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Artikel Ulasan/*Review Articles*

The Relationship between Carrying Activity and Low Back Pain: A Critical Review of Biomechanics Studies

(Hubungkait di antara Aktiviti Membawa Barang dan Sakit Pinggang: Satu Tinjauan Kritikal terhadap Kajian Biomekanik)

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ABSTRACT

The aim of this review was to systematically explore the underlying musculoskeletal biomechanical mechanisms of carrying and to describe its potential relationship with low back pain. This literature review was carried out using AMED, CINAHL, *Compendex and* MEDLINE *electronic databases. Articles published from 2004 to 2012 were selected for consideration. Articles were considered if at least one measurement of kinetics, kinematics or other related musculoskeletal parameters related to biomechanics were included within the study. After combining the main keywords, 677 papers were identified. However, only 10 studies met all the inclusion criteria. Age, body mass index, gender and level of physical activity were identified as the factors that may influence the biomechanics of carrying activity. Carrying a loaded backpack was reported leading to posterior pelvic tilt, reduced lumbar lordosis, but increased cervical lordosis, thoracic kyphosis and trunk forward lean. Furthermore, while carrying bilaterally, lumbo-pelvic coordination was also reported to be more in-phase, as well as reduced coordination variability in transverse plane. Future studies investigating the biomechanics of a standardized carrying activity for clinical test are recommended.*

Keywords: Biomechanics; low back pain; load carrying activity

ABSTRAK

Tujuan tinjauan ini ialah untuk meneroka secara sistematik apakah mekanisme biomekanik muskuloskeletal bagi aktiviti membawa barang dan menjelaskan hubungkait di antara mekanisme tersebut dengan sakit pinggang. Tinjauan kepustakaan telah dijalankan dengan menggunakan pangkalan data eletronik seperti AMED, CINAHL, *Compendex dan* MEDLINE. *Hanya artikel yang diterbitkan dari tahun 2004 hingga 2012 sahaja dipilih untuk tinjauan ini. Selain itu, artikel tersebut mestilah melibatkan sekurang-kurangnya satu pengukuran kinetik, kinematik atau parameter muskuloskeletal yang berkaitan. Selepas menggabungkan kata kunci utama, sebanyak 677 artikel telah dikenal pasti. Walau bagaimanapun, hanya 10 artikel yang telah memenuhi kriteria tinjauan ini. Umur, indeks jisim tubuh, jantina dan tahap aktiviti fizikal telah dikenal pasti sebagai faktor-faktor yang berpotensi untuk mempengaruhi biomekanik bagi aktiviti membawa barang. Membawa beg galas yang berisi telah dilaporkan boleh menyebabkan dongakan pelvis anterior, pengurangan lordosis lumbar, tetapi pertambahan kepada lordosis servikal, kipfosis torasik dan sandaran depan trunkus. Tambahan lagi, semasa membawa barang secara bilateral, koordinasi lumbo-pelvik telah dilaporkan lebih berkeadaan dalam-fasa serta mempunyai kebolehubahan koordinasi yang berkurangan dalam satah lintang. Kajian tentang biomekanik bagi aktiviti membawa barang yang piawai untuk pengujian klinikal adalah digalakkan pada masa hadapan.*

Kata kunci: Biomekanik; sakit pinggang; aktiviti membawa barang

INTRODUCTION

Carrying activities are known to associate with many medical problems such as low back pain (LBP), stress fractures, rucksack palsy, knee pain, foot blisters, metatarsalgia, local discomfort and local fatigue (Knapik et al. 1996). As one of the most common work-related musculoskeletal disorders, LBP has been reported to pose a large socio-economic impact on many countries (Collins et al. 2010). While the direct healthcare cost of LBP was estimated to be £1,632 million annually, the cost of informal care and production losses were estimated to be £10668 million in total (Maniadakis & Gray 2000). Furthermore, workers with LBP have been reported to have approximately three times the likelihood for work absenteeism as compared to non-LBP workers (Widanarko et al. 2012). In the industrial setting, manual material handling was reported to be a major contributing factor to LBP (Waters et al. 2006). Kuiper et al. (1999) has found that manual material handling activities such as lifting, carrying, pushing, pulling and combined MMH were the risk factors for various types of back disorders. Across the literature, Heneweer et al. (2011) has concluded that there were moderate to strong risk factor of LBP for heavy workload and the accumulation of loads or frequency.

Although many studies have attempted to explore the associations between manual material handling and LBP, most were epidemiological studies rather than examination of biomechanical mechanism. For instance, Eriksen et al. (2004) has reported that the frequency of lifting, carrying, and pushing heavy objects statistically predicted LBP-related sick leave of longer than eight weeks. However, according to a systematic review by Wai et al. (2010), with the exception of the findings from Eriksen et al. (2004), a causal relationship between occupational carrying and LBP could not be confirmed within other high quality epidemiological studies. Furthermore, although there were studies that have used video to record the activity, those studies were not considered as including robust biomechanical analysis by Wai et al. (2010). Whilst the severity of the exposure to LBP is described, none of the biomechanical parameters (i.e. kinetics or kinematics) were reported. Therefore, an in-depth biomechanical investigation is needed to complement these epidemiological findings in order to understand the mechanism which may lead to the development of LBP over time. The aim of this review was to systematically explore the underlying musculoskeletal biomechanics and related parameters of carrying (e.g. muscle activity or anthropometry) from the previous literature, as well as to describe its potential relationship with LBP.

METHODS

SEARCH STRATEGY

The Cochrane database was reviewed to ensure that there were no biomechanically focussed literature review on the association between carrying activity and LBP. After revealing that there was no such study, this literature review was carried out using AMED, CINAHL, Compendex and MEDLINE online databases based on three main keywords, namely biomechanics (i.e. carrying or weight bearing or moving or load carriage or backpack or walking or functional capacity evaluation or work capacity evaluation), low back pain (i.e. low back pain or backache or back injuries or back disorders) and carrying (i.e. carrying or weight bearing or moving or load carriage or backpack or walking or functional capacity evaluation or work capacity evaluation) (Figure 1). To ensure that the most contemporaneous papers were selected, articles published from 2004 to 2012 were selected. English-language publication and peer-reviewed articles only were selected and duplicates across databases were removed. Each article had to incorporate at least one biomechanical (i.e. kinetics or kinematics) or other related musculoskeletal parameters related to biomechanics. To establish a standardized concept, kinetics was defined as '*the study of the effects of forces on the motion*,' whereas kinematics was defined as '*the study of motion without reference to mass or force*' (Knudson 2003).

INCLUSION CRITERIA

For this review, the carrying activity was defined as moving from one place to another while manually holding a certain load. Studies were considered if the weight of the load carried was specified. Only carrying activities with a posterior, anterior, central, and/or lateral load were included because it was assumed that those variants were commonly performed in various work settings. At least one completed gait cycle must be performed during the activity. The title and abstract of papers identified were screened to clarify the suitability according to the aforementioned inclusion and the exclusion criteria. The full texts were then retrieved to assess the methodological quality and level of evidence.

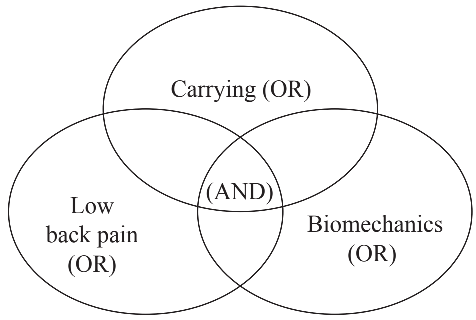

FIGURE 1. Boolean logic of the search strategy

EXCLUSION CRITERIA

No study design was excluded. This review did not include secondary studies (i.e. narrative literature review, systematic review and meta-analysis). Grey literature was also excluded. Any article was excluded if either carrying distance or carrying period was not reported. Dependent carrying such as having assistance from any mechanical device or other individuals to perform the carrying activity was also considered as exclusion criteria. Because this review aimed to investigate the aforementioned association among working population, any studies with participants aged less than 16 years old were excluded.

ASSESSMENT OF THE LEVEL OF EVIDENCE

Any biomechanics studies that met the inclusion criteria were considered. The level of evidence and methodological quality were determined according to the guideline provided in the Health Evidence Bulletins: Wales Project (Weightman et al. 2004). The level of evidence was adapted from Bandolier system (Table 1). As for the methodological quality, this guideline also provided a series of critical appraisal tools (CAT) to assess the methodological quality across various types of study design. Initially, it was assumed that most of the biomechanics studies were designed as cross-sectional because of its nature of laboratory investigation on human performance. Hence, this guideline was chosen because the adapted Bandolier system and the CAT provided within this document had a clear distinctive emphasis for this particular study design.

TABLE 1. Level of evidence

Level	Description
I	Evidence from a systematic review (which includes at least one randomised controlled trial and a summary of all included studies).
II	Evidence from a well-designed controlled trial of appropriate size.
III	Evidence from a well-designed intervention study without randomization.
IV	Evidence from a well-designed non-experimental study e.g. cohort, case-control or cross-sectional studies (also include studies using purely quantitative methods).
V	Opinions of resected authorities, based on clinical evidence, descriptive studies or reports of consensus committees.

RESULTS

IDENTIFICATION OF STUDIES

Figure 2 illustrates the method by which the relevant studies were included and excluded from the databases. After combining the major keywords (i.e. 'carrying,' 'low back pain' and 'biomechanics'), a total of 677 studies from 2004 to 2012 were found from AMED, CINAHL, Compendex, and MEDLINE. This number was then reduced to 572 after removal of duplicates. After screening for review articles, grey literature, and non-English articles, this number was further reduced to 467. Of these, 340 studies were biomechanics studies. Among those, only 23 studies were the studies of carrying activity. However, after reviewing the full texts, 13 studies were excluded because they used non-targeted participants (i.e. children, adolescent, pregnant women) or there was insufficient information about the carrying activity. Ten studies met all inclusion criteria and were critically reviewed (Figure 2). The descriptions of these studies were summarized in Table 2.

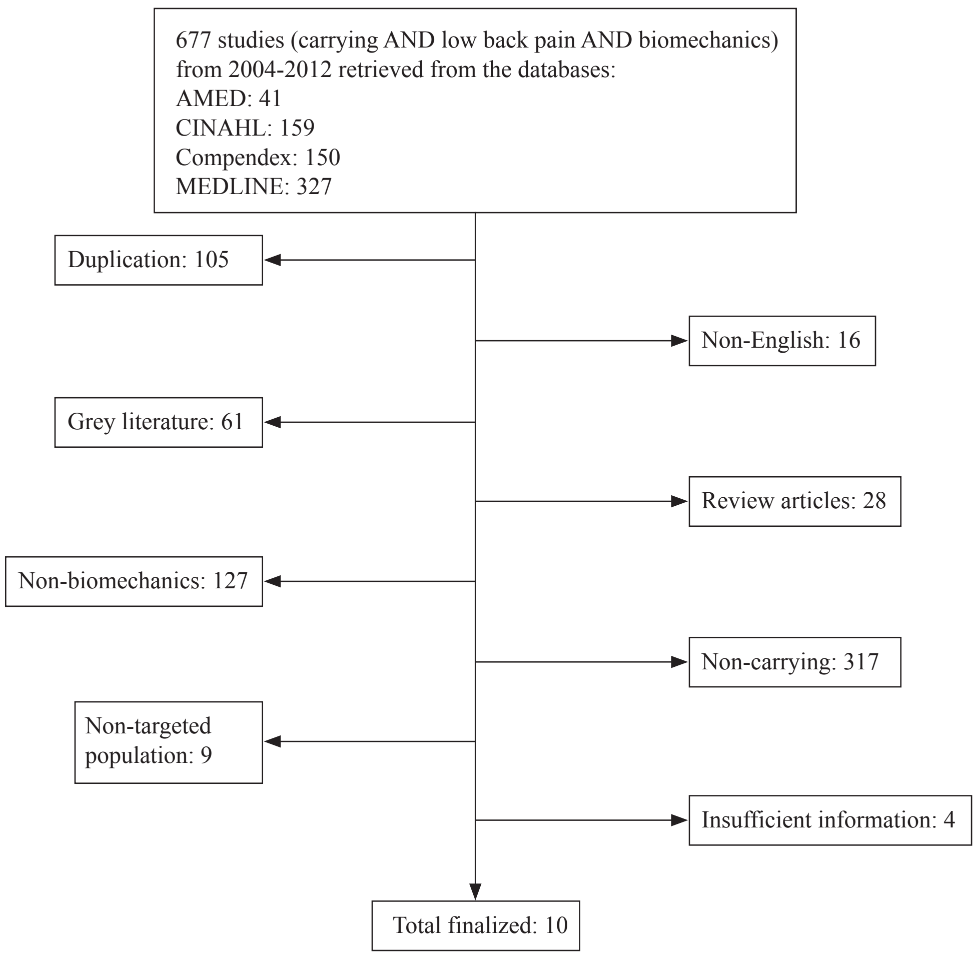

FIGURE 2. Flowchart of study selection

TABLE 2. Summary of studies

Author (year)	Participant	Carrying characteristic	Measurement technique and outcome parameters
Hung-Kay Chow et al. (2011)	13 healthy adults.	Carrying a backpack (10% BM) for 30 minutes, followed by 30 minutes of unloaded walking (speed = 1.1 m/s). (BM = body mass)	Electrogoniometric system with four gravitational-referenced accelerometers to measure changes in spinal curvature and trunk posture.
Simpson et al. (2011)	15 female recreational hikers.	Carrying a backpack with 4 mass conditions (no backpack, 10% BM, 20% BM, 30% BM and 40% BM) in an 8 km circuit at self-selected pace.	OPTOTRAK 3020 motion analysis system to measure sagittal plane peak trunk flexion angle relative to the horizontal and range of motion during stance phase.
Seay et al. (2011a)	11 male soldiers.	Walking (1.34 m/s) and running (2.46 m/s) with and without holding a rifle (rifle weight = 2.4 kg) for on treadmill for a total 16 minutes.	ProReflex motion analysis system to measure 3D segmental angles of pelvis and trunk
Majumdar et al. (2010)	10 male soldiers.	Walking while carrying 9 military load conditions at self-maintained pace for 10m each.	Hires Expert Vision System to measure 3D kinematic data.
Healey et al. (2008)	11 chronic LBP and 11 asymptomatic participants.	20 minutes of loaded walking tasks by wearing weighted vest (20% BM) each in the morning and in the afternoon at self-selected pace. 20 minutes of unloaded recovery position (side lying) was performed before and after the activity.	Stadiometer with linear variable high-resolution (LVDT) displacement transducer to measure changes in stature.
Healey et al. (2005a)	11 chronic LBP and 11 asymptomatic participants.	Four 20-minutes sessions of loaded walking tasks by wearing weighted vest (10% BM) at self-selected pace. 20 minutes of 4 unloaded recovery positions (side lying, 50º gravity inversion, spinal hyperextension, 11º supported) were performed before and after the activity.	Stadiometer with LVDT displacement transducer to measure changes in stature. Surface EMG to measure changes in muscle activity.
Healey et al. (2005b)	20 chronic LBP and 20 asymptomatic participants.	20 minutes of loaded walking tasks by wearing weighted vest (10% BM) at self-selected pace, and then followed by 40 minutes of unloaded recovery position (side lying).	Stadiometer with LVDT displacement transducer to measure changes in stature. Surface EMG to measure changes in muscle activity.
Rodacki et al. (2005)	10 obese and 10 non-obese participants.	30 minutes of walking task while carrying hand-load bilaterally (10% BM, 5% at each hand) at self-selected pace and 30 minutes of standing recovery period.	Stadiometer with LVDT displacement transducer to measure changes in stature.
Fowler et al. (2006)	6 healthy males.	Walking at self-selected pace for 8500 meter with and without carrying a standard Royal Mail bag containing 17.5% BM positioned on shoulder. The bag load was reduced gradually (10% reduction from the initial load).	ELITE BTS optoelectric system to measure 3D kinematics of the spine. Stadiometer with LVDT displacement transducer to measure changes in stature.
LaFiandra and Harman (2004)	11 male soldiers.	Carrying a backpack with three mass conditions (13.6 kg, 27.2 kg, and 40.8 kg) on treadmill for three minutes each (speed = 1.34 m/s).	Force transducers to measure forces exerted at the lower back, upper back and shoulders, and backpack centre of mass (COM). Qualisys Motion Capture system to measure position data to calculate the forces.

DESCRIPTION OF STUDIES

OVERVIEW OF RESEARCH DESIGN

All studies were classified as cross-sectional (level IV) because they were conducted over a short period of time. The carrying activities were assessed according to several criteria, namely the target population (job specific or non-job specific), load position (anterior, posterior, bilateral, central, or mixed), load weight (percentage of body weight or standardized), and carrying speed (self-selected pace or standardized). Among all, four studies included comparative groups to test their research questions. For instance, in order to examine the impact of chronic LBP on the variability of stature loss, stature recovery and/or paraspinal muscle activity while carrying a weighted vest, both chronic LBP and healthy (stated as 'asymptomatic') respondents were recruited (Healey et al. 2005a; Healey et al. 2005b; Healey et al. 2008). Likewise, Rodacki et al. (2005) used both obese and non-obese respondents to examine the impact of obesity on stature changes and stature recovery while both hands carried hand-loads (Table 2).

BIAS AND CONFOUNDING

For all studies, convenience sampling utilized, with the exception of Majumdar et al. (2010) which used random sampling. All studies were carried out with small sample size (< 30) and none of these studies reported a *priori* power calculation to determine sample size. Thus, type-II error may be present. Nevertheless, some studies did report on the appropriate effect size to indicate the magnitude of the observed effects. For instance, Seay et al. (2011a) used Cohen's *d* as the measure of effect size to estimate the magnitude of difference after performing the multiple pairwise comparison for a two-way repeated measures ANOVA. For that, they have adopted the Cohen's *d* conventional effect size (i.e. $d > 0.5$ represents clinically meaningful difference, while d > 0.8 represents large practical difference) (Cohen 1988). Healey et al. (2008) on the other hand, reported both correlation coefficient (r) and coefficient of determination (r^2) as the effect size measures for correlation tests. In the case of Majumdar and Pal (2010), although they reported the changes in the mean to elaborate the magnitude of difference after performing a *post-hoc* analysis, the true magnitude of changes between the group might still be influenced by its pooled standard deviation (with regards to the Cohen's *d* for independent groups).

Age, body mass index (BMI), gender and level of physical activity were the potential confounding variables addressed across the reviewed studies that can interfere with the primary biomechanical outcomes. Across all studies, the mean age and BMI ranged from 21.5 to 35.1 (young adulthood) and 20.1 kgm^{-2} to 36.6 kgm^{-2} (normal weight to obese), respectively. Only Rodacki et al. (2005) recruited obese respondents in order to investigate the impact of BMI on stature variations during and after a carrying activity. Most of the studies recruited single gender respondents to eliminate any possible gender effect. Although there were two studies reported using mixed gender respondents, the number of male to female respondents were or almost equal (Healey et al. 2005b; Healey et al. 2008). Still, there was no baseline comparison to confirm the effect of gender on the measured parameters. While aiming to determine the differences in the alteration of paraspinal muscle activity according to different unloading positions among chronic LBP and asymptomatic respondents, of all studies, Healey et al. (2005a) was the only study that did not mention anything on gender.

Half of the studies attempted to control physical activity level as one of the possible confounding factors (Healey et al. 2005a; Healey et al. 2005b; Rodacki et al. 2005; Healey et al. 2008). In these studies, the physical activity level can generally be divided into three types; habitual, short-term and immediate. As for the habitual type, the Baecke's Physical Activity Questionnaire and the NASA/Johnson Space Centre's Physical Activity Rating (PA-R) Scale were used as the measurements. The short-term physical activity was methodologically controlled by implementing strategies such as instructing the respondents to sleep for approximately 8 hours and/or preventing them from any stressful physical activity for 24 hours prior to the study session. Furthermore, to eliminate the effects of physical activities prior to arrival in the laboratory (immediate control), the participants were instructed to maintain a specific unloading position before the main experiment began. One of the methods was to maintain a left-side lying on a comfortable surface with the hip and knees flexed for 20 minutes (Healey et al. 2005a; Healey et al. 2005b; Healey et al. 2008). Other than that, Rodacki et al. (2005) instructed their respondents to lie in a Fowler's position for 30 minutes to allow spinal unloading.

ASSOCIATIONS WITH LOW BACK PAIN

KINETICS

LaFiandra et al. (2003) was the only study measuring kinetic parameters. In this study, force distribution on the lower back, upper back and backpack centre of mass while carrying a backpack with three mass conditions among soldiers were investigated. The backpack had an external frame, allowing both upper attachment (i.e. shoulder straps) and lower attachment (i.e. hip belt) to be the only points of contact between the backpack and the carrier. The results showed that the vertical and anterior/posterior forces exerted on the lower back, upper back and back pack centre of mass were increased as the back pack mass increased. For instance, at the lower back, mean $\pm$ standard deviation of the anterior forces resulted from the backpack with 13.6 kg, 27.2 kg and 40.8 kg were 27.86 $\pm$ 9.14, 58.78 $\pm$ 14.22 and 182.27 $\pm$ 21.63 respectively. Furthermore, regardless of the back pack mass, approximately 30% of the vertical forces generated by the backpack were transferred to the lower back by the use of the external frame and the hip belt.

The use of external frame and hip belt can possibly reduce the risk of having shoulder injury such as rucksack palsy. However, they also acknowledged that consistent anterior force on the lower back as exerted by the back pack may contribute to LBP.

KINEMATICS

Simpson et al. (2011) reported carrying a backpack weighted as low as 20% of body weight (BW) can increase the trunk flexion, as they reported that there was a significant decrease in the peak trunk flexion (sagittal plane relative to horizontal planes) angle from 84 $\pm$ 3 (0% of BW) to 78 $\pm$ 3 (20% of BW) (i.e. a smaller angle indicates increased trunk flexion). Moreover, trunk flexion was found to be greater while carrying the backpack in a longer distance. On the other hand, Majumdar and Pal (2010) found that only during mid-stance, significant changes in the percentage of gait cycle can be observed between no-load condition (22.7 $\pm$ 2.2) and other carrying conditions, namely a carrying rifle (24.1 $\pm$ 1.4), carrying a light machine gun (24.4 $\pm$ 1.2), carrying a haversack (24.5 $\pm$ 1.0), carrying a haversack and a light machine gun (24.7 $\pm$ 1.2) and carrying a backpack and a light machine gun (24.7 $\pm$ 1.3). During mid-stance, they also reported that the trunk flexion can reach a maximum flexion of 9.5° while carrying the maximum loaded (i.e. 17.5 kg). In another study, Hung-Kay Chow et al. (2011) studied the carry-over effects of carrying activity on trunk posture and also the repositioning ability of the spine after carrying a loaded backpack (i.e. 10% body weight). The repositioning ability was determined according to repositioning error (i.e. the difference between trunk forward lean and spinal curvatures with regard to the preload conditions). The results indicated that immediately after the load was removed, there were significant differences in repositioning errors of cervical lordosis (66%), thoracic kyphosis, lumbar lordosis (57%), pelvic tilt (44%) and trunk forward lean (54%). Even 30 minutes after that, the repositioning errors cannot be fully restored to the level of preload conditions. Therefore, they concluded that there might be a modification in spinal proprioception after the load carriage which can be associated to neck / back pain.

Seay et al. (2011a) carried out a study among healthy soldiers to investigate the upper body kinematics (i.e. ROM in sagittal, frontal and transverse planes), pelvis-trunk coordination (i.e. continuous relative phase) and the coordination variability while carrying a rifle (2.4 kg) in two different gait modes (i.e. walking and running). The results showed carrying a rifle with both hands produced a greater trunk transverse ROM (i.e. axial rotation) in running, but lower trunk sagittal ROM for both speed. In transverse plane, regardless of the gait mode, the pelvis-trunk coordination was more in-phase while carrying the weapon. Moreover, decreased coordination variability can also be observed in transverse plane as a result of carrying the weapon. Finally, they concluded that the decrease in coordination variability while carrying the weapon may contribute to LBP due to decreased pelvis-trunk system adaptability. In another study by Fowler et al. (2006), the participants were instructed to carry a loaded standard Royal Mail bag (17% of body weight), and the loads were decreased gradually throughout the activity. The result showed at the beginning of the task (i.e. heaviest loads) increased trunk lateral flexion at lumbar region in the opposite direction to the side where the bag was held (up to 12º) and increased forward flexion within the thoracic region (up to 6º). They have discussed that by displacing the participant's centre of mass in both planes (i.e. trunk was displaced in one plane, but coupled with movement in another different plane), this may increase the risk of LBP. Finally, they have concluded that the use of mailbag designs which does not allow side-to-side alternation (e.g. mailbag with waist-belt that fixes carrying position only to one side) were not recommended because it may cause long-term effect of postural deviation.

OTHER RELATED MUSCULOSKELETAL PARAMETERS

In conjunction with musculoskeletal biomechanics, other related parameters such as electromyography and stadiometry were also investigated throughout the studies. Five studies were conducted to measure changes in stature as a result of carrying activity (Healey et al. 2005a; Healey et al. 2005b; Rodacki et al. 2005; Fowler et al. 2006; Healey et al. 2008). Among those, two studies incorporated electromyography to analyse muscle activity during a recovery period after the carrying activity was done (unloading period) (Healey et al. 2005a; Healey et al. 2005b). Fowler et al. (2006) reported that among healthy respondents, stature loss (i.e. reduction in height) was doubled after the loaded carrying activity. Furthermore, although there was no difference in stature loss as compared to the control group, the chronic LBP group was reported to have a significantly lower stature recovery during the unloading period (Healey et al. 2005a; Healey et al. 2005b; Healey et al. 2008). However, there was no stature recovery observed in the obese group in comparison with the control group (Rodacki et al. 2005). They have discussed that this phenomena might be related to the fact that the obese respondents had already sustained a 'chronic' loading condition, in which can affect the intervertebral disc and other spinal structures, which in the future may lead to LBP. As for the electromyography, paraspinal muscle activity (i.e. erector spinae at LI-L2 and L4-L5 interspaces) was reported to be higher in chronic LBP groups both before the carrying activity and during the unloading period. This higher level of activity was suggested to increase compressive load on the spine, thus, preventing the intervertebral disk to recover at its initial height.

DISCUSSION

This review has discussed and summarized some possible confounding factors from the selected studies which include gender, age, BMI and level of physical activity. Gender difference was reported to affect some gait parameters because females usually walk with more anterior pelvic tilt and up-and-down oblique motion, more flexed, adducted and internally rotated hip joints and more valgus angles of the knee joint (Cho et al. 2004). According to de Schepper et al. (2010), while males were reported to have a greater frequency of osteophytes, the narrowing of intervertebral disc was more frequent in females. Furthermore, they also reported that as the age increased, both development of osteophytes and narrowing of intervertebral disc were also increased. The level of physical activity on the other hand, has been suggested to have a unique relationship with LBP (Heneweer et al. 2009). This relationship can be illustrated as a continuum that explains a dynamic interaction between risk of LBP and activity intensity. The risk of LBP was suggested to be at the highest level when the activity intensity is at both most minimum (i.e. total inactivity) and maximum (i.e. heaviest activity). For BMI, a meta-analytic evidence has indicated that overweight and obesity could increase the risk of LBP (Shiri et al. 2010). Spinal shrinkage was found to have a positive correlation with body mass. This could possibly be due to the impact of cumulative load from the body mass onto the spine (Yar 2008). However, the accuracy of BMI to indicate obesity is still controversial due to the fact that it cannot distinguish between fat-mass and fat free mass (Romero-Corral et al. 2008).

Backpack carrying has been reported as one of the most prevalent carrying methods throughout the selected studies. To reduce the forces on the shoulder and the upper back while carrying a loaded backpack (i.e. vertical and anterior/posterior), one of the common reported strategy was to incorporate a frame and a hip belt to the backpack. Previous study has showed that without the frame and the hip belt, the maximal pressure of shoulder straps of a 10.2 kg backpack can reach up to 203 mmHg (Holewijn 1990), which was doubled than the skin threshold for irritation and redness (i.e. 105 mmHg) (Husain 1953). Although this strategy can potentially reduce the risk of getting brachial plexus lesion such as backpack palsy, the additional forces on the lower back may increase the compressive loading of the lumbar spine, which eventually may cause other problems such as vertebral body damage and further degenerative change. Other strategies such as proper positioning of the backpack on the spine (i.e. upper back, middle back or lower back) and the use of front pack and double pack (i.e. both front and back) have also being studied throughout the literature. A systematic review by Golriz and Walker (2012) has summarized that low backpack should be avoided if the load was more than 15% of the body weight. They also reported although double pack can move the centre of gravity closer to the body and help to distribute the load between the front and back of the body, respiratory ventilation, upper limb movement and front visual field may become restricted.

Trunk flexion was reported to be the most common posture during backpack carrying. This may happen in order to counteract the posterior vertical force from the load, producing a resultant force onto the spine. For instance, carrying a 15% and 30% of body mass can result in the corresponding increase in lumbosacral force of 26.7% and 64% of body mass, respectively (Goh et al. 1998). When the spine (i.e. particularly at the lumbosacral region) has been exposed to this additional force over time, the risk of LBP are most likely to be increased. Wong et al. (2009) reported that workers with LBP spent significantly longer time in trunk flexion for more than 10° compared to normal workers. Furthermore, workers who use a minimum of 60° flexion for more than 5% of their working time has been reported to have an increased risk of LBP (RR = 1.5) (Hoogendoorn et al. 2000). Other than trunk posture, inter-segmental coordination has also been studied to describe a carrying activity. According to Yen et al. (2012), inter-segmental coordination can be described as '*the temporal-spatial coupling between adjacent body segments*,' whereas the coordination variability signposts the consistency of the coupling pattern is reproduced over time. In general, if a coupling pattern is constantly repeated, this is indicating low coordination variability. As a strategy to reduce pain, people may limit their inter-segmental coordination variability. For instance, among patellar femoral pain syndrome patients, they tend to have a lower coordination variability between the thigh and shank compared to normal individuals (Heiderscheit et al. 2002). In LBP patients, a reduced transverse plane coordination variability between pelvis and trunk has been reported (Seay et al. 2011b). Furthermore, Lamoth et al. (2006) has found that to compensate with this 'rigid' coordination in transverse plane, LBP patients tend to produce more variable coordination in frontal plane.

Post-exercise activity of paraspinal muscles was reported to be increased in LBP patients. Prolonged muscle activation could further lead to muscle fatigue. In general, fatigue was known to have a unique association with musculoskeletal pain. Alongside the pain itself, fatigue was reported to be one of the most common presentations of LBP (Demoulin et al. 2007). In general, fatigue can be described as '*the progressive decline in performance which can largely be recovered after a period of rest (reversible)*' (Allen et al. 2008). Furthermore, when the body mechanics is failing due to fatigue/pain, the body may initiate compensatory mechanisms to accommodate with the symptoms. Known as 'guarded movement' (Main & Watson 1996), this phenomenon may reduce the activity of any primary muscle and activating accessory muscles, which then could result in movement alteration from normal. In time, this phenomenon could further lead to the disuse of primary muscles by preventing any movements which are believed may trigger the pain (generally known as 'fear-avoidance' phenomenon) (Vlaeyen & Linton 2000). This may explain why the multifudus and paraspinal muscles were found smaller in chronic low back pain compared to control patients (Fortin & Macedo 2013).

According to the theory of compensation strategies by Hodges and Tucker (2011), when a particular muscle was fatigued, there will be a redistribution of activity within and between muscles. By using the sEMG, the redistribution of activity within muscles can be measured according to the onset of muscle activation. Furthermore, the redistribution between muscles can possibly be determined according to the functional myofascial connectivity between muscles (Myers 2009). It was assumed that muscles are integrated functionally according to specific fascial webbing. According to Myers (2009), these webbing can be classified as 'myofascial meridians.' Moreover, he stated that there were seven known myofascial meridians, namely the superficial back line, the superficial front line, the lateral line, the spiral line, the arm lines, the functional lines and the deep front lines. For instance, the superficial back line (i.e. iliocostalis lumborum, biceps femoris and gastrocnemius) and the back functional line (latissimus dorsi, gluteus maximus and vastus lateralis). Generally, these muscles are situated either posteriorly or laterally. The muscles within any specific myofascial meridians work together in a unique pattern, but with variable degree of activation. This may explains co-contraction among the muscles alongside specific myofascial meridians among LBP to compensate the role of any painful primary muscle.

Other than that, this review found that carrying characteristics among the studies were varied according to the intended target population. Knowledge about these variations is beneficial in order to understand the impact of various load positions while performing the carrying activity across different types of work. Clinically, one of the major assessments to determine the physical readiness for return-to-work is Functional Capacity Evaluation (FCE). Being regarded as the gold standard of vocational assessment (McFadden et al. 2010), the major role of the assessment is to analyse the consistency between a patient's performance in work-related physical activities and the relevant job demands. Although each activity has been used for different protocol in the assessment, a number of protocols can be grouped to represent primary job demand of a profession. For instance, a heavy manual worker may undergo a set of the functional capacity evaluation protocols differently than a professional driver or a teacher due to the different work demands. In other words, although the selection of the assessment protocols are varied across different professions, each protocol should still be carried out as a standardized activity to ensure good measurement quality (i.e. validity and reliability) across various professions.

Although studies related to carrying activity were available from the online databases, some studies were epidemiological rather than biomechanical. The main purpose of epidemiological study was to examine the relationship between the biomechanical exposure and the occurrence of low back pain rather than to explore the biomechanical mechanism behind it. This review also found that most of the studies on carrying activity have been carried on children and adolescence rather than adult population. This may be due to the fact that backpack carriage has been reported one of the most common risk factors leading to low back pain among school-age population. Furthermore, compared to carrying, researchers tend to focus more on lifting activity in the working population. Therefore, this review recommended future research to examine the impact biomechanics of carrying activity on working-age population by focusing on the nature of the activity performed at their workplace. Finally, this review also suggested further investigation on biomechanical parameters involved in a standardized activity as commonly performed in a functional capacity evaluation. By exploring the core biomechanical aspects that needed to be addressed during the evaluation, an emphasized, detailed, and systematic description of functional capacity of LBP can be produced to guide a safe and timely return-to-work process.

CONCLUSION

Prolonged trunk flexion has been reported to lead to an increased risk of LBP. Furthermore, increased muscle activity has been reported as one of the compensatory strategies to deal with fatigue and/or pain. Less lumbo-pelvic coordination variability may also be a possible presentation of LBP. Finally, it can be suggested from this review that there is a crucial need for a future study to investigate the changes in musculoskeletal function during carrying activity in a clinical setting to explore the biomechanical mechanism of the activity which can potentially lead to LBP.

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