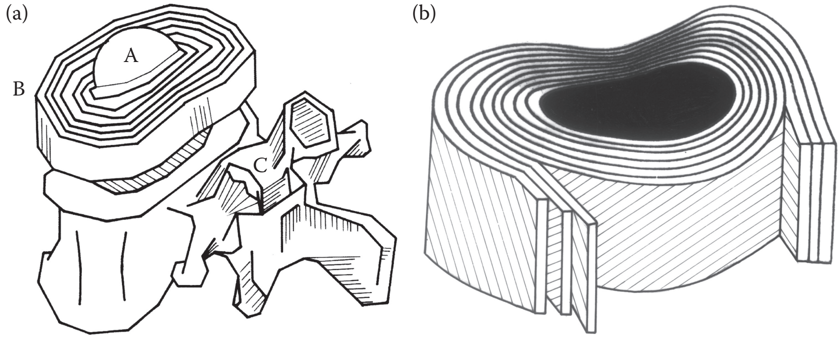

FIGURE 2.5 Intervertebral disk and vertebral body. (a) In this view, the superior vertebral body has been removed to reveal the intervertebral disk below. A is the nucleus pulposus, B is the annulus fibrosus, and C is the inferior facet joints at the rear. (From Kapandji, I.A. 1982. *The Physiology of the Joints*. Vols. 1–3. Churchill Livingstone, Longman Group, Edinburgh, UK. With permission.) (b) Details of the structure of the annulus fibrosus. The annulus consists of a number of layers of cartilage. The fibers in the layers run obliquely and in different directions, somewhat like the layers of a cross-ply tire. The outer layers run perpendicular to each other. (From Vernon-Roberts, B. 1989. *The Lumbar Spine and Back Pain, III*, M.I.V. Jayson, ed. Churchill Livingstone, Oxford, Edinburgh, UK. With permission.)

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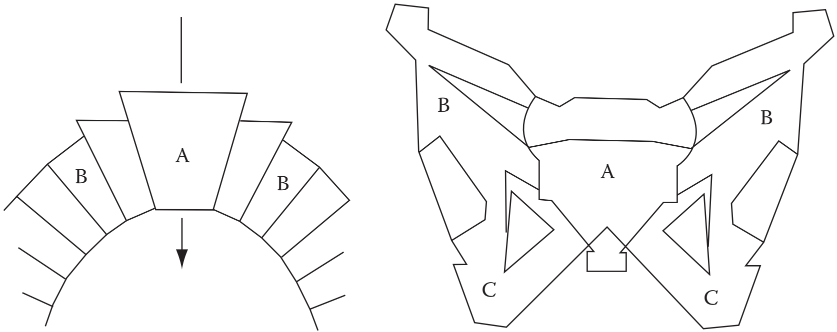

FIGURE 2.6 The pelvis as an arch. The pelvis viewed from the rear. A is the sacrum, B is the ilium, and C is the ischium. The sacrum acts like a true keystone in this plane. (Redrawn from Tile, M. 1984. *Fractures of the Pelvis and Acetabulum*. Williams & Wilkins, Baltimore, MD, London. With permission.)

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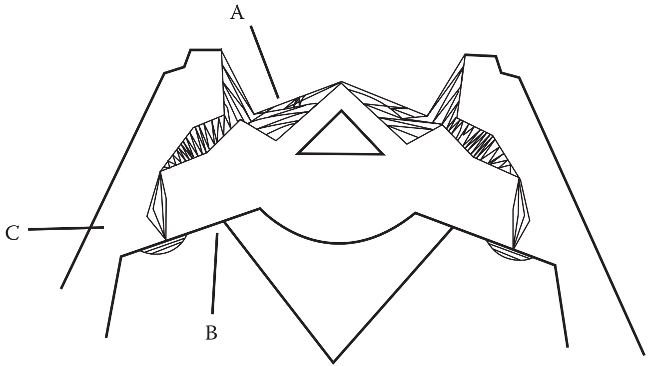

FIGURE 2.7 View of the sacroiliac joint from above. A represents the ligaments, B is the sacrum, and C is the pelvis. The ligaments act like the cables of a suspension bridge preventing the sacrum from slipping forward. If the joint is deformed by loading, the ligaments can be pinched by bone causing pain in the very low back usually on one side. (Redrawn from Tile, M. 1984. *Fractures of the Pelvis and Acetabulum*. Williams & Wilkins, Baltimore, MD, London. With permission.)

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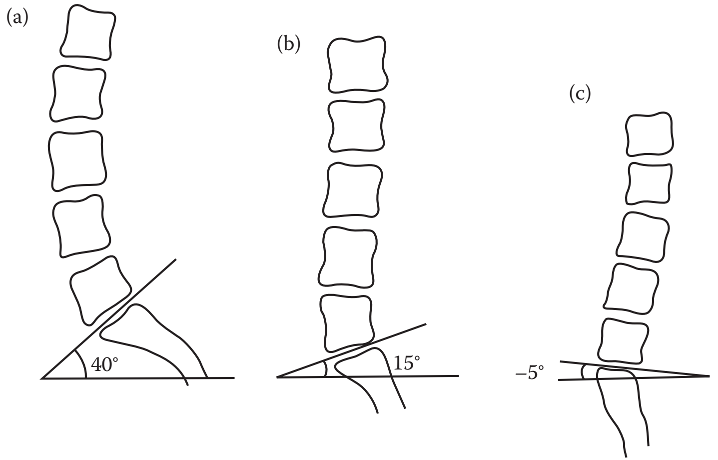

FIGURE 2.8 Relationship between sacral and lumbar angles. (a) Sacral angle and lumbar lordosis, as in standing, (b) Moderate sacral angle and fattened lordosis as in sitting on a chair with a backrest, and (c) Minimal sacral angle and tendency to lumbar kyphosis as in sitting on a low stool.

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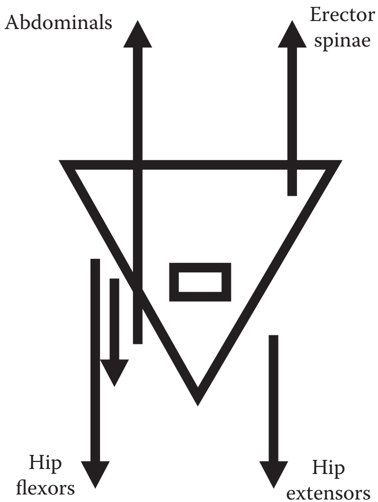

FIGURE 2.9 Schematic representation of the muscular system of the pelvis (sagittal view). When the abdominal or hip extensor muscles shorten, the pelvis tilts backward. The result is a flattening of the lumbar spine to maintain the trunk erect. When the hip flexors or erector spinae muscles shorten, the pelvis tilts forward. This is accompanied by a compensatory increase in the lumbar lordosis.

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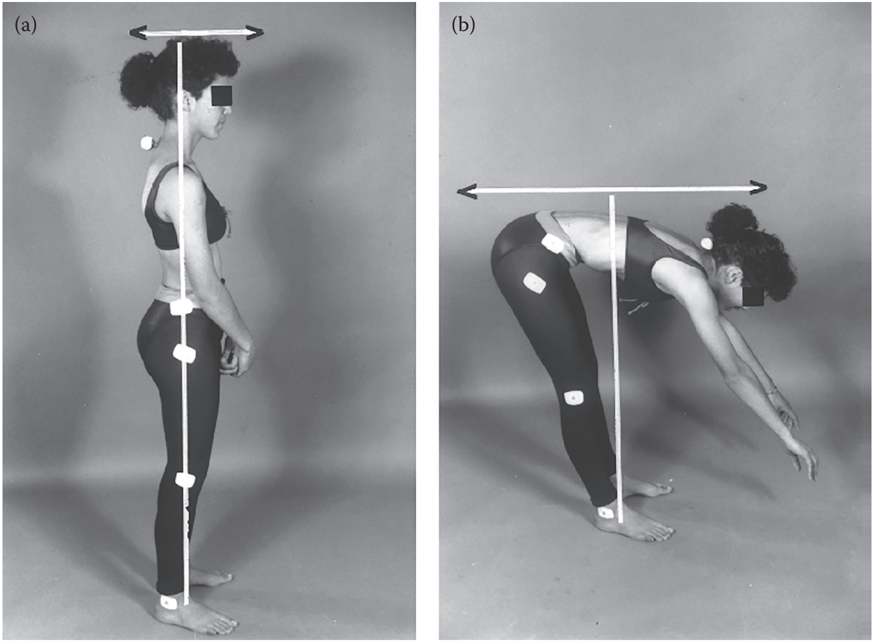

FIGURE 2.10 When the base of support is constrained, compensatory movements occur automatically to maintain postural stability demonstrating that the "attitudinal as well as the righting reactions" are indeed involuntary. (a) Balanced erect standing posture and (b) as the hip joints flex and the upper body moves forward, the ankle joints plantar flex to compensate and the lower body moves rearward, maintaining balance.

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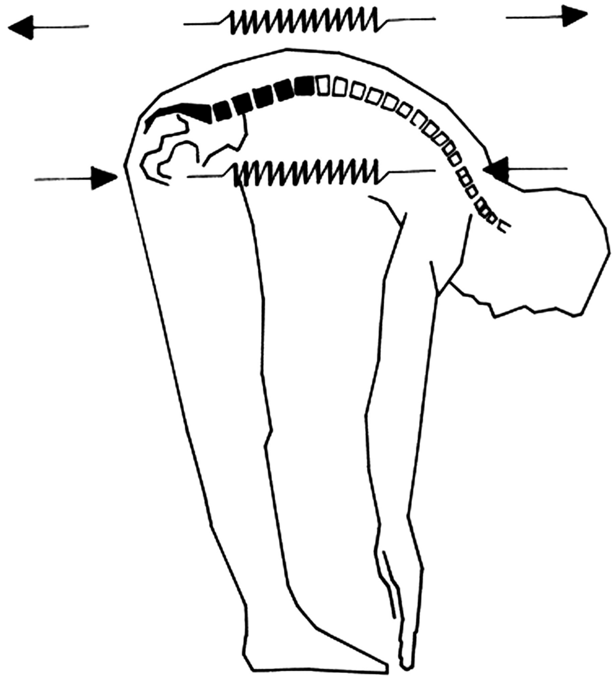

FIGURE 2.11 In this position, postural stress occurs in the form of compression of abdominal contents and intervertebral disks and stretching of the posterior spinal ligaments.

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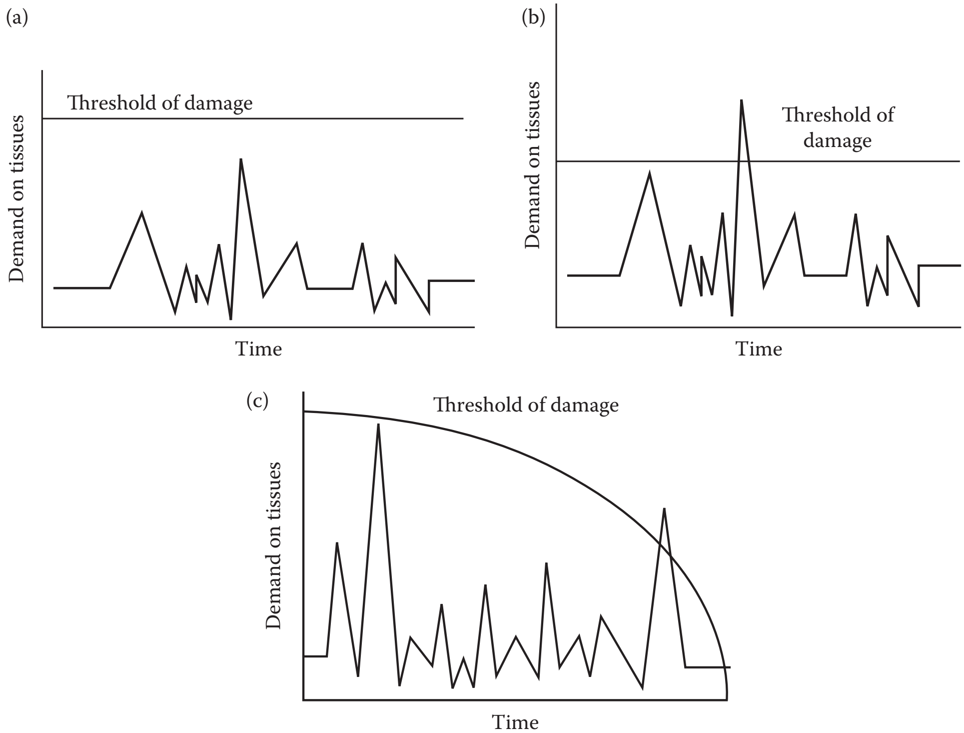

FIGURE 2.12 The specification of force limits for safety (a and b) is complicated by factors such as fatigue that can lower the threshold for injury of the tissues (c). (From Professor S. McGill, University of Waterloo, Canada. With permission.)

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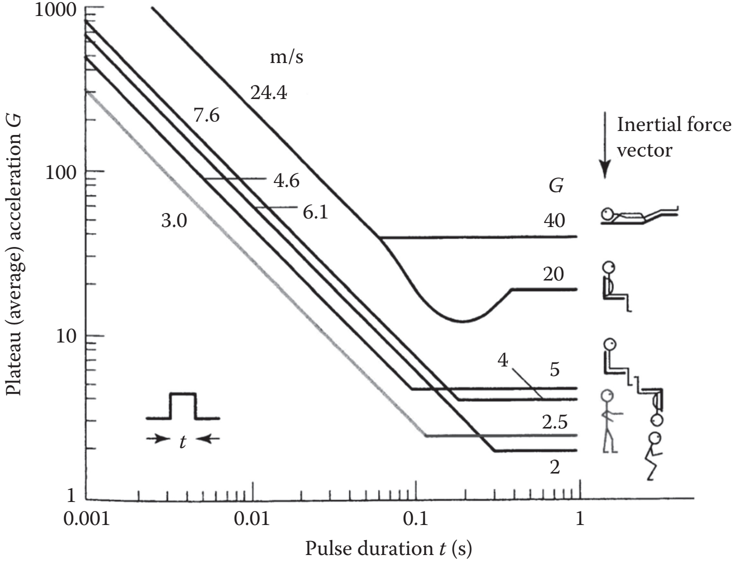

FIGURE 2.13 The tolerance to human whole-body impact for critical velocity change, critical acceleration level, and critical duration. (From Glaister, D.H. 1978. *Injury*, 9: 191–198. With permission.)

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FIGURE 2.14 Darren Taylor, also known as Professor Splash, dives from 8 m high into a 30-cm shallow pool of tomato sauce during a promotion at Darling Harbor in Sydney, Australia. Note the "belly flop" technique. (Courtesy of Darren Taylor.)

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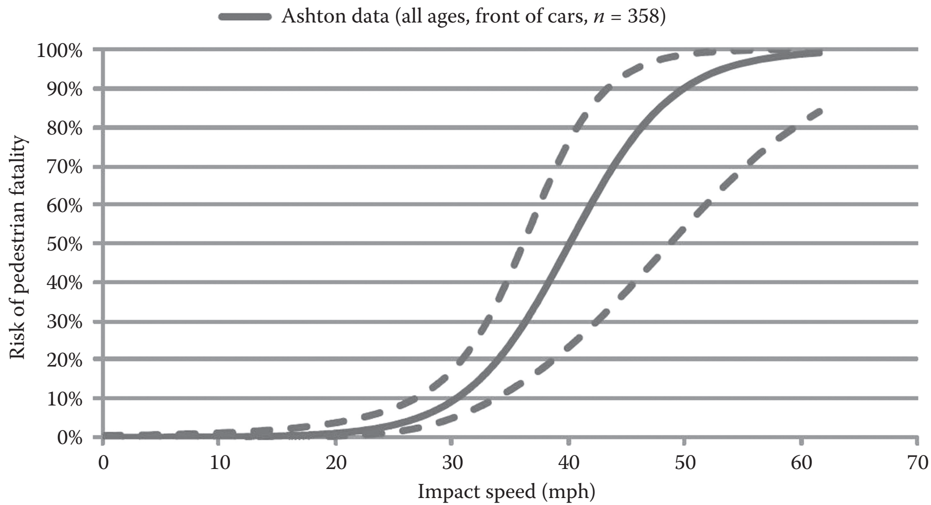

FIGURE 2.15 Risk of pedestrian fatality at different automobile impact speeds.

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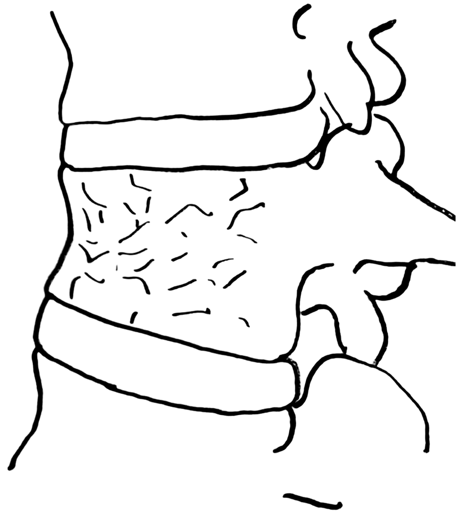

FIGURE 2.16 Wedge fracture at T12–S1.

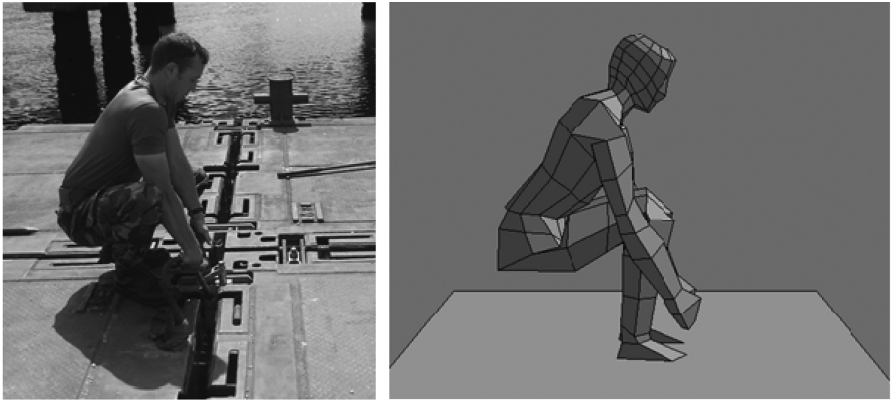

FIGURE 2.17 Sample output of SSPP (University of Michigan). Lifting a mooring bollard weighing 38.6 kg. Joint angles, measured from the photograph, were entered into the SSPP together with the mass of the operator. 3D SSPP analysis revealed an estimated 6880 ± 503 N in the lower back during this one-person lift. This is in excess of the recommended limit. The hip joints were the limiting joints in this posture and lift, with sufficient strength capability estimated in 58% of people, that is, 58% of males have sufficient hip strength to perform the lift.

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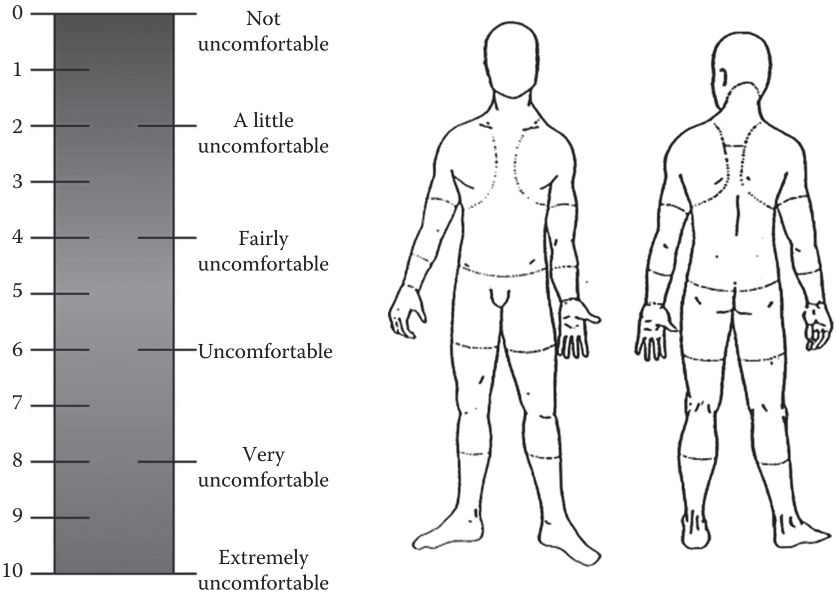

FIGURE 2.18 Body diagram for pain rating. These are often included in questionnaires for use in ergonomic surveys. Pain is often rated on a 10-point scale where 1 = mild discomfort and 10 = the pain could not be worse.

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Introduction to Human Factors and Ergonomics 4th Edition

RS BRIDGER

General requirements for humans in systems:

- External forces acting on the human body must not exceed its mechanical tolerance limits.
- Where the exertion of forces on external objects is required, the magnitude of forces must be within the strength and endurance limits of members of the user population.
- The task must be designed to minimize postural load (ALARP)
- Biomechanical risk factors for musculoskeletal injury must be identified and eliminated in the design.

The Body as a Mechanical System

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  - Biomechanical risk factors for musculoskeletal injury must be identified and eliminated in the design.

Function of the Lumbar Spine [2-7]

- Provides a conduit for the spinal cord
- In quadrupeds - acts like a suspension bridge to support the weight of the thorax and the abdominal organs
- In humans - a major part of the axial skeleton - supports the weight of superincumbent body parts
- The key postural adaptation that makes humans truly bipedal

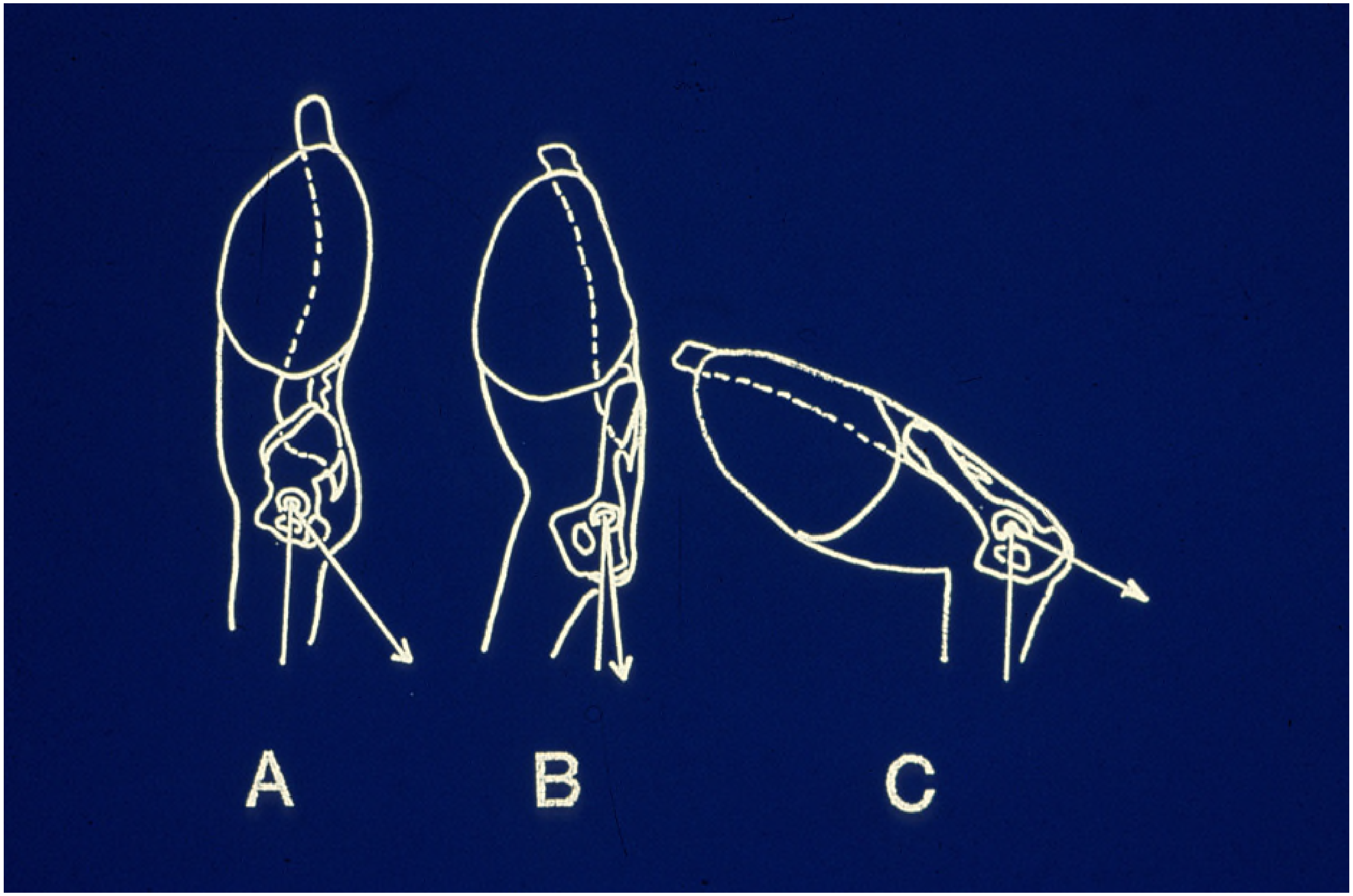
Some Aspects of Spinal Anatomy

- Spine is the axis of the upper body
- Transmits weight of superincumbent body parts to the pelvis
- Conduit for spinal cord
- Consists of 3 columns:
  - Anterior column of 24 vertebrae, not including the sacrum
  - Two posterior columns of stacked articular processes

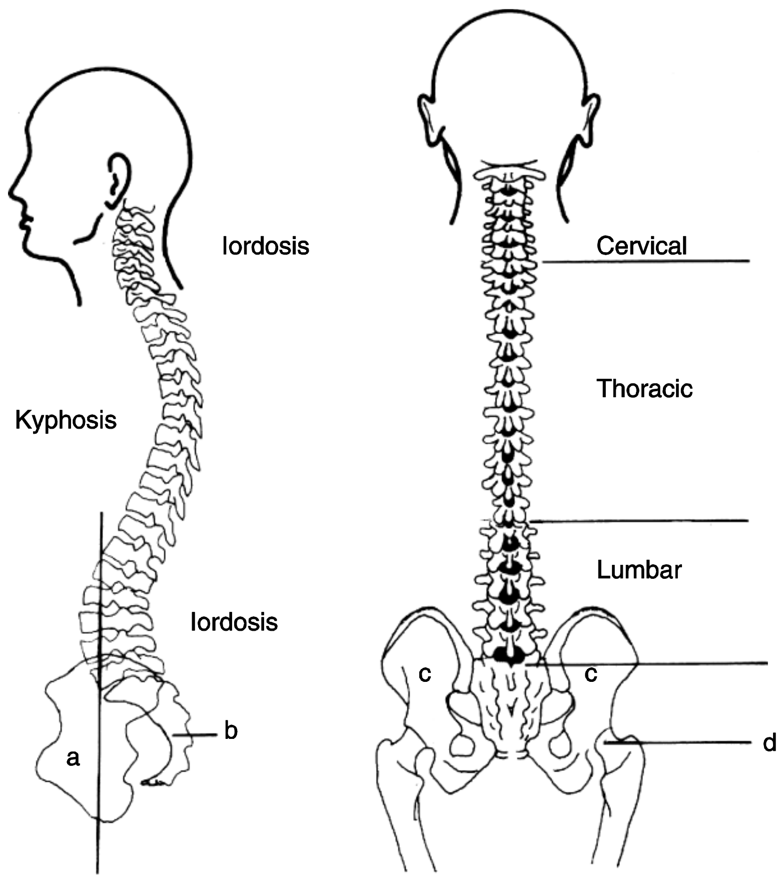
The Standing Posture 42-50

- Humans unique in their adaptation to standing on two legs
- Extra physiological cost of standing compared to lying down is only 6%
- Functional anatomy of standing in humans:
  - Pelvis tilted anteriorly
  - Lumbar and cervical spines extended to give "S" shape
  - Weight of superincumbent body parts passes through or close to joint centres from head to toe
  - Plantarflexors, iliopsoas, low back, neck extensors and jaw muscles are postural muscles. Low level isometric contraction
  - Body weight is "balanced" on a column of bone
  - The "Tent" analogy
- Natural sitting postures very different from sitting on chairs

The Standing Posture in Human and Other Primates



Spinal Curves



Overall Function of the Spine

- It’s a 3-D jigsaw puzzle that functions like a mast
- Short, deep muscles help to hold the vertebrae together
- Long, superficial muscles make the whole thing move
- The ‘Tent’ analogy and the concept of postural load.

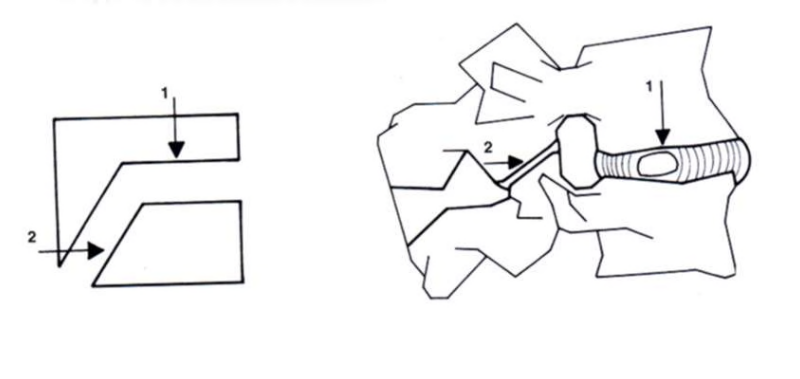
Mechanical Function of a Lumbar Motion Segment

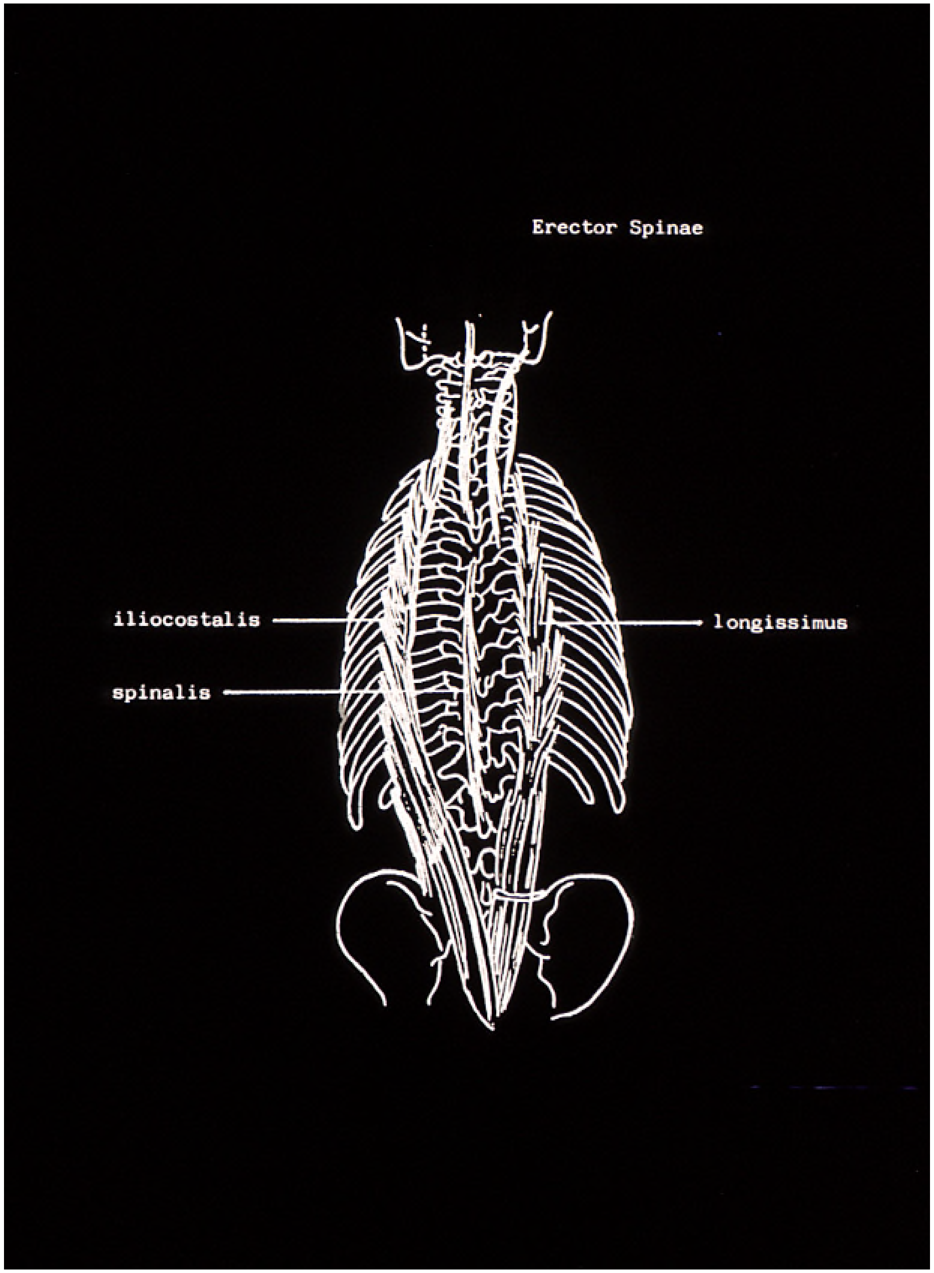
Intervertebral discs are ’spacers’

resist compressive force, providing space for movement in the segment

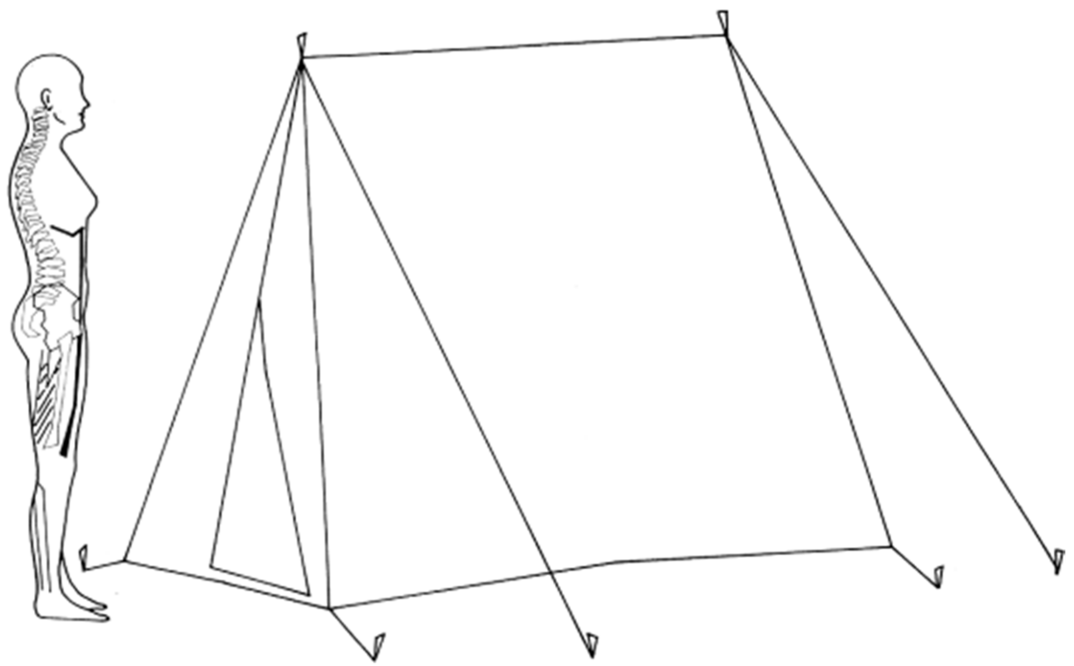
Facet joints resist shear (‘tangential’) force

Vertebral body is a shock absorber

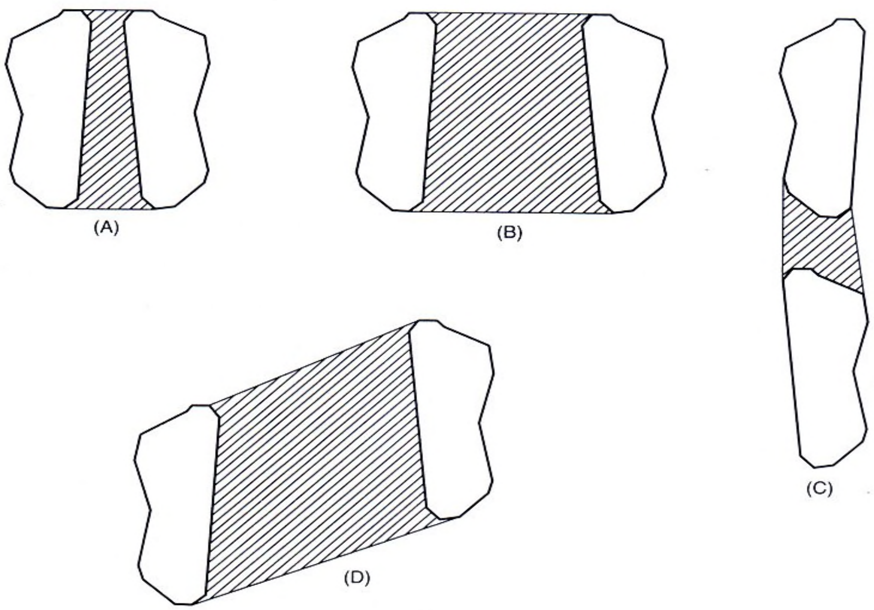


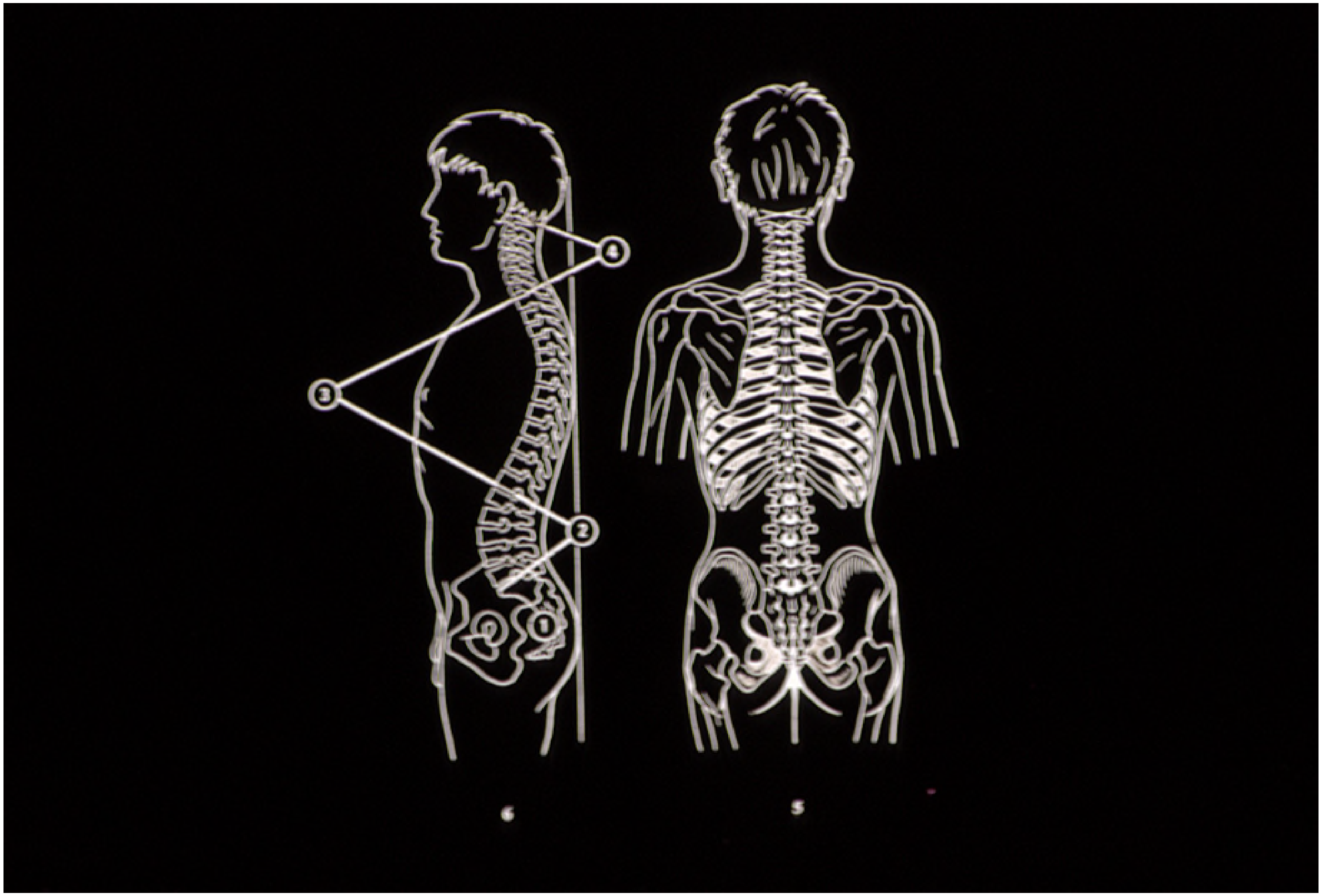

Erector Spinae
iliocostalis
spinalis
longissimus

The Tent Analogy



Base of Support

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2
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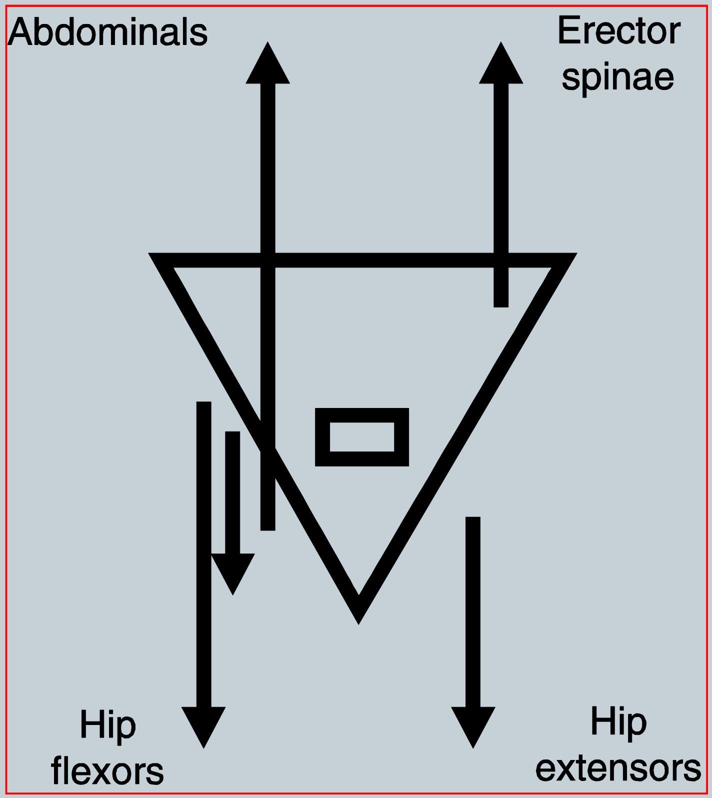
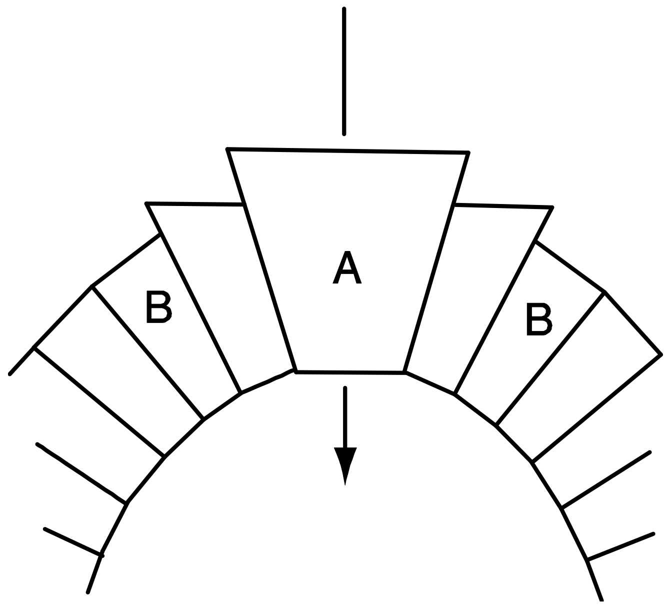
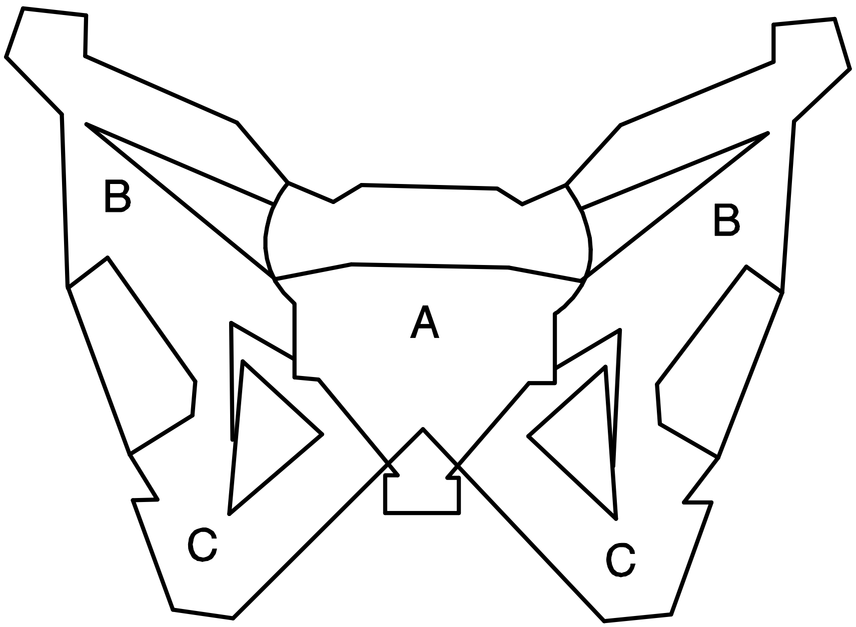
The Lumbo-Pelvic Mechanism

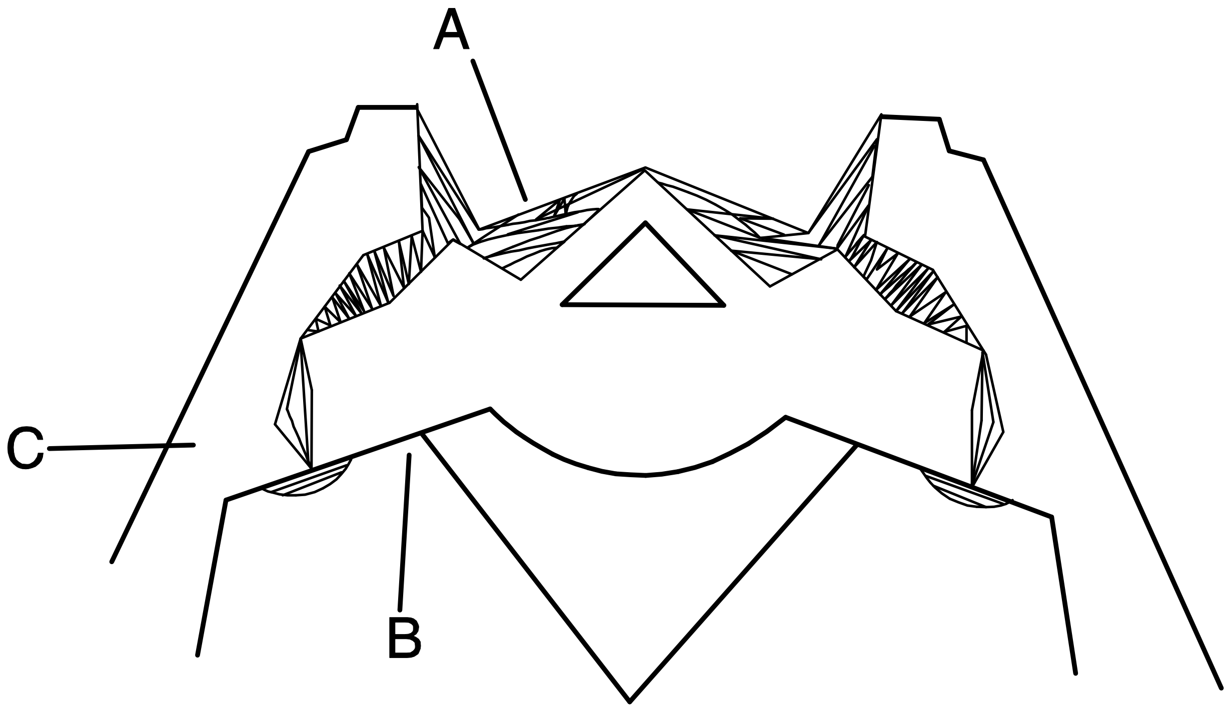


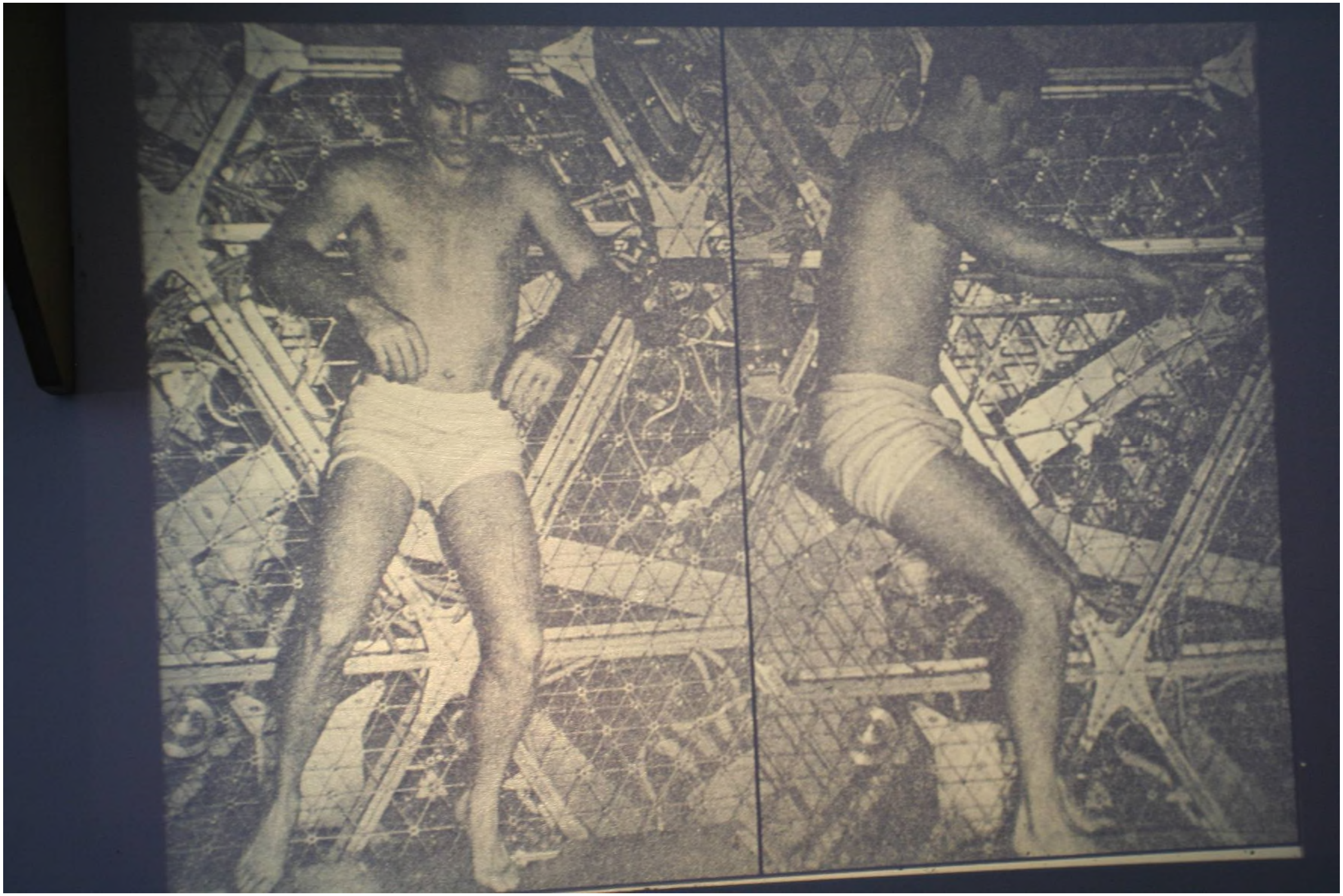
The Pelvis as an Arch



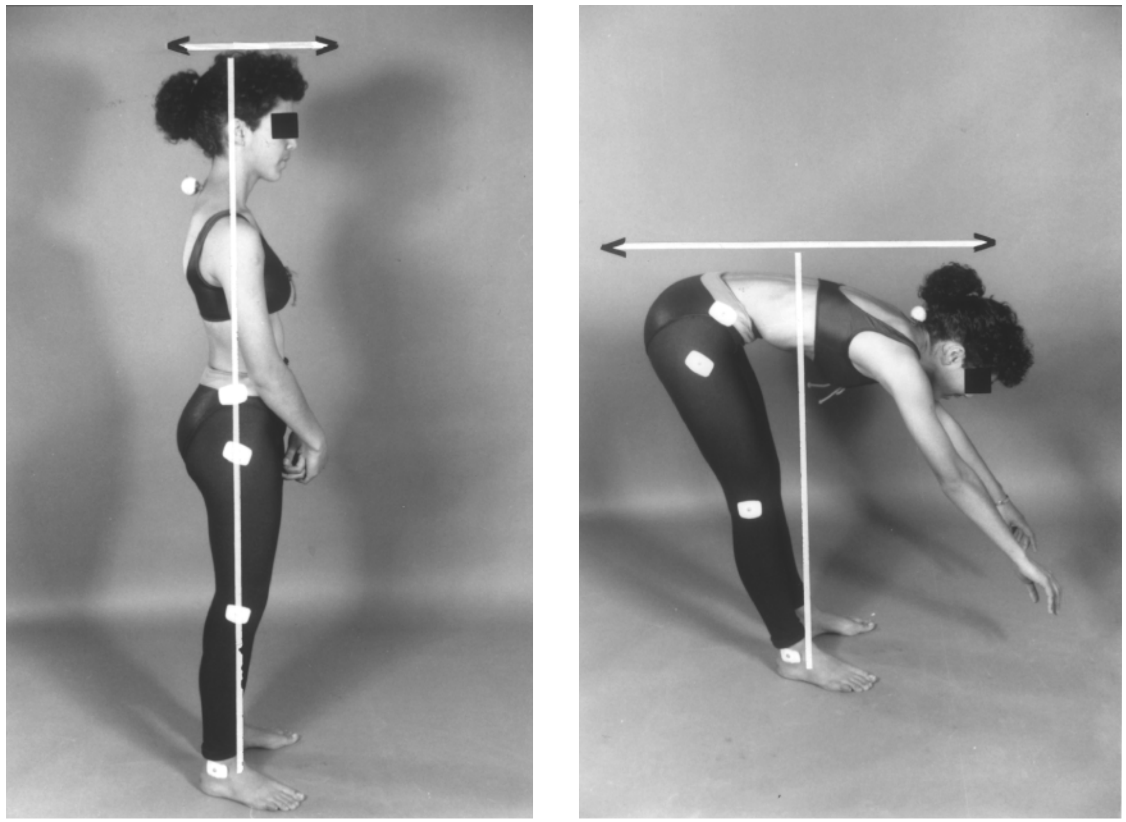


The Sacro-Iliac Joint Viewed From Above



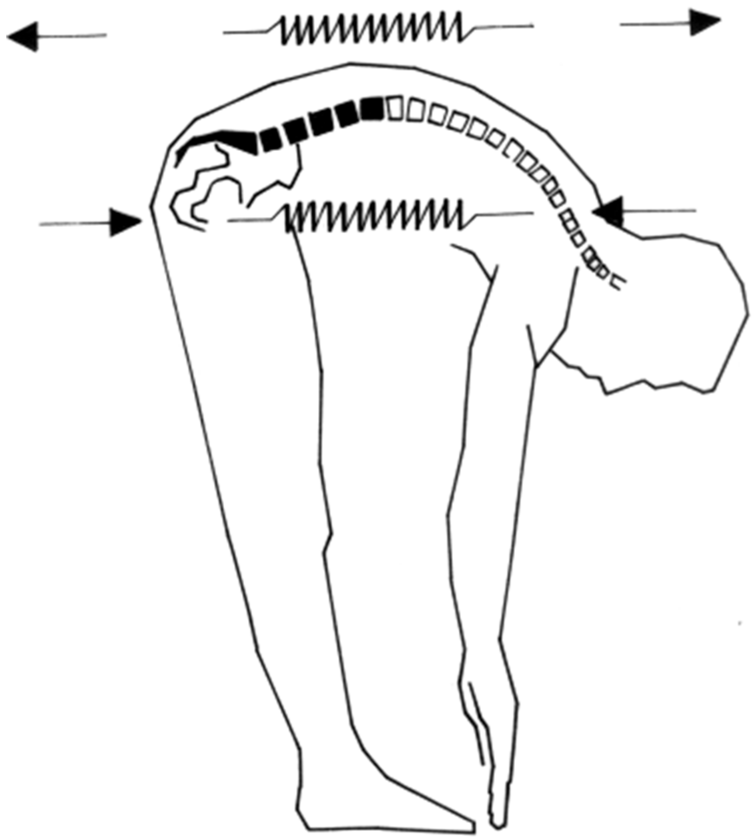


Postural Adaptation



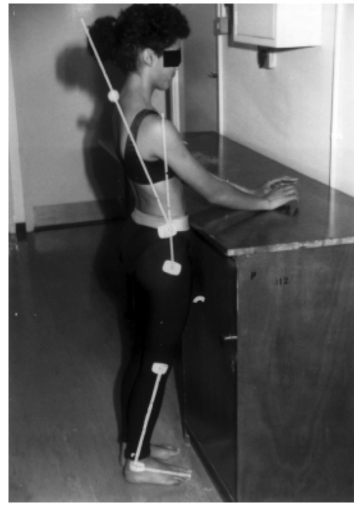
(a) (b)

Postural Adaptation and Tissue Loading



Postural Adaptation at Work


(a)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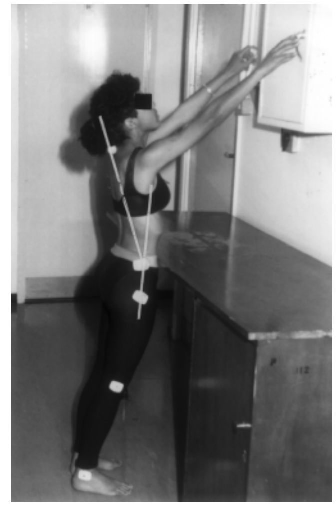
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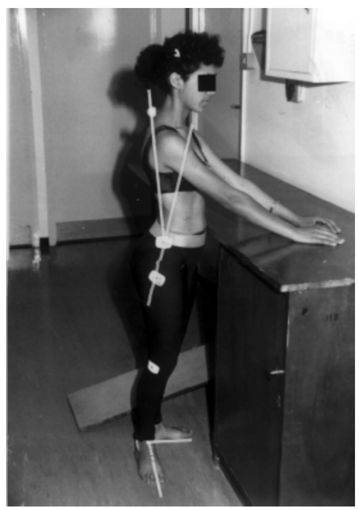
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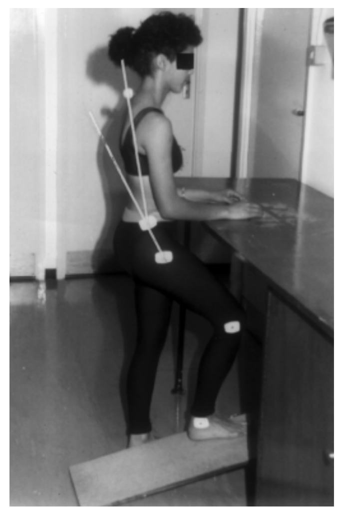
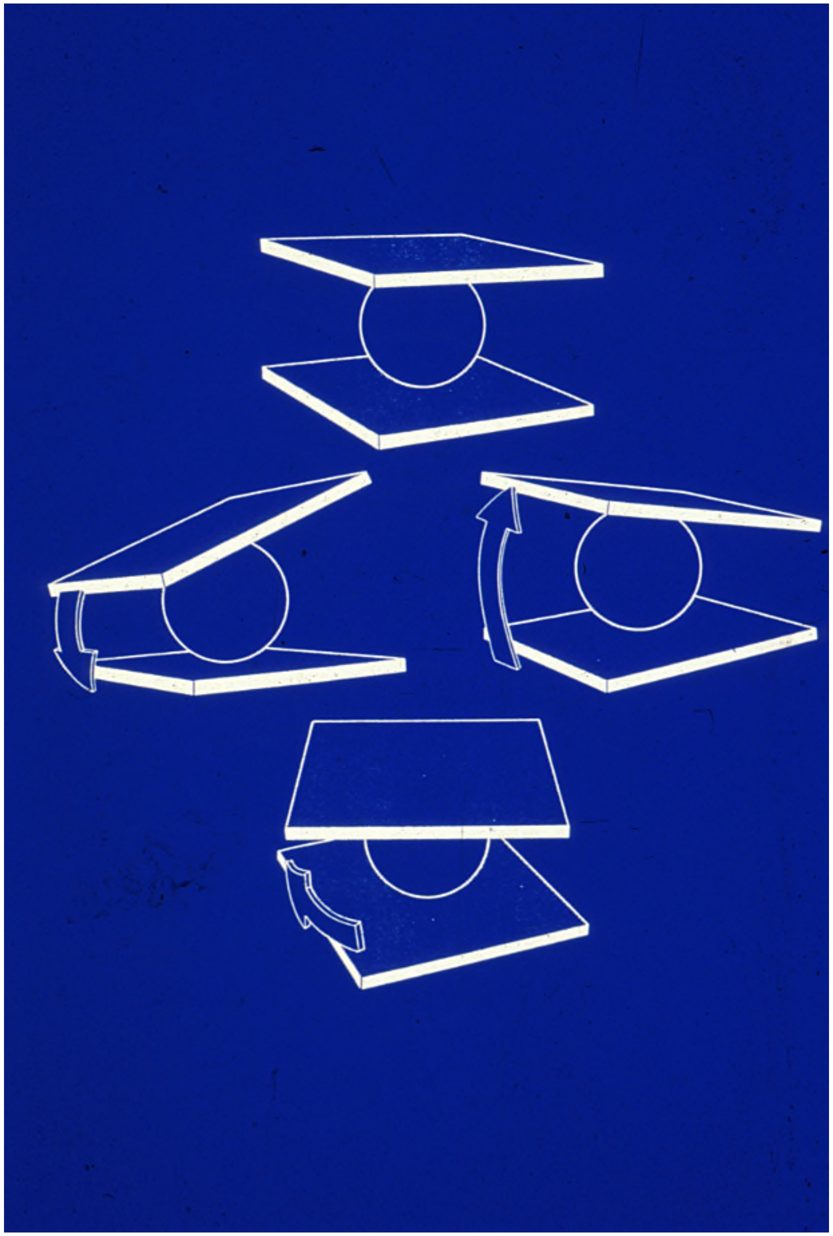

(e)

Intervertebral Discs

- Nucleus pulposus contains proteoglycans in solution
- Surrounded by layers of cartilage like the rings of an onion
- Fibres of the annular layers run obliquely, like the layers of a cross-ply tyre
- Nucleus is under positive osmotic pressure


N
A
a
b



Mechanical Functions of Components

- Vertebrae: to resist the compressive load - but the end plate is the weak link
- Facet joints: to resist the intervertebral shear force (particularly in the lumbar spine)
- Intevertebral discs: to separate the end plates of adjacent vertebrae and thus allow movement between the vertebrae
- Facets also play a role in *limiting* the movement that can take place

Where Does Back Pain Come From?

- Back muscles? Fatigue?
- Facet joints
- Outer rim of posterior annulus
- Sacro-iliac joint
- Nerve roots
- Vascular tissue that is not normally present
- The spinal joints are deep within the body, making it difficult to tell sometimes

Why does the Spine Fail?

- Disease and deformity (Scheurmann's disease, extra lumbar vertebra, congenital weaknesses etc.). People with these conditions are sometimes free of pain, though
- Ageing and degenerative processes
  - Lack of exercise, weak abdominal and back muscles
  - Disc degeneration and loss of "hydration"
  - Shortening of hamstring muscles and decreased mobility increases bending stresses on the spine
- Mechanical Failure: loading increases rate of cell death in the intervertebral discs
- Is chronic LBP "functional" is it a combination of several different factors interacting to produce a painful outcome?

The “Worn Out Lumbar Spine”: Some Suggested Features [8-11]

- Degenerated or herniated intervertebral discs
- Osteophyte formation as evidence of abnormal strain responses
- Shnorl’s nodes
- Vertebral end plate failure and calus formation
- Osteoarthritis of facet joints
- Spondylosis and spondylolisthesis
- Changes in back muscle biochemistry
- “Ragged red fibres” and increased “fatigue-ability” of back muscles
- Initial injury can lead to a vicious circle of maladaptation leading to further degeneration and loss of function.

Mechanical Failure

- The 3 main sites are:
  - The spine itself, including the ligaments
  - The muscles and their attachments
  - The trunk (hernias)

Mechanical Function of the Lumbar Spine [12-16]

- Vertebral bodies resist most (80%) of the compressive force acting down the spine
- Intervertebral discs also resist compression and allow small movements between vertebrae
- Facet joints protect the discs from shear and torsion
- Intervertebral ligaments prevent excessive bending
- Posture is fundamental to normal functioning - disc pressures increase in forward flexion and decrease in extension as the facet joints take more of the load. Facets may take 70% of compressive force if disc is severely degenerated.

Mechanical Failure of the Lumbar Spine

- Vertebral body is the weak link in the chain - vertebral end plate failure is common in life - evidence of microfractures in most cadaveric specimens
- Damage limit is 60% of SCTL and fatigue limit (under whole body vibration 20-30%).
- Fractures of the pars interarticularis caused by high shear forces and/or lumbar extension cause lumbar vertebra to move forward and down
- Extension and high bending moments cause damage to inferior margin of facet joints. 1-3 degrees of torsion can damage the joint surfaces

Mechanical Failure of the Lumbar Spine [17]

- 70% of spine's resistance to flexion is due to ligaments, rest is from the disc.
- In hyperflexion, the interspinous ligament is the first to go and is wholly or partially ruptered in 20% of cadaveric specimens
- Next to go are the facet joint capsular ligaments, then the disc
- Sustained flexion reduces ligament strength by 40% in 5 minutes and 67% in 1 hour. Ligamentous protection of discs is therefore reduced during subsequent flexions
- Discs are NOT damaged by compressive loading. Torsional loading damages the facet joints long before the disc. Compression , lateral bending and forward bending combined are the only known movements that cause lumbar disc prolapse

Mechanical Failure of the Lumbar Spine[18]

- Mildly degenerated discs may prolapse through existing radial fissures in the annulus
- Severely degenerated discs are too fibrous to prolapse which is why old people don't suffer this injury as often as the middle-aged
- There is a genetic predisposition to disc prolapse
- There is some evidence that sustained flexion lowers the blood supply to the lumbar spine by increasing the hydrostatic resistance to blood flow
- Increased intra-abdominal pressure MAY protect the spine by preventing implosion of the vertebral bodies, particularly the end plates, under sudden compressive loading

Where Does the Pain Come From?
A number of possibilities

- Mild reversible backache - no different from any other form of temporary myalgia of mechanical origin
- Pain from the muscles - DeLuca, Biederman - rapid fatigue of back extensors
- Pain in flexion - Snook's theory
- Pain in extension - disc degeneration leads to problems with the facet joints
- Pain in "re-extension" - viscous lengthening of posterior ligaments

Back Pain in the Workplace

- More than 25% of accidents involve handling goods of some kind (HSE)
- Most common cause of low back injury in US is falling, not lifting
- Low back pain accounts for 15% of all Liberty Mutual compensation claims and 23% of costs
- Low back pain more likely in those who regularly lift weights of 3kg. or more in their jobs
- Low back pain less likely in those who occasionally lift weights compared to not at all.
- Lifting is the commonest precipitating event for acute herniated lumbar intervertebral disc - compared to falling, standing, car driving etc.

Lies, Damn lies, Statistics and Costs

- Liberty Mutual insurance company data 1999
- 8.3% of low back claims account for 82.3% of total claim costs for LBP
- A small number of serious injuries last for more than 3 months and so the picture is very skewed
- Interventions need to target high risk areas and high risk people in order to cost-justify themselves
- Blanket preventative efforts are a blunt instrument. They may be morally defensible, but are rarely cost-ineffective
- Screening for cervical cancer as an example of “unhealthy prevention”

Prevalence of Back Pain

- Brattberg et al. 1989.
- Overall prevalence in population is high
- Multiple episodes are the norm
- Prevalence highest in 45-64 yr. age group
- LBP without radiation is the norm
- Prevalence increases with age
- Higher in females than in males
- Miedema et al. (1998). LBP became chronic in 28% of patients (7-year follow-up)

Prevalence of Back Pain

- LeBouef-Yde et al. 1998. 1 yr. Prevalence rises from 7% at 12 yrs to about 50% at 25 whence it levels off up to age 40.
- Prevalence higher in high-income than low-income countries and higher in city than in rural populations
- Prevalence higher in low-income countries in “enclosed workshops”.
- Major problem with all this over-reliance on “yes”/“no” answers and lack of information on severity

Need for a Holistic View

- Evidence that LBP complaints correlate with a variety of other conditions in survey data
  - No. of other pain sites
  - Degree of psychiatric disturbance
  - Response bias depends on personality traits and cultural patterns
  - LBP loss of workdays is associated with compensation claims for other musculoskeletal injury in the last 3 yrs (Daltroy et al. 1997)
- Need to look at the whole person

Safety Propaganda - The Wrong Message

- The spine is easily damaged. Medical treatment can help but the damage has been done
- Bed rest is the best answer when your back hurts - avoid physical activity
- Further investigations, even surgery, may be needed (reinforces the message that the pain is beyond the patient's control)
- Focus on pain avoidance (implicit message: assumption of normal life must await pain cessation)
- Encourages passivity, discourages coping/adaptation

Safety Propaganda - The Right Message

- Normally, there is no sign of any serious disease
- The spine is strong. Pain is not the same as damage
- Pain is a symptom that your back is not moving as it should be - it's just "out of condition"
- There are a number of treatments that can help - lasting relief depends on you
- Recovery depends on getting you back moving again - the sooner you are back on your feet, the sooner your back will feel better
- Don't let your back rule your life!

Contribution of Psychosocial Factors

- Between them, psychosocial factors account for over 30% of the variance in back pain disability
- Essential to take psychosocial factors into account when carrying out interventions/investigations in the area
- Suggests that psychosocial factors need to be included in the management of occupational low back pain
- COUNTER FATALISTIC BELIEFS!
- BUT……Don’t forget about the other 70%!

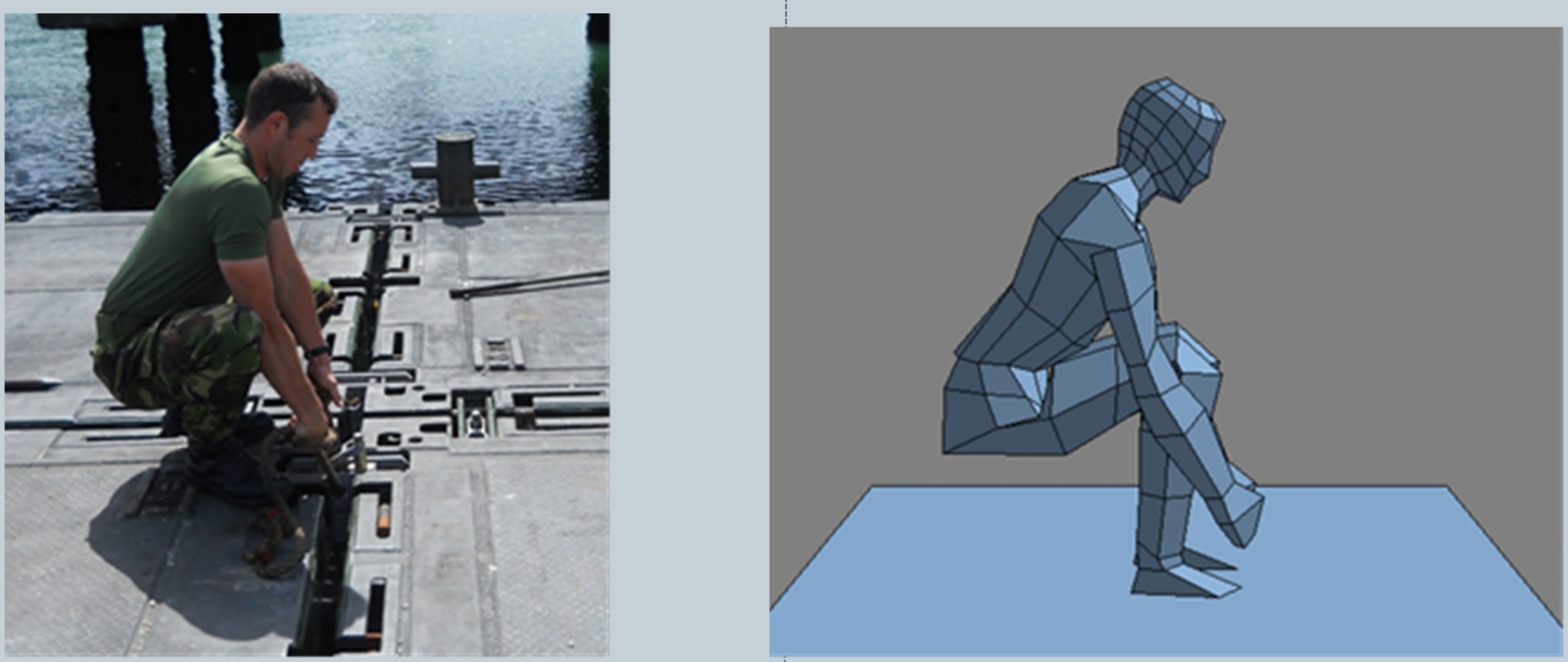
Problems Determining Work-Relatedness

- Mainly cross-sectional studies - can't make causal statements
- Outcomes measured as presence or absence of pain
- Exposure assessments are crude (e.g. job title)
- Lack of evidence of dose-response relationships
- An abundance of confounding variables
- Problems with risk factor epidemiology (plenty of evidence for "risk factors" but we still don't know what causes the disease).
- Odds ratios have enormous confidence intervals (e.g. 1.2-25)
- Possible solutions:
  - Large well-controlled studies across many different sectors
  - Small, tightly focused investigations of high risk areas with interventions and follow-up

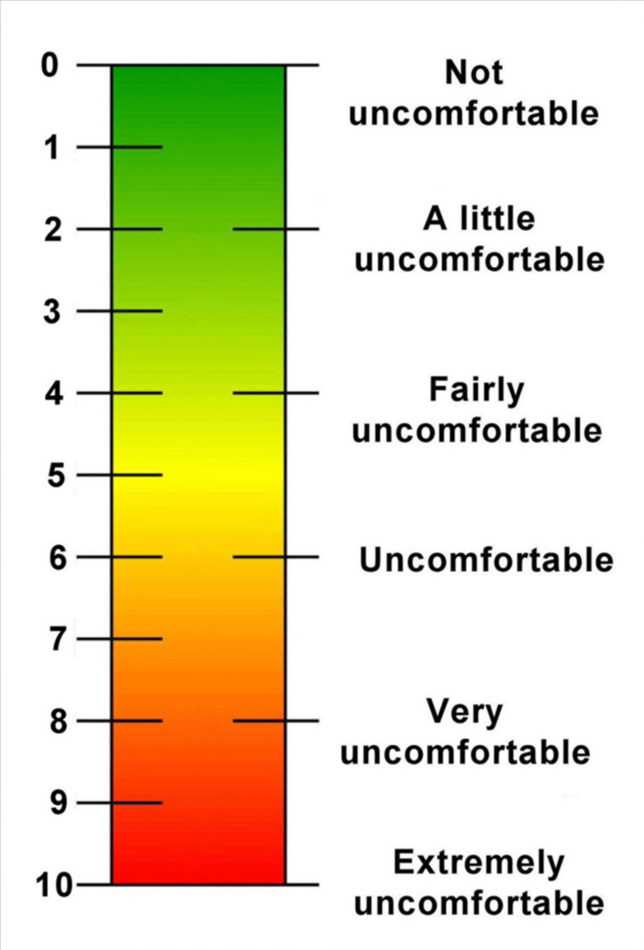
Risk Assessment

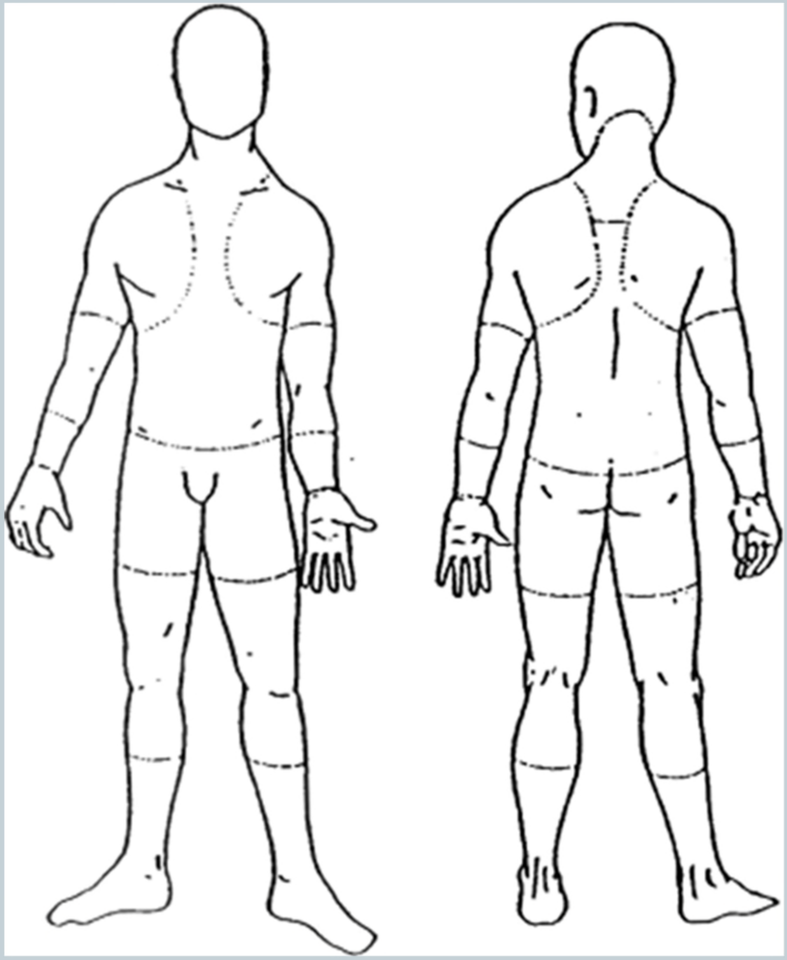
- Biomechanical Models (e.g. SSPP)
- NIOSH checklist
- Self reported regional discomfort

Figure 2.17



Body Diagrams





Summary

- Key characteristics for safe dynamic work:
  - Mechanical stability
  - Avoid fast movements
  - Damp high G forces
- Key characteristics of a good static posture
  - symmetry
  - an erect trunk
  - minimal static muscle activity
  - some kind of external support