Low Back Pain in Construction Workers

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Introduction

This document is a summary of an extensive review conducted into low back pain (LBP) in construction workers. It Includes research from sports medicine, - where postural, muscular and training factors have many parallel applications. Through personal observations and growing research evidence, it is apparent that an increasingly sedentary lifestyle is a significant risk factor for LBP. Muscle strength and endurance, low back posture, and the ability of the spine to withstand loads, are all very much influenced by static postures adopted over significant periods of the day.

The construction industry constitutes a substantial part of the workforce of most developed countries. In Australia, up to 15% of the male workforce, and around 3% of the female workforce, is employed in construction and related trades (Australian Bureau of Statistics). 88% of Australian construction workers are male.

This review contains many findings that it is hoped will assist in efforts to decrease low back injuries in construction workers. It emphasises the importance of training and preventative interventions. For workers new to the trade, the following findings are of particular relevance:

- Younger workers are often more prone to low back injury (LBI) due to endurance factors, less efficient work strategies, and postural influences.
- Workers who develop LBP often have 'poor movement strategies' that make them vulnerable to injury
- Evidence shows younger and inexperienced workers may be more 'trainable' in correct lifting and handling techniques, as they can be targeted before bad habits and injuries become established.

Injury mechanisms are analysed, and it is proposed that most attention in the industry needs to be focused on the effects of sustained and repetitive bending, and stresses due to lifting and lowering. The research shows that standard advice and instruction on lifting and handling techniques is often inadequate and incorrect. This article challenges the widely promoted advice to "bend the knees and not the back".

One of the recommended preventative interventions is the correct prescription of exercise. While pre-work stretching programmes are becoming more popular in the workplace, most are still based on out-dated & ineffective principles. The following evidence provided, and warm-up recommended, is for a work-specific and 'body-readiness' training intervention. There is also discussion of the benefits of a specific end-of-day stretching and exercise routine.

List of Abbreviations: LBP – low back pain; LBI – low back injury; MSK – musculoskeletal.

Contents

Anatomy of the Lumbar Spine

The spine is made up of a series of bones, called *vertebrae*. There are five vertebrae in the lower back region known as the *lumbar spine* (Figure 1). At the front of each vertebra is a solid circular block of bone called the *vertebral body*. The vertebral bodies are stacked one-on-top of the other, with a cushioning disc in-between, known as the *intervertebral disc* (see more on this below). At the back of each vertebra are bony projections which form joints. These are the *zygapophyseal joints*, often called 'facet' or 'Z' joints. The discs and Z joints guide and allow movement between each vertebra. The shape of the Z joints determines how much, and in which direction movement occurs. In the lumbar spine they allow quite a lot of bending from front to back, and a moderate amount from side to side. However they allow very little twisting - only 1° to 2° in each direction [1,15]. At the very rear of each vertebra is a bone projecting backwards, known as a *spinous process*. These are the bones you feel when you run your fingers along your spine. Each vertebra is connected to those above and below by an extensive network of *ligaments*. Ligaments join bone to bone, and hold joints together. All the vertebrae connected together make up the spine. The spine serves three main functions: 1. To bear load and transfer it between the legs and upper body; 2. To allow movement; 3. To contain and protect the spinal cord and nerves. The spinal cord runs through the *spinal canal*, directly behind each vertebral body. The lumbar *spinal nerves* extend out in pairs between each vertebrae, and form networks of nerves that spread throughout the lower body.

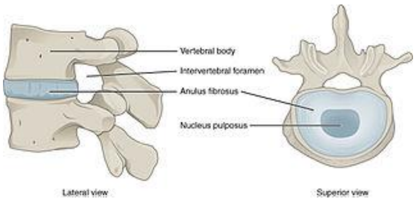

Fig. 1: Side and top view of lumbar spine
Image from Wikipedia

Looking at the spine from above, the discs appear circular, matching the shape of the vertebral bodies. Each disc has an outer 'shell', made up of layers of collagen fibres. This is known as the *annulus fibrosus,* or 'annulus'. The layers of collagen are arranged so that their fibres are directed in an alternate diagonal pattern, as seen in the diagram (Figure 2). The annulus resists bending movements, and in this way acts like a ligament [1,2,15]. The annulus at the back of the disc is thinner than in other regions, so not as strong [1,15]. Deeper within the disc is a gel-like substance, known as the *nucleus pulposus*, or 'nucleus'. This has the consistency of soft chewing gum. The disc functions as a shock absorber (transferring and decelerating loads between vertebrae), and as a joint that provides a pivot point for movement.

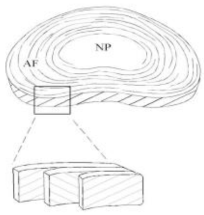

Fig. 2: Disc from above.
AF – annulus fibrosus;
NP – nucleus pulposus

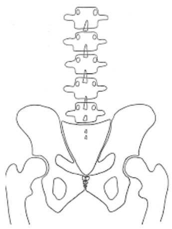

Fig. 3: Basic view of lumbar spine, pelvis & hips

The *thoracic spine* and ribs are connected above the lumbar spine. This region serves to transfer forces from the arms and upper body through the spine and pelvis, to support and protect internal organs, to allow effective breathing, and to enhance movement through the entire spine. Below the lumbar spine, the vertebrae are supported on the *sacrum* and *pelvis* (Figure 3). This region transfers loads between the legs and upper body. When working correctly, the hips, pelvis and spine produce coordinated and efficient movement. This helps to minimise stress on muscles and joints, and maximise transfer of forces throughout the entire locomotor system of the body.

Causes and Types of Low Back Injuries

Injury Mechanisms & Risk Factors

While a precipitating 'event' may often be described as a cause of LBP, it is important to be aware that most back injuries do not occur due to a single event. In the majority of cases, repeated or sustained positions and activities over many hours, day after day, make the low back more prone to injury [27,41,71].

General Risk Factors

Work Related Factors

Risk factors for low back injury (LBI) include frequent and sustained bending and twisting, static postures, sedentary occupations, lifting, rapid bending or twisting, excessive force or speed of movement, awkward postures, pushing and pulling, repetitive work, high work intensity, exposure to whole body vibration, and balance loss when the back is under load [1,4,6,17,40,41,50,51,53,60,71,73,80,86]. Injury may also result from sudden, unexpected movements or extra loading, or loads that move unpredictably [31,83,84]. Up to 12% of injuries have been attributed to a sudden loading event [83]. High volumes of spinal loading in a mid to end range bent positions is a particular risk factor in industry [17,18,23,67,81]. Maintaining or adopting a twisted spinal posture was found to be problematic if conducted for any greater than 10% of the work day [59]. Working while in pain was ranked highly by workers as a contributing factor [50]. In apprentice construction workers, 36% of injuries were related to either prolonged static positions or bending / twisting movements [85]. Careers involving driving a motor vehicle or machine excavator were also reported as high risk [97,130].

Individual Risk Factors

These include:

- Strength factors. The endurance capacity of the muscles in the lower back varies from person to person [15]. A lack of endurance was shown to be a risk factor for first-time back injury [13,14,57,76,97,118].
- Sedentary habits and lack of physical activity levels outside of work were shown to increase the risk of developing LBP [57]. There is mounting evidence that lack of flexibility, inefficient postures and poor movement techniques may contribute to LBP [18,23,67]. In particular, the movement of forward bending should be shared equally between the back and hip joints [18,57,89,91,94,129]. However many workers who develop LBP bend early and excessively into the back. Poor flexibility of the hips or hamstrings may contribute to this [18,129]. There is research evidence that static postures (such as sitting) influence how the person moves during dynamic tasks like lifting [87,97]. A study of apprentice construction workers showed that those who adopted sedentary postures outside of work had a three times greater risk for developing work-related LBP [85].
- Other individual factors which may have an effect on LBP development include general health, personality, psychological factors, beliefs, societal and cultural influences, and language [41].

Time Factors

The back is particularly vulnerable during the first one to two hours after rising from bed. This is partly because the tissues of the back are 'cold'. But more importantly, it is because there is significantly greater pressure and stiffness in the discs of our spine in the morning [1,2,38,71]. The discs absorb water during the night, and this is gradually squeezed out when we are upright during the day. Bending stresses in the morning can be up to 300% greater in the discs [71,112], and 80% greater in the ligaments, compared to later in the day [71].

Age

Younger workers. There are certain factors that make younger workers more prone to LBI. It has been found that during repeated bending and lifting tasks, a younger or inexperienced worker will adopt a posture involving greater flexion (bending), placing the spine in a more vulnerable position [16,81]. As well as adopting more harmful bending positions, younger workers tended to lack the adaptation strategies used by older workers which help to 'share the load' and minimise stress under different lifting tasks [16]. There is some evidence that younger workers have reduced low back muscle endurance compared to older workers [16].

Older workers. There is a gradual reduction in spinal range of motions after 30 years of age for males and 40 years for females [61]. This increase in stiffness, plus complex biochemical changes within the spinal tissues, has led some authors to speculate that increasing age is a risk factor for LBI in the workforce [16,85,86,92,117,121]. It has been suggested that the trend for an increased incidence of musculoskeletal (MSK) in industry, is in part attributable to the ageing workforce [92]. After 60 years of age, the spine has been found to be capable of bearing only approximately 66% of the loads manageable by younger spines [71]. It was found that an injury in an older worker was more likely to be severe, to lead to greater time off work, and be more costly to manage [16].

Sex

When matched for age and weight, there is evidence that the female spine can withstand around 66% of the load of the male spine [71].

Sustained Bending as a Risk Factor

While lifting is usually cited as the main cause of LBI in manual workers, this assumption may ignore significant risk factors preceding the lifting injury. The impact of sustained and repetitive bending should never be underestimated. Through progressive weakening of supportive tissues, and potential for increased disc protrusion, excessive bending creates a back that is vulnerable to injury in a range of even innocuous situations. Hazards associated with working bent forward are regularly quoted in the literature [4,26,59,81]. Lifting with a bent back after repeated or sustained bending will be particularly risky [121]. Working in extreme flexion was problematic if repeated for any more than 5% of the work day [59]. Some of the more important reasons bending is a major risk factor are described below:

- Spinal tissues (particularly the supporting ligaments and discs) are known to gradually stretch out under sustained load, - a phenomenon known as 'creep' [1,4,62,105]. This places the tissues at risk from end range or sudden movements [1,105]. The disc is more likely to be stretched beyond its bending limit [1], and discs take a greater brunt of the load after sustained bending [45]. After 5 minutes of full bending, the resistance of the tissues can be reduced by up to 42% [1]. After 30 minutes of bending, two minutes of upright recovery will only restore 50% of the resilience of the tissues [71]. In some instances, full recovery can take several hours or longer [113]. In contrast, spinal tissues recover rapidly from cyclic loading of shorter duration, which allows periodic recovery of normal tissue function [117]. It is not surprising that work that involves varied loads and positions had the lowest injury risk [71].
- End range bending of the spine places the muscles on full stretch, which leads to temporary muscle weakness or 'deactivation' [1,62,91,105]. This is known as *muscle inhibition*. Following a period of bending, inhibition can last for several minutes or even hours after the back returns to upright [62,113]. During this period, the spine is not being adequately protected by its muscles, potentially making it unstable [1,28,62,71].

- Intramuscular pressure is increased with bending, which leads to an inhibition of blood flow [81].
- The lever arm that the back muscles impose on the spine in reduced by up to 20% in full forward bending, making the muscles less effective in this position [8,15,81,82].
- Cyclic end-range loading leads to progressive weakening of spinal tissues, as it does throughout the rest of the body [37,45]. Experiments have shown that over 30 times more repetitions of movement can be withstood by spinal tissues loaded at mid-range, compared to end of range positions [45,81].

Lifting and Lowering

Lifting has consistently been reported as the major cause of LBI [8,56,119,121]. Lifting and bending was said to account for 33% [8] to 60% [31] of all work related LBP. 50% of acute back injuries were thought to be related to excessive or incorrect lifting [41]. Overall, 80% of all lifting related injuries were LBIs [31,56]. More specifically, lifting while twisting or bent sideways is a significant risk factor [26,50]. Reaching further than 25cm to lift was also described as an important risk factor [6], as was any lifting from the ground [108].

One study found 52% of manual materials handling activities involved lowering of weights [65], and it has been suggested this could be an equal or greater risk factor to lifting [31]. Lifting on unstable surfaces, and not having a solid two handed grip were other potential risk factors [6], as was excessive lifting speed [4].

Due to the complex and varied nature of lifting tasks, actual static load quantities for lifting are no longer specified. Past guidelines suggested 20 to 23kg as being the recommended maximum [6]. However, among many other factors, this did not take into account the effects of fatigue loading [45], which can dramatically lessen the weight that can be lifted safely. See below for a detailed description of lifting recommendations.

Pushing & Pulling

Due to ergonomic changes in industry, a lot of bending tasks are being replaced by pushing and pulling tasks, which may account for 50% of manual handling activities [67]. Up to 20% of industry LBP may be related to pushing or pulling manoeuvres [67].

Types of Injuries in Construction Workers

General Low Back Injuries

Structures that are prone to injury in the lower back include bones, joints, muscles, ligaments, and the intervertebral discs (see more on disc injury below). Bones are most vulnerable from compressive and backward bending loads [4,15,60,71]. Joints are most vulnerable from backward bending and twisting [1,4,15,60]. Ligaments are vulnerable to being over-stretched [4].

Disc Injuries

Disc injuries are thought to be the most significant spinal tissue injury resulting from bending and lifting-related causes [30,71,72]. The main types of disc injury are:

- An annular sprain or tear, where the ligament-like outer fibres of the disc are partially torn.

- More substantial progressive or sudden injury to the fibres of the annulus, that allows the inner nucleus to 'squeeze outwards'. This can result in a disc bulge, known as a *protrusion* or *herniation*. A large herniation is sometimes called a *prolapse*.
- A compression injury, with or without spinal bending, can damage the *vertebral endplate*, a ring of cartilage that separates the disc from the vertebral body.

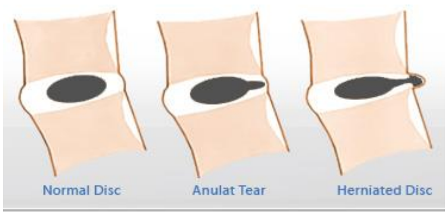

Fig. 4. Progression of disc 'bulging'

Disc injuries are known to result from activities that involve repeated or sustained bending [2,4,30,45,71], particularly when under a compressive or twisting load [1,4,71,72]. When the back is bent forward, the support from the bony joints is lessened, making the disc particularly vulnerable to side bending and twisting motions [1,4,17,60,80]. The fibres of the disc are much less tolerant to load in this position [80], a reason most herniations occur *posterolaterally* (to the back and one side of the disc) [4]. If a large load is carried, even a small amount of bending can lead to injury [1]. Repetitive full bending forwards-and-backward is also a potential risk factor [3,11,21]. In young people, healthy discs that are loaded dangerously are often at greater risk of developing a herniation compared to older more degenerative discs [21,112].

Non-Back Related Injuries

Analysis of injuries to areas other than the lower back is beyond the scope of this review. Briefly, after LBI the next most common areas of the body to be injured were the shoulders, neck, knees, wrists / hands, and elbows [6,25,50,52,85,120]. In some cases neck pain or injury resulted in higher health care costs and absenteeism than LBP (50). Some important factors leading to injury included:

Shoulder and Neck

Working overhead, i.e. with the arms above shoulder height, or looking upwards [26,86].

Knees

Kneeling and crouching [6,26]. This includes repetitive squat-lifting (see the section on lifting, below).

Wrists / Hands

Twisting, gripping, poorly designed tools and handles, and vibration forces [6,40.41].

Epidemiology of LBP

LBP in the General Population

The lifetime prevalence of LBP is consistently reported as being 80% [31,103,119]. It affects around 10% of the worlds' population at any point in time [114]. LBP is the most common reason for activity limitation in those under 45 years of age [31,41,70]. It is the primary health problem affecting quality of life [41]. 13% of all sick days in the UK, and 19% in Sweden, were due to LBP [51]. The incidence of LBP continues to rise [31,92]. Over the past 10 years in the US, while the percentage of disability has decreased for circulatory disorders (11.8% to 9.6%) and respiratory conditions (3.6% to 3.1%) it has increased for MSK injuries (20.6% to 25.4%), particularly LBP [132]. Currently, LBP is the third most frequent cause of disability behind arthritis and heart disease [31]. In the US 20%, and in Europe 40% of the population will suffer from LBP over the course of a year [31]. Of all MSK injuries, 20% were to the low back [30]. Also, 20% [56] to 25% [69] of all work-related, and 33% [56] to 40% [69] of all compensable injuries were to the low back. It was the second most common reason to visit a doctor, the fifth most frequent reason for hospital admission, and the third most common reason to require surgery [103]. In Australia in 1994, LBP cost the economy an estimated $400 million, with a workers compensation bill of $300 million [31]. In the US the corresponding cost was $15 to $30 billion [31]. Two per cent of the US workforce is compensated each year due to LBI [51].

LBP in Construction

While the lifetime incidence of LBP is reported at 80% for the general population, it was reported as 90% in construction [97]. In US construction in 1999, the incidence of LBI was said to be 50% higher than for all other industries [6]. In US manual handling jobs, 80% of work injuries were to the low back [31,65]. In injury surveys, 70% of workers reported LBP [6], 60% to 66% had suffered from LBP in the previous 12 months [41,50], and over 30% had experienced LBP during the previous week [50]. LBI accounted for 29% of all injuries in highway construction [26] and 25% across all industries [41]. In apprentice workers, 54.4% reported injuries to the lower back, for which 16.8% had consulted a physician, and 7.3% had missed work days during the previous year [85]. 23% of older workers required a physician visit for their LBP [6], In the US in the 1980's, 25% of all compensatory injuries were to the low back [24]. It was the main reason for work absenteeism [41] and the most common reason for early retirement [50,51].

For general construction related injuries, 82% of those surveyed had suffered at least one MSK injury, and the incidence of lost workdays from non-fatal injuries was highest for construction [50]. Construction accounted for 10 of the top 25 sectors requiring interventions for MSK injuries [6]. In Sweden, 72% of sick leave of over 4 weeks duration was due to MSK injury, with 54% due to LBI. MSK injuries in construction were 41.5 per 1000 workers, compared to 35.4 for other industries [54]. In apprentice construction workers, 76.8% reported MSK symptoms [85].

Prevention & Management

Workplace Training

Surveys have indicated that up to 91% of workers want information and training on health and safety, the nature of injury, lifting and handling methods, exercise programmes, and they also want better access to health services at the workplace [41,51,130].

Education

Back Care Principles

There is a great deal of advice that can be given to workers to assist them in preventing and managing LBP:

- Workers should be advised to look out for warning signs of damage: These include 'spasms' in the lower back muscles [113], and aches and pains that don't settle, particularly after a nights' rest [6]. Over-stretching the back muscles is sometimes associated with minor to moderate 'back spasms,' that may be a sign of impending or actual damage [62,91,113].
- Exercises and postural changes throughout the day can minimise and partially reverse the stresses imposed on the back [73,41,99]. In one study, mini-breaks were found to significantly reduce MSK discomfort levels [73]. After bending, some time spent standing, walking, and even performing back arching exercises can help with recovery of tissue function, and to reverse unhealthy pressures within the disc [11,71]. These exercises should be conducted frequently, particularly after sustained bending [99].

- Because it is known that spinal tissues can take several hours to recover after prolonged bending, this has implications for job design [71]. Variation and regular change of position is recommended. This could be assisted by rotating workers through different jobs.
- Avoid unduly loading the back at times when it is known to be vulnerable, such as the first part of the morning, after a long drive, or after repeated or sustained bending [71,112]. In one study, minimising early morning bending was shown to have a significantly beneficial effect on low back symptoms [112].

Advice on How to Manage Back Injuries

Workers should be given advice on how to manage their back if an injury occurs. Injuries can often be prevented from becoming serious if processes are put in place when symptoms are still mild [86]. When an acute injury occurs, management over the first few days is often critical, and can prevent an injury becoming chronic. As the mechanics of lumbar spine injury is extremely complex, workers with LBP often need a great deal of guidance and monitoring [86]. The role of on-the-job observation and management in improving recovery has not been described, and could be an important area of future research.

Training

Training to improve skills, along with health and safety, is often sadly lacking in the construction industry. In the US bricklaying industry, only 11% of surveyed workers had undergone apprentice training [50,51], and only 14% of these felt the training was adequate for the job [51]. Others reported training techniques were not applicable to what they did at work [130]. While 69% of surveyed construction companies in the US provided a lifting education programme [26], studies have shown that skills and safety procedures taught during training are rarely carried through to the workplace [24,30,70,76,130], and that the goals of training are often not achieved [9,30,44,70,76,103,121]. This could be for a number of reasons, including: a) questionable methods of training [24,30,44,70,121], such as basing manual handling training on teaching the squat lift (see section on Lifting & Handling) [24]; b) difficulty breaking pre-established methods and habits [24,70]; c) fast pace of the worksite [24]; or d) the benefits of training for one task are not transferrable to other tasks [30,43].

For learning to be effective, participants need to: a) know why the information is relevant to them; b) understand the reasons for change; c) have the motivation to make changes; d), take an active involvement in the learning process; and e) be provided with ongoing re-evaluation [108]. What is also required is a multidimensional approach to training [30], providing job-specific instruction in the work environment [24,70], and preferably providing all of this while workers are still young [70]. The eventual aim is to stimulate effective subconscious learning [24,35,70].

Studies on 'body mechanics' training (teaching efficient movement and body awareness), lifting techniques training, and manual handling instruction, are reported below. This training should address the body positions which place the back at greatest risk – sustained flexion, lifting / lowering, excessive reaching & twisting, and sudden maximal effort [70]. Body awareness includes making the worker conscious of where 'end-range' spinal positions are, so they can minimise or avoid these [97]. In a study of apprentice workers, a body mechanics instruction programme was found to be effective in the short-term [70]. In a study of adult manual workers, a 3 to 6 week lifting programme (using the 'semi-squat' technique – see below) was progressed to gradually more intense lifting, and to functional work tasks such as shovelling, mattocking, and digging [108]. The authors reported excellent results and no injuries among the 69 trainees [108]. Another study on lifting and handling training, reported excellent results on improving strength, endurance, and lifting technique [69]. Repetition of training is considered an essential aspect of successful learning [24]. Skills and knowledge should be developed to help workers cope with, and problem-solve through, difficult job-specific situations [70]. Ongoing training for several weeks, with regular observation and feedback, is required for lasting benefit [108,121]. This should help to overcome the lack of transferability of training through to workplace utilisation. Body mechanics instruction needs to be situation dependent [69] and constantly updated.

One intended aim of lifting and handling training should be to teach the worker to stabilise the spine to prevent unwanted movement, while generating mobility and power through the legs and hips. This is based on sound research and training methods [28,71]. Research from elite sporting populations, and analysis of expert versus novice, or injury-resistant versus injury-prone manual handlers, reveals complex but useful information [29,43,44,67,71,131]. This includes evidence regarding: a) effective use of the legs to spare the back [29,67,71]; b) variations in techniques to minimise or take advantage of leverage and joint forces [44]; c) efficient push / pull strategies [67,71]; and d) practice of efficient postures and basic movements which can be transferred back to improving dynamic movements [97].

Lifting and Handling

The literature on the 'correct' lifting technique is controversial [8,12,53,65]. The advice of 'bend the knees and keep the back straight to lift' has been endorsed for at least 70 years [24,35]. In a recent study, 80% to 90% of experts in health and physical fitness promoted this advice, even though most had reservations about doing so [108]. What is interesting is that Davis et al questioned this advice 50 years ago[35], yet it is still the most common recommendation for lifting. Figure 5 shows a typical diagrammatic representation of this lift as recommended in industry[6]. This is known as the 'squat' or 'knee' lift, as opposed to the 'stoop' or 'back' lift where the knees are straight and the back bends. The advice on squat lifting is often provided with the disclaimer that this technique may only be effective with small, light loads [40]. However this advice has been found to be questionable for the vast majority of lifting situations. This is for the following reasons:

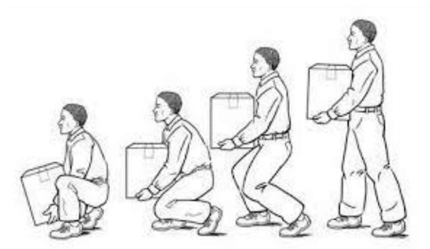

Fig. 5: The squat-lift. From. From *Simple Solutions – Ergonomics for Construction Workers* [6]

- Investigations have found that a very small percentage of lifts can be performed this way [8,9,31,37,56,79,107,108,121].
- Clinical observation and research evidence shows that people bend their backs as much, or sometimes more, when squatting to lift [26,37,38,56,72,82]. In Figure 6, the image on the left shows how excessive lower back bending can occur with squat lifting [82].
- Squat lifting from the ground was found to be impossible without substantial low back bending [38].
- Injury risks were similar for squat compared to stoop lifting [26].
- Both expert and novice lifters converted from a squat to more upright lifting style with repeated lifting, or when weights became heavier [24,31,35,60,105,107,121].
- The quadriceps (front thigh muscles that straighten the knees) do not have the strength or endurance capacity to perform repeated squat lifts [35,53,107].

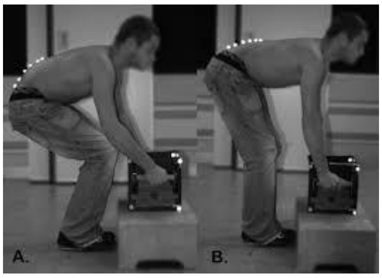

Fig. 6. From *Mawston & Boocock 2012*

- Squat lifting results in the subject consuming more oxygen, and is reported as significantly more tiring [8,9,53,60,115,121].
- The long-leverage and mechanical advantage afforded by using the hip and thigh muscles is significantly lost when the hips drop below the knees [60].
- The lift is more likely to be off-balance, and require the load to be further away from the lifter's centre of gravity with squat lifting [9,37,53]. This can increase lower back compressive forces by up to 50% [31].
- The squat lift was found to be a difficult technique to teach [115].

While most research on lifting style has focused on squat as opposed to stoop lifting, many experts are more likely to advocate the 'freestyle' or 'semi-squat' lifting method. This is a combination of the two techniques described above. (See Sedgwick & Gormley, 1998 for an illustration comparing the three lifting styles [108]). If performed correctly, a semi-squat lift should ensure that neither the back nor knees bend excessively. It has the following advantages:

- It employs the much larger and more powerful hip and posterior thigh muscles [15,118].
- Unlike squat lifting, the semi-squat technique is said to be easy to teach [108].
- The centre of mass of the body is already raised, so has less distance to travel [53,107].
- When instructed to use the technique most comfortable, workers invariably choose the semi-squat lift [8,31,35,107]. In particular, elite weightlifters use this way of lifting [1,8,71].
- Older and more experienced workers were found to lift this way [9,16,24,43,44].

In reality, the lifting style adopted will depend on many factors that will vary between each situation and individual [12,15,44]. It may be unrealistic to teach a specific 'technique' [44,108], although in one study training of the semi-squat lift was found to assist safe performance of other strenuous activities [108]. Regardless, experts in health and movement should consider incorporating aspects of the following into workplace training interventions: body awareness, movement skill acquisition [44], efficient use of the feet [9,43] and hips [71], correct shoulder positioning relative to the ground [43], training muscle and nervous system 'preparedness' for sudden or unexpected loads [83], and the appropriate use of asymmetrical positions [31,44]. Proficient use of body weight [71], leverage [44] and directing forces through the centre of gravity of the body [71], are aspects displayed by expert compared to novice workers [67]. What may be more important than the actual lift style, is attention to the posture adopted by the low back [8,28,71,82], and the distance of the load from the body [15]. One author felt too much attention was paid to the back, and not enough to efficient use of the rest of the body, particularly the legs [44].

Workplace Interventions

Pre-Work Exercise Programmes

Stretching

Stretching programmes have become increasingly popular in industry. In US construction companies, 47% had introduced a pre-work stretching programme [26]. However there has been no evidence that stretching improves performance or helps to prevent injury. There is, however, overwhelming evidence that a dynamic or active warm-up is more appropriate and effective (see below).

Job-Specific Dynamic Warm-up

This information is based on a separate literature review I completed on dynamic warm-up versus stretching. More information, and the reference list is available on request.

As with much of the research for this article, the evidence presented is based on the latest findings in professional sport as well as industry. Many, if not most sports, continue to incorporate a static stretching programme into their pre-match or pre-training warm-up. There is growing evidence that this is ineffective for injury prevention and performance (Choi & Rajendran 2014; Kendall 2011; Lewis 2014; Sim et al 2009; Troumbley 2010). Static stretching is also potentially harmful when used as part of a warm-up, as it has been shown to decrease performance & body 'preparedness' (Chan et al 2012; Fletcher 2011; Sim et al 2009; Troumbley 2010; Weerapong 2005). Even if a dynamic warm-up is performed first, and then followed by stretching, the benefits of the warm-up may be lost or reversed (Sim et al 2009). The best warm-up gets the body ready for what will be required during the activity to follow. This entails increasing the temperature of muscles and joints, enhancing muscle reaction time and the ability to generate power quickly, and well as 'waking-up' the nervous system. The best approach to achieving these requirements is a dynamic warm-up that prepares the mind and body for the strenuous demands to follow (Sim et al 2009; Troumbley 2010; Weerapong 2005). The warm-up should train the brain and nervous system as much as the muscles, and practicing correct body movements helps to establish healthy techniques for the complex work movements ahead.

Future Directions

Musculoskeletal Screening

In professional sport, due to the strenuous nature of competition, and high injury rates encountered, pre-season musculoskeletal screening is used extensively. The chief aim of this is to identify risk factors, and modify them to prevent injury. Arguably, workers in construction engage in more strenuous day to day activities than many professional sportspeople. In an ideal environment, new trainees in construction would be screened before they begin regular heavy work, to identify pertinent risk factors. Many of these have been discussed in previous sections. Factors particularly relevant include muscle endurance levels, flexibility through the back, hips and hamstrings, and analysis of postures and movement patterns adopted during bending, lifting and other manual tasks [23]. The advantage screening would provide to the worker is that it would allow an individual assessment of what areas of prevention, flexibility and fitness they most need to concentrate on. This would hopefully give them further motivation and direction to assist their development into an 'industrial athlete'. I have conducted a literature review of musculoskeletal screening in various sports, and have developed a protocol for screening workers in industry.

After-Work Exercise for Injury Prevention

Improved muscle strength and endurance are protective against LBI [13,14,23,33,46,57,76,118]. Exercise and stretching programmes have been found to be effective in improving flexibility and muscle endurance, both in workers and athletes [23,26,73,97]. In one study of 'expert' manual materials handlers, an exercise programme brought about a 76% increase in strength levels [46]. There were also significant improvements in flexibility, and dramatic reductions in levels of perceived exertion [46]. For the type of sustained work and effort required by workers in construction, training in aerobic capacity, strength, power and endurance would be highly desirable [108]. This would incorporate training the 'core' to ensure the muscles of the trunk can control unwanted movement, while the muscles of the hips and thighs are trained to provide both mobility and power to movement [60]. Flexibility training may be particularly relevant for older workers, as after the fourth decade of life flexibility is known to progressively decrease with age [61,117]. Research has not yet investigated whether this loss of flexibility is reversible, but regular work-supervised end of day stretching would provide an excellent environment and opportunity for improvement [61].

On-site Monitoring and Physical Interventions

Observational studies have been conducted to predict the stresses on construction workers, and analyse the movements and postures common to particular manual tasks. The problem with most of these studies is that they are limited to specific tasks and short-duration surveillance. They are not an accurate representation of the dynamics of the job over several hours [55]. There would be tremendous advantages for training facilities or construction companies to employ on-site expert health and safety personnel. Getting to know and to observe workers and processes over an extended period, would provide much more information, and allow evolution of a continually improving injury prevention system. Risks would become more apparent with time, and could be prioritised and addressed in order. Workers would be observed, and any displaying 'pain behaviours' could be identified [40], often before they even acknowledge they are in pain. Such health personnel could provide on-the-spot management, give advice about any task modification strategies that may be required, and give consistent and reliable advice on injury management and exercises.

Ergonomic Interventions

A comprehensive discussion of ergonomic interventions is beyond the scope of this review. This area has been studied widely. While early reports were encouraging, later results have been equivocal. In one systematic review, ergonomic interventions were not found to be any more effective than no intervention in preventing back and neck pain [39]. The results of ergonomic changes and interventions will obviously be dependent on many factors, and will vary greatly from site to site. Interventions in this area will continue to adapt as new knowledge, equipment and procedures become available.

Summary

This article summarises the findings of a review into low back pain in the construction industry. The prevalence of LBP in this sector is higher than in all other surveyed areas of the workforce. The mechanisms and risks relating to LBP were explored, and the main conclusions were:

- Certain individual risk factors can make some workers more vulnerable to LBI compared to others. Training can help to modify these risk factors.
- There is evidence that developmental and experiential factors can influence the occurrence of LBP in young compared to older workers. Some factors make younger workers more vulnerable, however it is also theorised that these workers have a greater scope to respond favourably to training interventions.
- Lifting is widely reported as the major contributing factor to LBI. It is argued, however that sustained and repetitive flexion may be the main contributing factor for many workers with LBP. The pathophysiological changes brought about by this common industrial posture can increase spinal vulnerability to injury from lifting and other back-loading tasks.
- The advice to "bend the knees, not the back" is challenged.

An analysis was made of the evidence relating to workplace training interventions and prevention programmes. It is argued that such programmes have often failed to provide adequate or appropriate training. While there is still a lot of research needed in this area, improved knowledge of lifting techniques and efficient body mechanics factors can provide guidance to health workers, industry managers, and workers, to help them to continue to develop ever improving methods of injury prevention.

References

1. Adams, M & Dolan, P (2007). How to use the spine, pelvis, and legs effectively in lifting. In Vleeming, A et al (eds). Movement, Stability and Lumbopelvic Pain (2nd ed). Churchill Livingstone Elsevier, UK, 167-183.
2. Adams, M et al (1994). The strength in anterior bending of lumbar intervertebral discs. Spine, 19, 19, 2197-2203.
3. Adams, M et al (1988). The lumbar spine in backward bending. Spine, 13, 9, 1019-1026.
4. Adams, M & Hutton, C (1982). Prolapsed intervertebral disc – a hyperflexion injury. Spine, 7, 3, 184-191.
5. Adams, M & Hutton, C (1981). The relevance of torsion to the mechanical derangement of the lumbar spine. Spine, 6, 241-248.
6. Albers, T & Estill, C (2007). Simple Solution – ergonomics for construction workers. NIOSH, Department of Health and Human Servises, Centre for Disease Control & Prevention. http://www.cdc.gov/niosh/docs/2007-122/pdfs/2007-122.pdf
7. American Conference of Governmental Industrial Hygienists (ACHIH) Threshold Limit for Lifting Value (TLV). http://www.washingtonsafepatienthandling.org/images/acgih_lifitng_tlv.pdf
8. Arjmand, N & Shirazi-Adl, A. (2005). Biomechanics of changes in lumbar posture in static lifting. Spine, 30, 23, 2637-2648.
9. Authier, M et al (1996). Manual handling techniques: comparing novices and experts. International Journal of Industrial Ergonomics, 17, 419-429.
10. Bakker, E et al (2007). Spinal mechanical load: a predictor of persistent low back pain? A prospective cohort study. European Spine Journal, 16, 933-941.
11. Balkovec, C & McGill, S (2012). Extent of nucleus pulposus migration in the annulus of porcine intervertebral discs exposed to cyclic flexion only versus cyclic flexion and extension. Clinical Biomechanics, 27, 766-770.
12. Bazrgari, B. et al (2007). Analysis of squat and stoop dynamic lifting: muscle forces and internal spinal loads. European Spine Journal, 16, 687-699.
13. Biering-Sorensen, F (1984). Physical measures as risk indicators for low back trouble over a one-year period. Spine, 9, 2, 106-119.
14. Biering-Sorensen, F (1983). A prospective study of low back pain in a general population I. Occurrence, recurrence, and aetiology. Scandinavian Journal of Rehabilitation Medicine, 15, 2, 71-79.
15. Bogduk, N (2012). Clinical and Radiological Anatomy of the Lumbar Spine, 5th ed. Churchill Livingstone Elsevier.
16. Boocock, M et al (2015). Age-related differences do affect postural kinematics and joint kinetics during repetitive lifting. Clinical Biomechanics, 30, 136-143.
17. Burnett, A et al (2008). Lower lumbar spine axial rotation is reduced in end-range sagittal posture. Manual Therapy, 13, 300-306.
18. Burnett, A et al (2004). Spinal kinematics and trunk muscle activity in cyclists: a comparison between healthy controls and non-specific chronic low back pain subjects – a pilot investigation. Manual Therapy, 9, 211-219.
19. Cable, J (2007). Don't strain yourself. Occupational Hazards, 36-41.
20. Caldwell, J et al (2003). The effects of repetitive motion on lumbar flexion and erector spinae muscle activity in rowers. Clinical Biomechanics, 18, 704-711.
21. Callaghan, J & McGill, S (2001). Intervertebral disc herniation: studies on a porcine model exposed to highly repetitive flexion/extension motion with compressive force. Clinical Biomechanics, 16, 28-37.
22. Campbell, A et al (2013). Back pain in tennis players: a link with lumbar serve kinematics and range of motion. Medicine and Science in Sports and Exercise, Epub.
23. Caneiro, J et al (2013). Cognitive functional therapy for the management of low back pain in an adolescent male rower: a case report. Journal of Orthopaedic and Sports Physical Therapy, 43, 8, 542-554.
24. Carlton, R (1987). The effects of body mechanics instruction on work performance. American Journal of Occupational Medicine, 41, 16-20.
25. Choi, S et al (2014). Critical analysis of work-related musculoskeletal disorders and practical solutions in construction. Proceedings of the 58th Annual Human Factors and Ergonomics Society, 1633-1637.
26. Choi, S (2012). A study of trade-specific occupational ergonomics considerations in the U.S. construction industry. Work, 42, 215-222.
27. Choi, S & Rajendran, S (2014). Construction workers perception of stretch and flex program effectiveness in preventing work-related musculoskeletal disorders. Proceedings of the XXVI Annual Occupational Ergonomics & Safety Conference, El Paso, Tx, 19-25.
28. Chowewicki, J & McGill, S (1992). Lumbar posterior ligament involvement during extremely heavy lifts estimated from fluoroscopic measurements. Journal of Biomechanics, 25, 1, 17-28.
29. Chowewicki, J et al (1991). Lumbar spine loads during the lifting of extremely heavy weights. Medicine and Science in Sports and Exercise, 23, 10, 1179-1186.
30. Clemes, S et al (2010). What constitutes effective manual handling training? A systematic review. Occupational Medicine, 60, 101-107.
31. Cole, M & Grimshaw, P (2003). Low back pain and lifting- a review of epidemiology and aetiology. Work, 21, 2, 173-184.
32. Cook, et al (2003). Symptoms of musculoskeletal disorders among apprentice construction workers. Applied Occupational & Environmental Hygiene, 18, 1, 57-64. [?summarised]
33. da Costa, B & Vieira, E (2008). Stretching to reduce work-related musculoskeletal disorders: a systematic review. Journal of Rehabilitation Medicine, 40, 321-328.
34. Dale, A et al (2012). Using process evaluation to determine effectiveness of participatory ergonomics training interventions in construction. Work, 41, 3824-3826.
35. Davis, P. et al (1965). Movements of the thoracic and lumbar spines when lifting: a chrono-cyclophographic study. Journal of Anatomy, 99, 1, 13-26.
36. Descarreaux, M et al (2010). Changes in flexion-relaxation response induced by hip extensor and erector spinae muscle fatigue. BMC Musculoskeletal Disorders, 11, 112.

37. Dolan, P et al (1994a). Bending and compressive stresses acting on the lumbar spine during lifting activities. Journal of Biomechanics, 27, 10, 1237-1248. [?summarised / where is it]
38. Dolan, P et al (1994b) Passive tissues help the back muscles to generate extensor moments during lifting. Journal of Biomechanics, 27, 8, 1077-1085.
39. Driessen, M et al (2010). The effectiveness of physical and organisational ergonomic interventions on low back and neck pain: a systematic review. Occupational and Environmental Medicine, 67, 277-285.
40. Ergonomic Guidelines for Manual Materials Handling, (2007). NIOSH, Cincinnati. California Dept. of Industrial Relations. Publication No 2007-131. http://www.cdc.gov/niosh/docs/2007-131/pdfs/2007-131.pdf
41. Ergonomics Manual for Mason Tenders, (2000). N.Y. State Laborers Health & Safety Trust Fund. The Occupational & Industrial Orthopaedic Centre, N.Y. http://www.lhsfna.org/LHSFNA/assets/File/PDF/Ergonomics%20Manual%20for%20Mason%20Tenders.pdf
42. Frost, D et al (2012). Is there a low-back cost to hip-centric exercise? Quantifying the lumbar spine joint compression and shear forces during movements used to overload the hips. Journal of Sports Sciences, 30, 9, 859-870.
43. Gagnon, M (2005). Ergonomic identification and biomechanical evaluation of workers strategies and their validation in a training situation: Summary of research. Clinical Biomechanics, 20, 6, 569-580. [?summarised]
44. Gagnon, M (2003). The efficacy of training for three manual handling strategies based on the observation of expert and novice workers. Clinical Biomechanics, 18, 601-611.
45. Gallagher, S et al (2005). Torso flexion loads and the fatigue failure of human lumbosacral motion segments. Spine, 30, 20, 2265-2273.
46. Genaidy, A et al (1994). Effects of a job-simulated exercise programme on employees performing manual handling operations. Ergonomics, 37, 95-106. [showed good+ results in strength, endurance, flexibility, but didn't look at injury rate. On file, not printed]
47. Gerling, M & Brown, S (2013). Architectural analysis and predicted functional capacity of the human latissimus dorsi muscle. Journal of Anatomy, 223, 2, 112-122.
48. Gill, K et al (2007). Regional changes in spine posture at lift onset with changes in lift distance and lift style. Spine, 32, 15, 1599-1604.
49. Goldsheyder, D et al (2015) Prevention of work-related musculoskeletal disorders in construction laborers. ResearchGate. https://www.researchgate.net/publication/228729827_Prevention_of_work-related_musculoskeletal_disorders_in_construction_laborers
50. Goldsheyder, D et al (2004). Musculoskeletal symptom survey among cement and concrete workers. Work, 23, 111-121. [?Summarised]
51. Goldsheyder, D et al (2002) Prevention of work-related musculoskeletal disorders in construction laborers. Occupational & Industrial Orthopaedic Centre (OIOC).
52. Hazardous Manual Tasks Code of Practice. (2011). Safe Work Australia. http://www.safework.sa.gov.au/uploaded_files/CoPHazardousManualTasks.pdf
53. Heiss, D et al (2002). Balance loss wen lifting a heavier than expected load: effects of lifting technique. Archives of Physical Medicine and Rehabilitation, 83, 48-59. [? Summary / article]
54. Hess, J et al (2010). Ergonomic best practice in masonry: regional differences, benefits, barriers, and recommendations for dissemination. Journal of Occupational and Environmental Hygiene, 7, 446-455.
55. Hess, J et al (2004). A participatory ergonomics intervention to reduce risk factors for low back disorders in concrete laborers. Applied Ergonomics, 35, 427-441.
56. Holder, L (2013). The effect of lumbar posture and pelvis fixation on back extensor torque and paravertebral muscle activation. Thesis: Auckland University of Technology, Faculty of Health and Environmental Sciences.
57. Holmstrom, E & Ahlborg, B (2005). Morning warming-up exercise – effects on musculoskeletal fitness in construction workers. Applied Ergonomics, 36, 513-519.
58. Holmstrom, E et al (1992). Low back and neck/shoulder pain in construction workers: occupational workload and psychological risk factors. Part 2: relationship to neck and shoulder pain. Spine, 17, 6, 672-677.
59. Hoogendoom, W et al (2000). Flexion and rotation of the trunk and lifting at work are risk factors for low back pain – results of a prospective cohort study. Spine, 25, 23,3087-3092.
60. Hsiang, S et al (1997). Low back pain and lifting technique – a review. International Journal of Industrial Ergonomics, 19, 59-74.
61. Intolo, P et al (2009). The effect of age on lumbar range of motion: a systematic review. Manual Therapy, 14, 596-604.
62. Jackson, M et al (2001).Multifidus EMG and tension-relaxation recovery after prolonged static lumbar flexion. Spine, 26, 7, 715-723.
63. [Jam, B (2005). The neurophysiological effects of the creep phenomenon and its relation to mechanical low back pain.]
64. Johnson, E et al (2010). Effect of hamstring flexibility on hip and lumbar spine joint excursions during forward-reaching tasks in participants with and without low back pain. Archives of Physical Medicine and Rehabilitation, 91, 1140-1142.
65. Lariviere, C et al (2002). A biomechanical comparison of lifting techniques between subjects with and without chronic low back pain during freestyle lifting and lowering tasks. Clinical Biomechanics, 17, 89-98.
66. Lee, R & Wong, J (2002). Relationship between the movements of the lumbar spine and hip. Human Movement Science, 21, 481-494.
67. Lett, K and McGill, S (2006). Pushing and pulling: personal mechanics influence spine loads. Ergonomics, 49, 9, 895-908.
68. Li, Y et al (1996). The effect of hamstring muscle stretching on standing posture and on lumbar and hip motions during forward bending. Physical Therapy, 76, 836-845.
69. Lieber, S (2000) Effects of body mechanics training on performance of repetitive lifting. The American Journal of Occupational Therapy, 54, 2, 166-175.
70. McCauley, M (1990). The effects of body mechanics instruction on work performance among young workers. American Journal of Occupational Therapy, 44, 5, 402-407.
71. McGill, S (2007). Low back disorders – Evidence based prevention and rehabilitation (2nd ed). Human Kinetics, Champaign, Il.

72. McGill, S (1997). The biomechanics of low back injury: implications on current practice in industry and the clinic. Journal of Biomechanics, 30, 463-475. [quoted in Mawston & Boocock 2012, as showing squat lift can → LS F+. Check it].- hhaven't finished
73. McGorry, R & Courtney, T (2006). Worksite exercise programmes - are they an effective control for musculoskeletal disorders of the upper extremities? Professional Safety, 51, 4, 25-30.
74. McGregor, A & Hikins, D. (2009). Lower limb involvement in spinal function and low back pain. Journal of Back and Musculoskeletal Rehabilitation, 22, 219-222.
75. Machado, L et al (2006). The McKenzie method for low back pain: a systematic review of the literature with a meta-analysis approach. Spine, 31, 9, E254-E262.
76. Maher, C (2000). A systematic review of workplace interventions to prevent low back pain. Australian Journal of Physiotherapy, 46, 259-269.
77. Marras, W et al (2000). Prospective validation of a low back disorder risk model and assessment of ergonomic interventions associated with manual material handling tasks. Ergonomics, 43, 11, 1866-1886.
78. Marras, W et al (1995). Biomechanical risk factors for occupationally related low back disorders. Ergonomics, 38, 2, 377-410. [digital, 35 pp, NS. Print 2-6; 24-30]
79. Marras, W et al (1993a). Quantification and classification of low back disorders based on trunk motion. European Journal of Physical Medicine and Rehabilitation, 3, 218-235.
80. Marras, W et al (1993b). The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders – the effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. Spine, 18, 5, 617-628.
81. Mawston, G & Boocock, M (2015). Lumbar posture biomechanics and its influence on the functional anatomy of the erector spinae and multifidus. Physical Therapy Reviews, 20, 3, 178-186.
82. Mawston, G & Boocock, M (2012). The effect of lumbar posture on spinal loading and the function of the erector spinae: implications for exercise and vocational rehabilitation. New Zealand Journal of Physiotherapy, 40, 3, 135-140.
83. Mawston, G et al (2007). The effects of prior exposure, warning, and initial standing posture on muscular and kinematic responses to sudden loading of a hand-held box. Clinical Biomechanics, 22, 275-281.
84. Mawston, G et al (2007). The effects of prior warning and lifting-induced fatigue on trunk muscle and postural responses to sudden loading during manual handling. Ergonomics, 50, 12, 2157-2170. [not finished]
85. Merlino, L et al (2003). Symptoms of musculoskeletal disorders among apprentice construction workers. Applied Occupational and Environmental Hygiene, 18, 1, 57-54.
86. Minna, S & Mika, N (2012). Relationship between construction workers musculoskeletal disorders and occupational health service activities. Work, 41, 3753-3756.
87. Mitchell, T. et al (2008). Regional differences in lumbar spinal posture and the influence of low back pain. BMC Musculoskeletal Disorders, 9, 152.
88. Moreside, J and McGill, S (2012). Hip joint range of motion improvements using three different interventions. Journal of Strength and Conditioning Research, 26, 5, 1265-1273.
89. Nelson, J et al (1995). Relative lumbar and pelvic motion during loaded spinal flexion / extension. Spine, 20, 2, 199-204. . Journal of Strength and Conditioning Research, 27, 10, 2635-2643.
90. Moreside, J and McGill, S (2013). Improvements in hip flexibility do not transfer to mobility in functional movement patterns.
91. Olson, M & Solomonow, M (2004). Flexion-relaxation response to cyclic lumbar flexion. Clinical Biomechanics, 19, 769-776.
92. Oude Hengel, K et al (2011). Intervention mapping as a framework for developing an intervention at the worksite for older construction workers. American Journal of Health Promotion, 26, 1, e1-e10.
93. Nelson, J et al (1995). Relative lumbar and pelvic motion during loaded spinal flexion/extension. Spine, 20, 2, 199-204.
94. Pal, P et al (2007). Hip and lumbar continuous motion characteristics during flexion and return in healthy young males. European Spine Journal, 16, 741-747.
95. Parkinson, S et al (2013). Upper and lower lumbar segments move differently during sit to stand. Manual Therapy, 18, 390-394.
96. Parreira, P et al (2015). Can patients identify what triggers their back pain? Secondary analysis of a case-crossover study. Pain, ePub ahead of print.
97. Perich, D et al (2011). Low back pain in female adolescent rowers: a multi-dimensional intervention study. Knee Surgery, Sports Traumatology & Arthroscopy, 19, 1, 20-29.
98. Potvin, J et al (1991). Trunk muscle and lumbar ligament contributions to dynamic lifts with varying degrees of trunk flexion. Spine, 16, 9, 1099-1107.
99. Preventing Musculoskeletal Disorders in Construction Workers (1999). Electronic Library of Construction Occupational Safety & Health. Occupational Safety and Health Administration. US Dept of Labor. http://elcosh.org/document/1648/d000560/preventing-muskuloskeletal-disorders-in-construction-workers.html
100. Prevention of Musculoskeletal Disorders in the Workplace. United States Department of Lobor. https://www.osha.gov/SLTC/ergonomics/
101. Riihimaki, H et al (1989). Low back pain and occupation: a cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work. Spine, 14, 2, 204-209.
102. Roehrig, M (2011). Stretching: an easy solution to a growing problem. Construction Executive, p34. http://old.constructionexec.com/Issues/October_2011/Special_Section3.aspx.
103. Roffey, D et al (2010). Causal assessment of workplace manual handling or assisting patients and low back pain: results of a systematic review. The Spine Journal, 10, 629-651.
104. Sahrmann, S (2002). Diagnosis & Treatment of Movement Impairment Syndromes. Mosby, Missouri.
105. Sanchez-Zuriaga, D et al (2010). Is activation of the back muscles impaired by creep or muscle fatigue? Spine, 35, 5, 517-525.

106. Safe Work Australia: Hazardous Manual Tasks Code of Practice, Dec. 2011. http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/640/COP_Hazardous_Manual_Tasks.pdf
107. Schipplein, O et al (1990). Relationship between moments at the L5/S1 level, hip and knee joint when lifting. Journal of Biomechanics, 23, 9, 907-912.
108. Sedgwick, A & Gormley, J (1998). Training for lifting; an unresolved ergonomic issue. Applied Ergonomics, 29, 5, 395-398.
109. Shum, G et al (2010). Back pain is associated with changes in loading pattern throughout forward and back ward bending. Spine, 35, 25, E1472-E1478.
110. Simon, J et al (2014). Discogenic low back pain. Physical Medicine and Rehabilitation Clinics of North America, 25, 305-317. [haven't finished summarising]
111. Smith, D et al (2011). The effect of lumbar extension training with and without pelvic stabilisation on lumbar strength and low back pain. Journal of Back and Musculoskeletal Rehabilitation, 24, 4, 241-249.
112. Snook, S et al (2002). The reduction of chronic, nonspecific low back pain through the control of early morning lumbar flexion: 3 year follow-up. Journal of Occupational Rehabilitation, 12, 1, 13-19.
113. Solomonow, M et al (2003). Flexion-relaxation response to static lumbar flexion in males and females. Clinical Biomechanics, 18, 273-279.
114. Steffens, D et al (2015). What triggers an episode of acute low back pain? A case-crossover study. Arthritis Care and Research, 67, 3, 403-410.
115. Straker, L & Duncan, P (2000). Psychophysical and psychological comparison of squat and stoop lifting by young females. Australian Journal of Physiotherapy, 46, 27-32.
116. Thomas, J & France, C (2008). The relationship between pain related fear and lumbar flexion during natural recovery from low back pain. European Spine Journal, 17, 97-103.
117. Twomey, L & Taylor, J (1982). Flexion creep deformation and hysteresis in the lumbar vertebral column. Spine, 7, 2, 116-12.
118. Udermann, B et al (1999). Pelvic restraint effect on lumbar gluteal and hamstring muscle electromyographic activation. Archives of Physical Medicine and Rehabilitation, 80, 428-431.
119. Vakos, J et al (1994). Electromyographic activity of selected trunk and hip muscles during a squat lift: effect of varying the lumbar posture. Spine, 19, 6, 687-695.
120. Van der Molen, H et al (2005). Implementation of participatory ergonomics intervention in construction companies. Scandinavian Journal of Work and Environmental Health, 31, 3, 191-204.
121. van Dieen, J. et al (1999). Stoop or squat: a review of biomechanical studies on lifting technique. Clinical Biomechanics, 15, 685-696.
122. van Wingerden, J et al (2004). Stabilization of the sacroiliac joint in vivo: verification of muscular contribution to force closure of the pelvis. European Spine Journal, 13, 3, 199-205.
123. Visser, S et al (2014). Guidance strategies for a participatory ergonomic intervention to increase the use of ergonomic measures of workers in construction companies: a study design of a randomised trial. BMC Musculoskeletal Disorders, 15, 132.
124. Vleeming, A., et al (1995). The posterior layer of the thoracolumbar fascia – its function in load transfer from spine to legs. Spine, 20, 7, 753-758.
125. Waters, T et al (1994). Applications Manual for the Revised NIOSH Lifting Equation. US Dept of Health & Public Services.
126. Waters, T et al (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics, 36, 7, 749-776.
127. Weinstein, M, et al (2005). Can design improve construction safety?: Assessing the impact of a collaborative safety in design process. Journal of Construction Engineering and Management, 131, 1125-1134. [? Summary/article]
128. Wingerden, J-P et al (2008). Differences in standing and forward bending in women with chronic low back pain or pelvic girdle pain. Spine, 33, 11, E334-E341.
129. Wong, T & Lee, R (2004). Effects of low back pain on the relationship between the movements of the lumbar spine and hip. Human Movement Science, 23, 21-34.
130. Wright, E & Haslam, R (1999). Manual handling risks and controls in a soft-drinks distribution centre. Applied Ergonomics, 30, 311-318. [quoted by Clemes et al 2010 – showing T'g isn't carried through in workplace practices] –do have it ? digital
131. Wrigley, A et al (2005). Differentiating lifting technique between those who develop low back pain and those who do not. Clinical Biomechanics, 20, 254-263.
132. Deyo, R et al (2009). Overtreating chronic back pain: time to back off? Journal of the American Borad of Family Medicine, 22, 1, 62-68.