Low Back Pain in Construction Workers

Paul Monaro, Musculoskeletal & Sports Physiotherapist, MAPA, MMPA, MSPA.
Contact: info@cssphysio.com.au Further Information: www.cssphysio.com.au

Introduction

This document is a summary of an extensive review conducted into low back pain (LBP) in construction workers. 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. The incidence of LBP in construction workers was found to be 50% higher than for all other industries [6].

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, inefficient 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. Alternatives are recommended. There is also a brief discussion of possible future directions in injury prevention.

Contents

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 spine 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:

- Lumbar spine muscle endurance. 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 [18,23,67,18,57,89,91,94,129]. There is research evidence that static postures (such as sitting) influence how the person moves during dynamic tasks like lifting [87,97].
- 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 mainly due to increased hydrostatic disc pressure and stiffness [1,2,38,71]. 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, placing the spine in a more vulnerable position [16,81]. In addition, 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 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, as well as 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 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].

Sustained Bending

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. Sustained and repetitive bending is often the major precipitating factor to LBI. Through progressive weakening of supportive tissues, and potential for increased disc pathology, 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 day [59].

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].

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 lumbar spine include bones, joints, muscles, ligaments, and the intervertebral discs (see more on disc injury below). Bones are most vulnerable from compressive and extension loads [4,15,60,71]. Joints are most vulnerable from extension bending and twisting [1,4,15,60]. Ligaments are particularly vulnerable in flexion and rotation [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.
- More substantial progressive or sudden injury to the fibres of the annulus, resulting in disc *herniation or prolapse*.
- A compression injury, with or without spinal flexion, resulting in damage to the *vertebral endplate*.

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* [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].

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 in construction workers 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 include:

Shoulder and Neck

Working overhead, 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]. 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%) [132]. Currently, LBP is the third most frequent cause of disability behind arthritis and heart disease [31].

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] In apprentice workers, 54.4% reported injuries to the low back, for which 16.8% had consulted a physician, and 7.3% had missed work days during the previous year [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, including 'spasms' in the lower back muscles [113], and aches and pains that don't settle, particularly after a nights' rest [6].
- 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].
- 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.
- Advice to 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].

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]. After acute injury, correct management over the first few days is often critical, and can help to prevent an injury becoming chronic. As the mechanics of lumbar spine injury are extremely complex, workers with LBP often need a great deal of guidance and monitoring [86].

Training

Training to improve skills, along with health and safety, is often cursory or entirely lacking in the construction industry. In US bricklayers, 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 [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].

Studies on 'body mechanics' training, 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 injurious end-range spinal positions [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]. Body mechanics instruction needs to be situation dependent [69] and constantly updated.

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' 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]. In fact, squat lifting has been found to be impractical for the vast majority of lifting situations [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 6A, excessive lumbar flexion is seen with a squat lift technique [82]. 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. If performed correctly, a semi-squat lift should ensure that neither the back nor knees bend excessively (Fig 6B). 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] .

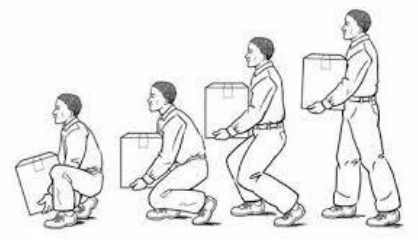

Fig. 5: The squat-lift. From. From *Simple Solutions – Ergonomics for Construction Workers, NIOSH* [6]

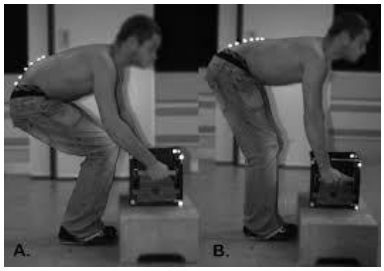

Fig. 6. Knee or squat lift (A) and a form of 'semi-squat' lift (B). With permission, *Mawston & Boocock 2012, NZ J Physio* [82]

Workplace Interventions

Pre-Work Exercise Programmes

Stretching

Stretching programmes have become increasingly popular in industry. In a 2012 study of 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.

Job-Specific Dynamic Warm-up

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 [27,143,144,149,153]. Static stretching is also potentially harmful when used as part of a warm-up, as it has been shown to decrease performance & body 'preparedness' [135,138,149,153,154] . 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 [149,153,154].

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 these 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. Those particularly relevant include muscle endurance levels, flexibility through the back, hips and thighs, and analysis of postures and movement patterns adopted during bending, lifting and other manual tasks [23]. The author has undertaken a recent screening examination of novice construction trainees, and the results will be available in the near future.

After-Work Exercise for Injury Prevention

One construction training facility in Sydney is currently trialling and end-of-day strength and flexibility programme. This has been designed based on research, clinical experience of the author, and recent MSK screening results. 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 [23,26,46,73,97]. 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].

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:

- Individual risk factors can make certain workers more vulnerable to LBI compared to others. Training can help to modify some of 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. Sustained and repetitive flexion is also a significant contributing factor for many workers with LBP.
- It is recommended that further attention in industry be afforded to interventions such as skills and body mechanics training, lifting techniques training, and manual handling instruction.
- 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 (
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.
133. Anderson, J (2005). Stretching before and after exercise: effect on muscle soreness and injury risk, Journal of Athletic Training, 40, 3, 218-220.
134. Ayala, F et al (2014). Acute effects of static and dynamic stretching on hamstrings' response times. Journal of Sports Sciences, 32, 9, 817-825.
135. Chan, K et al (2012). Stretching in the prevention of hamstring strains: attitudes, beliefs and current practices among football coaches in Mauritius. Open Journal of Preventive Medicine, 2, 2, 141-148.
136. da Costa, B & Vieira, E (2008). Stretching to reduce work-related musculoskeletal disorders: a systematic review. Journal of Rehabilitation Medicine, 40, 321-328.
137. Di Cagno, A et al (2010). Pre-exercise static stretching effect on leaping performance in elite rhythmic gymnastics. Journal of Strength & Conditioning Research, 24, 8, 1995-2000.
138. Fletcher, I (2011). The acute effect of commonly used preparation strategies on short-term high-intensity motor capabilities. University of Bedfordshire, Doctor of Philosophy by Publications.
139. Herbert, R., & Gabriel, M., (2002) Effects of stretching before and after exercising on muscle soreness and risk of injury: systematic review, British Medical Journal, 325, 468-470.
140. Holmstrom, E & Ahlborg, B (2005). Morning warming-up exercise – effects on musculoskeletal fitness in construction workers. Applied Ergonomics, 36, 513-519.
141. Ingraham, S. (2003) The role of flexibility in injury protection and athletic performance – have we stretched the truth? Minnesota Medicine, 86, 5, 58-61.
142. Jamtvedt, G et al (2010). A pragmatic randomised controlled trial of stretching before and after physical activity to prevent injury and soreness. British Journal of Sports Medicine, 11, 1002-1009.
143. Kendall, B (2014). The effects of different warm-up methods on anaerobic power. Western Michigan University. Masters Thesis, Paper 527.
144. Lewis, J (2014). A systematic literature review of the relationship between stretching and athletic injury prevention. Orthopaedic Nursing, 33, 6, 312-320.
145. Maher, C (2000). A systematic review of workplace interventions to prevent low back pain. Australian Journal of Physiotherapy, 46, 259-269.
146. Samuel, M et al (2008). Acute effects of static and ballistic stretching on measures of strength and power. Journal of Strength & Conditioning Research, 22, 5, 1422-1428.
147. Serra, A et al (2013). Experience in resistance training does not prevent reduction in muscle strength evoked by passive static stretching. Journal of Strength & Conditioning Research, 27, 8, 2304-2308.
148. Shrier, I. (1999) Stretching before exercise does not reduce the risk of local muscle injury: a critical review of the clinical and basic science literature. Clinical Journal of Sports Medicine, 9, 4, 221-227.
149. Sim, A et al (2009). Effects of static stretching in warm-up on repeated sprint performance. Journal of Strength and Conditioning Research, 23, 7, 2155-2162.
150. Simic, L., Sarabon, N., & Markovic, G., 2013, Does pre-exercise static stretching inhibit maximal muscular performance? A meta-analytical review. Scand J Med Sci Sport, 23, 2, 131-148.
151. Schneider, S (2015). Can stretching programs prevent back injuries? Laborers Health & Safety Fund of North America. http://www.lhsfna.org/index.cfm/lifelines/february-2015/can-stretching-programs-prevent-back-injuries/
152. The warm-up and cool-down. Australian Sports Commission website: http://www.ausport.gov.au/participating/coaches/tools/the_training_session/Warmup-Cooldown
153. Troumbley, P (2010). Static versus dynamic stretching effect on agility performance. Utah State University. Masters Thesis.
154. Weerapong, P (2005). Pre-exercise stretegies: the effects of warm-up, stretching, and massage on symptoms of eccentric exercise-induced muscle damage and performance. Auckland University of Technology, Doctor of Philosophy.