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Ergonomic Impact of Spinal Loading and Recovery Positions on Intervertebral Disc Health: Strategies for Prevention and Management of Low Back Pain

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1. Introduction

According to the United States Department of Labor, over three million nonfatal injuries and illnesses occurred in private industry during the year 2009. Of these work related injuries 195,150 injuries involved the lumbar spine (U.S. Department of Labor, Bureau of Labor Statistics, 2009). The cost of work related low back injuries has been estimated to exceed 16 billion dollars. Low back pain accounts for an estimated 149 million lost work days per year. The estimated cost of this lost productivity is $28 billion (U.S. Department of Labor, Bureau of Labor Statistics, 2009). The costs in terms of medical care as well as lost productivity have brought the prevention of these injuries to the forefront in occupational medicine.

Management of low back pain, particularly work related injuries, is very controversial with numerous different treatment approaches ranging from osteopathic manipulations to work hardening programs. However, these strategies have been marked by many non-scientific interventions. A comprehensive understanding is essential for clinicians to implement effective evidence-based treatment and prevention. The purposes of this chapter are to (1) review the anatomical, biomechanical, and physiological mechanisms that contribute to the health of the lumbar spine with particular emphasis on the IVD, (2) consider mechanisms that may cause pain and dysfunction in the lumbar spine, and (3) present specific strategies for prevention and management of work related low back pain based on the biomechanical and physiological response of the lumbar IVD.

2. Intervertebral disc anatomy and physiology

The functional spinal unit consists of the two adjacent vertebral bodies, the IVD, and the adjoining ligaments and fascia that cross the segment. In comparison to the axial spine as a whole, the lumbar IVD to vertebral body ratio is the largest in the lumbar spine, approximately 1:3 ratio. Along with action of the iliopsoas muscle, it is the intervertebral disc height that accounts for the normal lordotic posture observed in the sagittal plane. The intervertebral disc provides resistance to compressive loads at the spine while simultaneously allowing very complex multi-planar movements to occur (Urban & Roberts, 2003). The intervertebral disc can be divided into three separate regions; anulus fibrosus, nucleus pulposus, and cartilaginous endplate (Sizer et al., 2001).

The annulus fibrosus forms the outer walls of the IVD. The annulus is considered fibrous cartilage and is comprised of predominantly type I collagen (Urban & Roberts, 2003). The fibers of the annulus are arranged in fifteen to twenty five concentric lamellae at approximately 60 degree angles from the vertical plane (Urban & Roberts, 2003). The annulus has three distinct zones. The outer third attached to the outer aspect of the adjacent vertebral bodies. The middle third directly attaches to the cortex of the vertebral body, while the inner third is confluent with the cartilaginous end-plate and creates a continuous envelope around the nucleus pulposus (Sizer et al. 2001). Innervation is only present in the outer third of the annulus in healthy intervertebral discs (Urban & Roberts, 2003). The posterior portion of the annulus is innervated by the sinuvertebral nerve while the anterior portion of the outer annulus receives sensory fibers through the paravertebral sympathetic trunks (Morinaga et al., 1996).

The nucleus pulposus is a gelatinous, highly hydrated structure comprised primarily of type II collagen and water binding proteoglycans. It is sandwiched between the cartilaginous endplate inferiorly and superiorly. The endplate is comprised of hyaline cartilage, and is the boundary between the vertebral body and the IVD.

2.1 Intervertebral disc nutrition

The intervertebral disc is primarily an avascular structure with the reported occurrence of blood vessels in the outer most anulus fibrosus being very rare (Crock & Goldwasser, 1984; Freemont et al., 1997). Without the presence of blood vessels the IVD is primarily dependent on diffusion for small solutes and fluid flow for larger protein molecules (McMillan et al., 1996). Nutrient diffusion into the IVD is linked to the cycle of lost water with compression and the in-flow of water with removal of loads (Sehgal & Fortin, 2000).

The intervertebral disc consists of a relatively small concentration of fibroblasts, which are the cells responsible for production of collagen and the proteins that comprise the extracellular matrix (Nordin & Frankel, 1989). All cells including fibroblasts utilize glucose and oxygen for energy, and produce waste products such as lactate. Selard and colleagues found that concentrations of oxygen and glucose, within the lumbar IVD, were lowest in the center of the nucleus pulposus (Selard et al., 2003). This was also the area where the highest level of lactate was found. This is presumably a result of the central nucleus being at the furthest point from the endplate vertebral body interface. These small oxygen and glucose molecules are primarily supplied to the nucleus pulposus via diffusion through the cartilaginous end plate (Holm et al., 1981; Rajasekaran et al., 2004). Rajasekaran and colleagues confirmed the primary role of the cartilaginous endplate with their in-vivo magnetic resonance imaging (MRI) study that documented the diffusion patterns of injected gadodiamide (Rajasekaran et al., 2004). Degeneration is a part of the normal aging process that all tissues experience, while IVD degradation is an acceleration of this process, and occurs under pathological conditions where the normal balance between nutrition and waste elimination fails. The delineation between degradation and normal age related degeneration is very difficult to categorize.

2.2 Normal aging in the lumbar intervertebral disc

The normal degenerative process that occurs in the IVD begins in the second decade of life when endplate vascularity gradually decreases to a complete absence of vascular tissue (Boos et al., 2002). This is a progressive process with peak degenerative alterations normally occurring between fifty and seventy years of age, with the degenerative process being largely influenced by genetic factors (Battié et al., 2009; Kalichman & Hunter, 2008). Several authors have reported altered IVD nutrition as being the primary catalyst for the age related degenerative process (Boos et al., 2002; Rajasekaran et al., 2004; Urban & McMullin, 1988). The loss of endplate vascularity beginning in the second decade substantially decreases diffusion of vital nutrients to the nucleus.

Degenerative changes at the cartilaginous end plate precede changes within the nucleus (Boos et al., 2002). These histological changes include disorganization of collagen fibers and mucoid degeneration. In addition, sclerosis of the vertebral body can also occur in advanced stages cartilaginous end plate degeneration. As previously stated, the cartilaginous endplate plays a primary role in the nutritional status of the IVD, and disruption of the endplate hastens the degenerative process. It has been suggested that a classification system based on endplate diffusion characteristics may be the most appropriate way of determining the differences between normal aging and pathological degradation (Rajasekaran et al., 2004).

The nucleus pulposus undergoes histological changes with degeneration as well. The nucleus becomes more fibrotic with increased disorganization of collagen fibers. The most critical change that occurs is a decrease in proteoglycan content (Urban & Roberts, 2003). Proteoglycans bind water and maintain the normal hydration levels of the nucleus. This decrease in proteoglycan content is reflected in the decreased hydration levels seen in degenerated IVDs (Urban & McMullin, 1988).

The morphological changes that occur in the annulus fibrosus during IVD degeneration include: radial fissures within the annulus, disassociation of lamellar fibers with resulting bulging (inward inner third and outward outer third), and mucoid degeneration (Adams et al., 2000). Another consequence of degeneration with important clinical implications is nerve in-growth into the inner two thirds of the annulus (Coppes et al., 1997). This further increases the possibility of pain generation from the IVD.

3. Lumbar intervertebral discogenic pain

The degenerative histological changes that occur in the annulus fibrosus are most frequently associated with discogenic pain (Adams et al., 1996; Edwards et al., 2001; Zhao et al., 2005). The results of proteoglycan content and decreased hydration within the nucleus pulposus is diminished load distribution (Buckwalter, 1995). Zhao and colleagues proposed IVD disc dehydration, and the resulting loss in segmental height, as being one of the possible causes of pain in degenerated discs (Zhao et al., 2005). They hypothesized that pain in dehydrated degenerative discs occurred as a result of increased stress concentrations within the nociceptive posterior annulus. Adams and colleagues found similar high stress peaks in the posterior annulus of degenerated IVD in their study of in-vitro IVD stress profiles (Adams et al., 1996). McNally and colleagues assessed in-vivo lumbar IVD disc stress profiles in patients undergoing provocative discography, and found that pain was predictive of abnormal posterior annulus stress concentrations and depressurized nucleus pulposus (McNally et al., 1996). These findings suggest that the loss of hydration and the loss of segmental height associated with lumbar IVD degeneration may be an important contributing factor in mechanical low back pain.

Although the origins of low back pain are widely debated and imaging has done little to clarify this debate, the IVD is the most common source of low back pain in adults (DePalma et al., 2011). There are imaging findings that are characteristic of IVD degeneration; however, these findings do not necessarily correlate with the symptoms associated with low back pain. Based on MRI findings, lumbar IVD herniation rates in asymptomatic populations have been found to be as high as 76%, (Boos et al., 1995). Deyo and colleagues estimated that 85% of individuals with low back pain may experience non-specific low back pain (Deyo et al., 1996). This indicates that the vast majority of individuals experiencing low back pain will not have any specific diagnostic imaging findings that explain their symptoms.

The Magnetic Resonance Imaging finding most associated with IVD degeneration is diminished nucleus signal intensity on T2 weighted images. In advanced stages of degeneration, narrowing of the IVD space can be observed on plane radiographs. High-intensity zones within the annulus fibrosus on T2 weighted MRI are associated with degenerative annular tears (Schmidt et al., 1998).

With the absence of definitive imaging to identify symptom related IVD degeneration, subjective and objective clinical findings can provide important information on the functional spinal unit. Cook and colleagues in a Delphi study of physical therapists reported common subjective and objective signs of non objectifiable instability (Cook et al., 2006). One of the consequences of IVD degeneration and diminished hydration is a reduction in segmental stability. Zhao and clleagues proposed IVD dehydration and resulting increases in stress concentrations in the posterior annulus as being one of the possible causes of pain in degenerated discs (Zhao et al., 2005). The subjective and objective findings associated with this diminished stability include: long history of intermittent back problems, complaints of “catching” sensations, transient neurological symptoms/deficits, experience of “twinges”, minor activities causing significant complaints, rotation causing sharp shooting pain, and pain with prolonged activities (Cook et al., 2006).

Loss in IVD height and hydration can result in decreased mechanical energy dissipation, radial IVD bulging, and increased zygapophyseal joint loading (Adams et al., 1990) Cinotti and colleagues reported diminished foraminal height with narrowing of the IVD space (Cinotti et al., 2002). They hypothesized that this loss in foraminal height, along with resulting buckling of the ligamentum flavum, may be the cause of the symptoms associated with foraminal stenosis.

4. Lumbar intervertebral disc loading and recovery postures

Throughout the course of the day, the Lumbar IVD demonstrate viscoelastic creep properties that determine the overall stature of an individual. Tyrrell and colleagues used in-vivo stadiometry measurements to detect 19.3 mm (1.1% of stature) variation in height between first arising and the end of the day (Tyrrell et al., 1985). Paajanen and colleagues using MRI to confirm the role of the intervertebral disc, reported similar results with subjects losing 13 and 21 mm of height during the day (Paajanen et al., 1994). Stadiometry and MRI are the two primary methods of measuring spinal height change following loading and recovery conditions. Stadiometry has been shown to be a valid and reliable clinical tool to assess spinal height when compared to quantifiable measures made from MRI (Kanlayanaphotporn et al., 2002; Kourtis et al., 2004; Owens et al., 2009; Pennell et al., 2012). Stadiometry assessment has advantages over MRI in terms of costs, use in clinical setting, as well as the ability to measure subjects that simultaneously sustain compressive loads of the trunk.

Several authors have assessed the ergonomic impact of work related spinal loading. Eklund and Corlett used stadiometry to assess the specific effects of work related postures and activities including types of office chairs and standing activities (Eklund & Corlett, 1984). Helander and colleagues used a stadiometer to compare changes in height following periods of prolonged sitting that were accompanied by either standing or walking rest breaks (Helander et al., 1990). Leivseth and Drerup, also measured spine height, to assess the impact of sustained sitting and standing work activities with greatest shrinkage occurring during work activities in standing (Leivseth & Drerup, 1997).

Static loading, particularly while sitting, has been associated with increased work related low back pain (Fryer et al., 2010). Knowledge of interventions and postures that can potentially offset these affects can have an important impact on treatment and prevention of work related low back pain. A primary focus of ergonomics research been on recovery positions designed to restore spinal height. Magnusson and colleagues reported greater height recovery following loaded sitting, with ten minutes of prone hyperextension lying when compared to prone lying in neutral (Magnusson et al. 1996). Additional studies have demonstrated that sustained supine flexion and sidelying flexion position also increase spine height following periods of seated loading. (Gerke et al., 2011; Owens et al., 2009).

5. Prevention and management strategies for low back pain in the workplace

Management of low back pain secondary to disc related disorders can be challenging for the patient and clinician. Providing appropriate ergonomic suggestions based on the biomechanics of the lumbar IVD can improve the tolerance to work. Ergonomic suggestions that aim to maintain an optimal amount of disc hydration while minimizing disc pressure will be discussed.

The sitting position is a common quandary for individuals experiencing back pain secondary to a disc related disorder. Sitting is generally not very well tolerated by an individual. However, the sitting position is difficult to avoid during travel to work. Sitting is also a common position adopted at work. Therefore, the sitting position should be carefully evaluated if there are discogenic symptoms.

Sitting position without support to the lumbar spine creates nearly 50 % increase in IVD pressure compared to sitting with lumbar support. Previous research by Wilke and colleagues demonstrated how various sitting positions can affect the pressure of the IVD (Wilke et al. 2001). Selecting a chair with back support is ideal for the person experiencing low back pain related to IVD pathology. In contrast, sitting on a stool or chair without adequate thoracolumbar back support can cause an increase in disc pressure as previously measured (Wilke et al., 2001). In many work settings, a specific back support may be suggested by a clinician. Location of the back support is often identified as a position of greatest comfort for the individual. A back rest in the thoracic spine may also be recommended if the goal is to bring more surface contact to the spine. As suggested by previous research, thoracic spine support decreased the amount of, thoracic spine support decreased the amount of intra-discal pressure in the lumbar spine (Wilke et al., 2001). In addition, it is important for individuals to have adequate foot support if the occupation requires a large amount of time in the sitting position. Proper foot support provides stability to the spine and decreases use of the abdominal muscles while in sitting. If the feet are unsupported, the weight of the legs can increase the lordosis creating an uneven stress distribution in the lumbar spine. In addition, tension from a tight iliopsoas muscle can also create the potential for more lordosis if the feet are unsupported in sitting.

When working with patients experiencing discogenic low back pain, it is also important for clinicians to consider the time of day as it relates to IVD hydration. Sleeping for greater than 6 hours will allow the IVD to imbibe fluid. As indicated previously, the amount of IVD hydration following a prolonged unloaded position such as sleeping can cause an increase in IVD pressure immediately after waking. The patient may feel stiffness in the lumbar region or difficulty standing up straight. After moving the trunk or walking for several minutes to a few hours, the stiffness may subside, allowing more freedom with movement. A creep response allows the disc to dehydrate. The IVD dehydration that occurs with moving and walking will decrease lumbar intradiscal pressure following a period of rest in supine or sidelying position. Therefore, a person may feel more comfortable with lumbar motion following activities that dehydrate the lumbar spine rather than immediately after waking. Lumbar range of motion may also increase after the lumbar intervertebral disc has been cautiously loaded for a brief period of time secondary to dehydrating the lumbar disc. Based on the increased hydration and increased IVD pressure associated with first arising in the morning, individuals with lumbar discogenic pain should avoid forward bending immediately after waking (Snook et al., 1998). Time should be allowed for the lumbar IVD pressure to decrease as a result of normal loading. In fact, it is advisable for the patient experiencing low back pain secondary to a lumbar IVD related disorder to be active in an upright position immediately after waking. In addition, the clinician may suggest gentle, pain free, repetitive lumbar range of motion to assist with dehydrating the lumbar disc before performing forward bending activities. As the day progresses, it may be safer to perform activities that involve a larger range of motion including flexion exercises (Table 1).

Lifting can also increase pressure in the IVD. If the integrity of the posterior annular fibers of the lumbar IVD’s are compromised, lifting will increase the load placed on the IVD. Therefore, heavy lifting soon after waking should be avoided. Lifting with loads close to the body will create a shorter external moment arm for the lumbar musculature. Lifting with loads further from the body creates a large external moment arm and subsequently requires the thoracolumbar extensors to contract with greater force. The increase in contraction by these thoracolumbar extensors will create an increase in IVD pressure to counter the external moment produced by the load anterior to the body. Hence, body mechanics instructions incorporate advice to keep external loads close to the body. Even small loads may produce a large increase in IVD pressure.

	Intervertebral Lumbar Disc Dehydration Activities	**Intervertebral Lumbar Disc Re-hydration Activities**
Types of activities	- Gravity activities Walking Jogging - Repetitive cyclic trunk motions (Figure 4 - 5) - Trunk & pelvic rotations - High frequency, low duration motions	-Gravity Eliminated activities Supine Sidelying Prone Reclined -Sustained positions -Trunk lateral flexion positions -Low frequency movement, longer duration motions
Treatment Intervention	- 3-dimensional axial separations with rotation oscillations in extension (Figure 6)	- 3-dimensional axial separation sustained with flexion side-bend (Figure 7)
Time of day for activities	Early in am or in the afternoon after lying for 10-15 minutes	Afternoon, evening

Table 1. Application of Intervertebral Lumbar Disc Dehydration Principles.

While it is important for the clinician to understand the importance of IVD dehydration for the younger individual with discogenic low back pain, the importance of IVD rehydration cannot be overlooked. Occasionally, a person with pain from the IVD may experience pain towards the end of the day. The research involving IVD hydration is ideal because many of the recovery positions can be easily adopted in the home environment. In addition, the focus of many research articles involving the change in spine height with hydration and dehydration positions has been to identify individualized patient education suggestion. The primary limitation of research related to IVD hydration is that changes in spine height have only been demonstrated for a short duration. Ongoing research should emphasize longitudinal trials with patients applying these techniques to determine the long-term efficacy of patient education. It would also be beneficial to evaluate the continued affects of IVD hydration positions on spine height, severity of symptoms and function over an extended period of time. Moreover, much of the research has been performed on young, healthy individuals. More research involving patients with known disc degeneration will allow greater generalizability.Supine flexed postures (Figure 1) have been shown to provide a similar hydration effect on the lumbar IVD (Owens et al., 2009). Other alternative recovery positions have been shown to facilitate hydration of the lumbar IVD (Figure 2 A & B) (Gerke et al. 2010). Gerke and colleagues found that 10-15 minutes in the sidelying position will also allow a temporary amount of lumbar IVD rehydration (Gerke et al. 2010). In summary, there are a variety of positions that can be utilized to rehydrate the lumbar IVD. Utilizing a supine or sidelying position may not be available in every occupation. However, choosing the most comfortable and convenient exercise or position before an increase in pain from the lumbar IVD is felt, may prolong the amount of time an employee can tolerate work without back pain.

Fig. 1. Sustained Supine Flexed Posture.

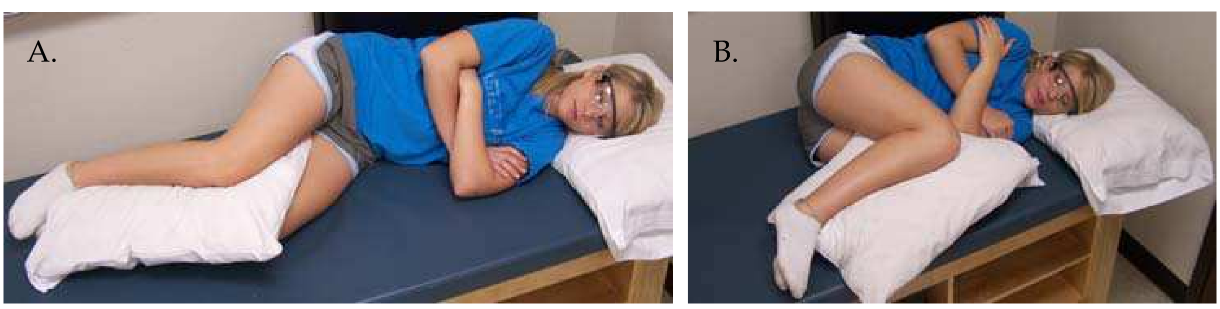

Fig. 2. A & B – Sustained Side-lying Flexed Postures.

Included in these recent findings is research performed on individuals suffering from low back pain related to nerve root compression syndrome. Simmerman and colleagues found that individuals performing aquatic traction (Figure 3) by hanging on pool noodles with 2.3 kg weight on each ankle demonstrated decreased pain as well as increased spinal height (Simmerman et al, 2011). The greatest impact that this line of research involving IVD hydration has had is that these recommendations and activities can be carried out in non clinical home based settings. Patient and individual education is the focus of this intervention strategy.

The primary limitation of research related to IVD hydration is that changes in spinal height have only been demonstrated for the short term. On- going research should emphasize longitudinal trials with subjects/patients applying these techniques to find out the efficacy of education and application over prolonged periods of time on spinal height change, symptoms and function.

Fig. 3. Aquatic Traction.

5.1 Considerations for the injured employee

Employees are often provided light duty work options. It can be common for an employee with discogenic low back pain secondary to a repetitive lifting injury or a one-time episode of excessive lifting to receive light duty restrictions which allows a more rapid return to work. In some scenarios, the employee is often counseled to perform tasks that are perceived to be easier because the task is completed in a sitting position. However, as previously mentioned, a seated position increases lumbar IVD pressure. Frequent interruptions from the seated position would allow a change in the stress distribution of body weight. Wilke et al. found that standing positions could be a better alternative than prolonged sitting (Wilke et al., 2001). While an employee may be removed from heavy lifting loads that compromised the lumbar IVD, the seated tasks could be limited in duration and recommendations for an unloading exercise or position could also used between seated tasks. Limiting the duration of sitting to 30 minutes may be beneficial to the patient experiencing pain from discogenic low back pain.

Advising employees regarding their sleeping habits can also help return the injured employee to work more comfortably. As previously discussed, the pressure in the lumbar IVD increases each hour of rest as the disc imbibes fluid. Therefore, it may be wise to prevent the lumbar IVD from absorbing water in the unloaded positions during sleep. Sleeping a shorter duration of time can be helpful to prevent the lumbar IVD from imbibing fluid and increasing pressure. In addition, activity after multiple hours of rest may also improve the exchange of waste products and nutrition. Employees on light duty may be encouraged to walk throughout the day. In most scenarios, walking can be therapeutic for an employee experiencing discogenic low back pain. Cyclic loading such as walking has been shown to diminish the effects of lumbar disc dehydration. However, according to Sizer and colleagues, pain with walking may be secondary to the attachment of the ligaments of Hoffman to the posterior fibers of the lumbar IVD (Sizer et al., 2002). These fibers can be loaded with tension from the sciatic nerve through hip flexion, knee extension and ankle dorsiflexion (Gilbert et al., 2007). These lower extremity positions can tension the sciatic nerve as often experienced while walking. Hip flexion can be diminished with shorter steps. If walking is an activity that provokes symptoms, ambulating with shorter steps should be considered when the employee notices discomfort.

In summary, to promote optimal nutrition of the lumbar intervertebral disc, repetitive activities such as walking should be encourage in the early morning to dehydrate the disc, while sitting with support or reclined or lying is more advisable by mid and end of the day to re-hydrate the disc. Frequent short breaks from static loaded working positions are advised at least every couple of hours to stimulate fluid diffusion throughout the disc (Trinkoff et al., 2006). Counseling employees with discogenic low back can be challenging. Simple recommendations such as avoiding bending or lifting early in the morning may have a significant impact on an individual's recovery.

Fig. 4. Repetitive Extension in Prone.

Fig. 5. Repetitive Extension in Prone.

Fig. 6. 3-Dimensional Axial Separation with Rotation Oscillations in Extension.

Fig. 7. 3-Dimensional Axial Separation Sustained with Flexion and Side-bending.

6. Conclusion

Low back pain has a negative financial and medical burden on society, with an estimated 80% of individuals experiencing an acute episode of low back pain at some period in their lives. Chronic low back pain is the leading cause of work-related disability for individuals under the age of forty five (Buckwalter, 1995). It is critical for healthcare professionals to have knowledge of the anatomical and biomechanical contributions to low back pain. Identifying a specific structural cause of low back pain, despite the controversy that exists, is critical for prevention and management strategies. The lumbar IVD is the primary biomechanical restraint of motion at the vertebral segment, and has been shown to play a primary role in low back pain. Intervention strategies that influence the hydration of the lumbar IVD can play beneficial role in the management of work related low back pain.. An evidenced based approach that considers these factors can be helpful in the management of work related low back pain.

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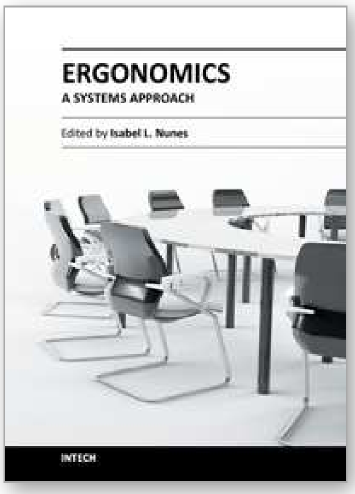

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This book covers multiple topics of Ergonomics following a systems approach, analysing the relationships between workers and their work environment from different but complementary standpoints. The chapters focused on Physical Ergonomics address the topics upper and lower limbs as well as low back musculoskeletal disorders and some methodologies and tools that can be used to tackle them. The organizational aspects of work are the subject of a chapter that discusses how dynamic, flexible and reconfigurable assembly systems can adequately respond to changes in the market. The chapters focused on Human-Computer Interaction discuss the topics of Usability, User-Centred Design and User Experience Design presenting framework concepts for the usability engineering life cycle aiming to improve the user-system interaction, for instance of automated control systems. Cognitive Ergonomics is addressed in the book discussing the critical thinking skills and how people engage in cognitive work.