Traditional Posterior Load Carriage: Ergonomic Assessment and Intervention Efficacy

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ABSTRACT

There is a high prevalence of musculoskeletal symptoms (MSS) among manual material handling (MMH) workers. However, limited investigations have been undertaken among one large group of workers using a particular MMH method called traditional posterior load carriage (PLC). Such load carriage is typically done without the use of an assistive device (e.g., backpack) in developing countries, and involves exposure to known risk factors for MSS such as heavy loads, non-neutral postures, and high levels of repetition. The current work was completed to investigate the characteristics of the PLC task and physical effects on workers, and to evaluate a practical intervention that may help improve the task. The first study investigated, through structured interviews with 108 workers, the types, prevalence, and impacts of MSS. PLC workers incur a relatively high MSS burden, primarily in the lower back, but also in the feet, knees, shoulders, and neck. These MSS were reported to interfere with daily activity, but only few workers sought medical treatment. Workers suggested several task improvements including the use of a belt, hook, or backpack/frame, and changes in the carriage method. The second and third study investigated, in a laboratory setting involving nine healthy males, the effects of load mass and size, and the use of a simple intervention, respectively, on factors related to low back pain risks during PLC. Increasing load mass caused increased torso flexion, lumbosacral flexion moment, abdominal muscle activity, and torso movement stability in the frontal plane. Increasing load size also caused higher torso flexion, peak torso angular velocity and acceleration, and abdominal muscle activity. Complex interactive effects of load mass and size were found on paraspinal muscle activity and slip risk. The intervention, involving a simple frame to support a load, and use with a higher load placement was found to be potentially beneficial as indicated by reduced lumbosacral moment and ratings of perceived discomfort in several anatomical regions compared to the traditional PLC. Outcomes of this research can facilitate future ergonomic guidelines and interventions to improve working conditions and occupational health and safety for PLC workers.

Keywords: Traditional load carriage; low back pain; spine; kinematics; kinetics; intervention

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Chapter 1: Introduction

Work-related musculoskeletal symptoms (MSS) cause substantial economic burden and adverse effects on workers worldwide (Galukande et al., 2006; Lubeck, 2003). Overexertion injuries associated with manual material handling (MMH) are among the major adverse consequences, and which account for ~25% of work-related injuries (Liberty Mutual Research Institute for Safety, 2010) and cost up to $40 billion in the U.S. alone (Anderson and Budnick, 2009). Many studies have associated MMH tasks with the development of diverse MSS (Bigos et al., 1986; Kuijer et al., 2011; Kuiper et al., 2005; Kuiper et al., 1999; Marras, 2000; NIOSH, 1997; Snook, 1978; Takala, 2010). One aspect of MMH, and of particular interest here, is traditional posterior load carriage (PLC), which involves human transportation of loads on the back, without the use of a backpack or other assistive devices, and which involves exposure to known risk factors for MSS such as heavy loads, non-neutral postures, and high levels of repetition.

Several studies have investigated PLC tasks done with the use of a backpack, and which have indicated that such tasks likely increase the risk of MSS in several body regions including the lower back, neck, shoulder, upper back, arms, and hands (Birrell & Hooper, 2007; Korovessis et al., 2005; Skaggs et al., 2006). PLC using a backpack can alter an individual's posture (Al-Khabbaz et al., 2008; Charteris, 1998; Chow et al., 2006; Grimmer et al., 1999), shifting the center of mass posteriorly and causing a forward lean to maintain balance (Goodgold et al., 2002; Grimmer et al., 2002; Hong & Cheung, 2003). PLC also causes a higher level of muscle activation (Bobet & Norman, 1984; Ghori & Luckwill, 1985; Motmans et al., 2006) and a delayed muscle activation (Simpson et al., 2011), both of which can be considered less efficient and effective aspects of motor control and potential mechanisms contributing to MSS (Hodges &

Richardson, 1996; Van Tiggelen et al., 2009).

One major MSS commonly associated with MMH task is low back pain (LBP). Back injuries have been reported to have the highest incidence rate that require days away from work (BLS, 2010). During PLC, the risk of LBP is hypothesized to be increased due to higher external moment about the L5/S1 joint and non-neutral trunk postures (Al-Khabbaz et al., 2008; Bobet & Norman, 1984; Charteris, 1998; Chow et al., 2006; Grimmer et al., 1999). These risk factors may further interact with each other, leading to other potential adverse effects including increases in muscle activity, loss of balance, motor control error, and increases in spinal load.

Increased external moments on the spine can lead to higher levels of back muscle activity, and can thereby induce localized fatigue (Knapik et al., 1996; Negrini & Carabalona, 2002). Indirect evidence suggests, furthermore, that back muscle fatigue increases the risk of LBP. Such fatigue increases the peak bending moment at the lumbar spine (Bonato et al., 2003; Dolan & Adams, 1998), which appears to be related to decreased muscle performance. Additionally, reductions in back extensor strength and endurance times have been shown to be related to such reduced performance (Potvin & Norman, 1993; Sparto et al., 1997). Back muscle fatigue can also delay the onset of muscle contraction, which indicates a disturbance of motor control and may result in poor muscular stabilization of the spine (Hodges & Richardson, 1996).

As noted earlier, PLC tasks using a backpack can alter normal posture (Al-Khabbaz et al., 2008; Charteris, 1998; Chow et al., 2006; Grimmer et al., 1999). The external load on the back shifts the system's center of mass posteriorly, and individuals typically adopt a forward lean to maintain balance (Goodgold et al., 2002; Grimmer et al., 2002; Hong & Cheung, 2003). Further, non-neutral trunk postures adopted during the performance of PLC tasks may increase postural sway. For example, a study by Heller et al. (2009) found substantial changes in postural sway among female subjects while wearing a military backpack (with 18.1 kg of load). There were greater magnitudes of postural sway in both the anterior-posterior (AP) and medial-lateral (ML) directions. Palumbo et al. (2001) also found a decline in movement velocity and directional control within the sagittal plane when subjects carried a 7.7 kg load with a backpack. In a dynamic situation, forward trunk lean can alter anterior and posterior musculature recruitment pattern, which may lead to a decreased directional control in the AP direction (Palumbo et al., 2001).

Such postural instability due to PLC tasks can cause a higher level of muscle activation and delayed muscle activation (Kollmitzer et al., 2002; Slijper & Latash, 2000; Toussaint et al., 1997), both of which can be considered less efficient and effective aspects of motor control and potential contributors to LBP. Errors in human motor control can cause deficiencies in movement execution (Massion et al., 2004). Since motor control is essential for performing whole body motions such as carrying, lifting, lowering, pushing, and pulling (Frank & Earl, 1990), an association between motor control errors and LBP risk has been theorized (McGill, 2004; Preuss & Fung, 2005).

Some other studies show a reciprocal relationship between localized muscle fatigue and loss of stability. Muscle fatigue may induce losses of stability while performing PLC tasks. It can reduce or impair postural stability through a disturbance in motor control systems including the central nervous system and relevant sensory feedback systems (Allen & Proske, 2006; Björklund et al., 2000; Pline et al., 2005; Taimela et al., 1999). Many studies have found supportive evidence regarding possible changes in motor control under localized muscle fatigue conditions. Nussbaum (2001) demonstrated that muscle fatigue even in a non-critical body part (i.e., the shoulder) can alter postural stability. In other context such as lifting, Sparto et al. (1997) showed that postural stability also decreased during lifting-induced fatigue tests. A study by Granata & Gottipati (2008) supports that fatigue can alter dynamic torso stability. Thus muscle fatigue has an association with compromised motor control strategies, both of which are related to an increased risk of LBP.

In addition to causing a decline in directional control and postural stability, non-neutral body and spinal alignment can increase spinal compression (Adams et al., 2006). For example, a study by Chow et al. (2011) showed that the duration and position of load carriage substantially increases spinal compression as measured by a stadiometer over time. It was found that prolonged spinal compression seems to accumulate and to remain elevated even after a period of standing rest was given to the participants. Subsequently, cumulative spinal load might increase the risk of LBP (Norman et al., 1998).

Although MSS risk increases when performing PLC tasks with a backpack, as noted above, the relevant studies have been conducted using particular populations (military personnel, students, and hikers). Relatively few investigations have been undertaken among one large group, however, for whom carrying heavy loads is a daily aspect of their work, and who are essentially overlooked in the literature. These are workers performing MMH tasks in developing countries (Lloyd et al., 2010a). PLC methods are common in developing countries, wherein this and other more traditional methods of work are still adopted (Scott, 2009). For a variety of historical, political, social, and/or economic reasons, such traditional methods are used commonly for carrying heavy loads such as rice, flour, and diverse other industrial/commercial products. Further, PLC among these workers is typically done without the use of a backpack or other assistive devices and involves exposure to known risk factors for MSS as mentioned earlier.

Thus, existing evidence regarding the effects of PLC (e.g., on muscle activity and loss of stability) are less relevant and/or applicable for traditional PLC tasks conducted in developing countries. Existing reports on traditional load carriage methods, including head loading, have been limited to experimental studies assessing physiological cost (Charteris et al., 1989; Datta et al., 1973; Lloyd et al., 2010b; Maloiy et al., 1986; Minetti et al., 2006), gait (Heglund et al., 1995), and ratings of perceived discomfort (Lloyd et al., 2010a). None of these studies, though, has documented the prevalence of MSS among PLC workers in the field. Therefore, evaluating PLC tasks in relation to MSS, especially as done without assistive devices, is still considered an important topic of investigation, to better understand the scope of the problem and the mechanism(s) of MSS development, and to facilitate ergonomic interventions.

The objectives of the current research were to: 1) investigate the types and prevalence of MSS related to PLC among workers in a developing country; 2) assess the effects of important task demands, related to load mass and size, on torso kinematics and kinetics, muscle activity, torso dynamic stability, and slip risk; 3) evaluate the efficacy of a potential intervention to reduce exposure to factors related to LBP risk associated with PLC. These objectives are addressed in the three subsequent chapters. Chapter 2 addressed the first objective through a structured interview involving 108 PLC workers in eight cities in Indonesia. Evidence of MSS and relevant task characteristics obtained from this served as a basis for the two subsequent chapters. Chapter 3 focused on the second objective, through an experimental study involving nine participants, and Chapter 4 addressed the last objective using a second experimental study. A summary of the current research is included in the final chapter (5), which also discusses several implications and suggestions for future research.

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Chapter 2: Musculoskeletal Symptoms Associated with Traditional Posterior Load Carriage: An Assessment of Manual Material Handling Workers in Indonesia

Khoirul Muslim and Maury A. Nussbaum

ABSTRACT

Concerns have been raised regarding the high prevalence of musculoskeletal symptoms (MSS) among manual material handling (MMH) workers. However, limited investigations have been undertaken among one large group of workers using a particular MMH method called posterior load carriage (PLC). This is typically done without the use of a backpack in developing countries, and involves exposure to known risk factors for MSS such as heavy loads, non-neutral postures, and high levels of repetition. The purpose of this study were to 1) determine the types and prevalence of MSS among PLC workers and the impacts of these MSS on workers, 2) explore job demands potentially contributing to MSS, and (3) obtain input from workers regarding possible improvements, to facilitate future interventions. Structured interview applied to 108 workers, to assess PLC worker characteristics and job demands in eight cities in Indonesia. MSS were reported in all anatomical regions evaluated, with symptoms most commonly reported at the lower back (72.2%), feet (69.4%), knees (64%), shoulders (47.2%), and neck (41.7%). Logistic regression indicated that MSS in the lower back were associated with longer work hours/day, MSS in the hands were associated with load mass, and MSS in the ankles/feet were associated with stature and load carriage frequency. MSS were reported to interfere with daily activity, but only few workers sought medical treatment. Possible improvements included the use of a belt, hook, or backpack/frame, and changes in the carriage method. The study suggests that PLC workers incur a relatively high MSS burden. Future studies are needed to develop and evaluate practical interventions and specific guidelines to improve working conditions and occupational health and safety for PLC workers.

Keywords: musculoskeletal symptoms, low back pain, load carriage, developing country

2.1 Introduction

Manual material handling (MMH) tasks have been associated with the development of diverse musculoskeletal symptoms (MSS) in many studies (Bigos et al., 1986; Kuijer et al., 2011; Kuiper et al., 2005; Kuiper et al., 1999; Marras, 2000; NIOSH, 1997; Snook, 1978; Takala, 2010). MMH comprises a diverse set of tasks, including lifting, lowering, pushing, pulling, and carrying. One type of manual material handling, and of particular interest here, is a set of activities that has been termed "posterior load carriage" (PLC: Anderson et al., 2007; Chow et al., 2011; Li, 2009; Steele et al., 2003), and which involves the human transportation of loads on the back. PLC often involves the carriage of quite heavy loads, in non-neutral postures, with frequent repetitions, and over long durations. Several studies have been reported on PLC tasks done with the use of a backpack, and which have indicated that such tasks likely increase the risk of MSS in several body regions including the lower back, neck, shoulder, upper back, arms, and hands (Birrell & Hooper, 2007b; Korovessis et al., 2005; Skaggs et al., 2006). PLC using a backpack can alter an individual's posture (Al-Khabbaz et al., 2008; Charteris, 1998; Chow et al., 2006; Grimmer et al., 1999), shifting the center of mass posteriorly, and causing a forward lean to maintain balance (Goodgold et al., 2002; Grimmer et al., 2002; Hong & Cheung, 2003). PLC also causes a higher level of muscle activation (Bobet & Norman, 1984; Ghori & Luckwill, 1985; Motmans et al., 2006) and a delayed muscle activation (Simpson et al., 2011), both of which can be considered less efficient and effective aspects of motor control and potential mechanisms contributing to MSS (Hodges & Richardson, 1996; Van Tiggelen et al., 2009).

Although MSS increase when performing PLC tasks with a backpack, as noted above, the relevant studies have been conducted using particular populations (military personnel, students, and hikers). Relatively few investigations have been undertaken among one large group, however, for whom carrying heavy loads is a daily aspect of their work, and who are essentially overlooked in the literature. These are workers performing MMH tasks in developing countries (Lloyd et al., 2010a). PLC methods are common in developing countries, wherein this and other more traditional methods of work are still adopted (Scott, 2009). For a variety of historical, political, social, and/or economic reasons, such traditional methods are used commonly for carrying heavy loads such as rice, flour, and diverse other industrial/commercial products. Further, PLC among these workers is typically done without the use of a backpack or other assistive devices (Figure 2.1) and involves exposure to known risk factors for MSS (i.e., heavy loads, non-neutral postures, and high levels of repetition). Existing reports on traditional load carriage methods, including head loading, have been limited to experimental studies assessing physiological cost (Charteris et al., 1989; Datta et al., 1973; Lloyd et al., 2010b; Maloiy et al., 1986; Minetti et al., 2006), gait (Heglund et al., 1995), and ratings of perceived discomfort (Lloyd et al., 2010a). None of these studies, though, has assessed the prevalence of MSS among PLC workers in the field. Therefore, evaluating PLC tasks in relation to MSS, especially as done without assistive devices, is still considered an important topic of investigation, to better understand the scope of the problem and the mechanism(s) of MSS development (Al-Khabbaz et al., 2008), and to facilitate injury prevention.

Figure 2.1. Illustrations of posterior load carriage practice among manual material handling workers in Indonesia. Captured are two different workers from a traditional market (left) and a loading-unloading dock (right). Workers typically adopt a forward-lean posture while handling a load, using bare hands without the use of an assistive device.

To address the lack of available evidence regarding MSS among PLC workers, this study had three objectives. Completing these was intended to provide a basis for future studies, such as on the effects of different task conditions and to design/evaluate potential interventions. Specifically, we: (1) determined the types and prevalence of MSS among MMH workers using the PLC method and the impacts of these MSS on workers; (2) explored job demands potentially contributing to MSS; and (3) obtained input from workers regarding possible improvements, to facilitate future interventions.

2.2 Methods

2.2.1 Study design

A cross-sectional assessment was completed among MMH workers who are using PLC methods, with a specific focus on workers doing so without the use of a backpack or other assistive devices. This assessment was done in Indonesia, a developing country in which MMH and use of PLC is common. Structured interviews were used along with observations and measurements, to determine the presence of MSS in several anatomical regions, estimate the impacts of these MSS on the workers, evaluate typical job demands, and to obtain worker suggestions for potential improvements to their PLC tasks.

2.2.2. Participants

A total of 108 participants completed the procedures, and were in eight cities in Indonesia (i.e. Yogyakarta, Sleman, Gunung Kidul, Solo, Klaten, Tulung Agung, Kediri, and Jakarta Utara). Assessments were conducted at loading-unloading docks, Indonesia National Food Logistic Agency warehouses, fertilizer manufacturer warehouses, and traditional markets. Participants were limited to individuals who reported working in a PLC job for at least one year; this exclusion criterion was used to minimize potential carry-over MSS from previous jobs. With cooperation from foremen/supervisors, participants were recruited at the worksites using direct contacts and advertisements. Monetary compensation was provided to participants, with a value approximately equal to one meal. Prior to beginning the interview, each participant provided verbal informed consent using procedures approved by the Virginia Tech Institutional Review Board.

2.2.3 Procedures

MSS were determined using questions from the Standardized Nordic Questionnaire (SNQ) (De Barros & Alexandre, 2003; Dickinson et al., 1992; Kuorinka et al., 1987). This tool has been used in several epidemiological studies of work-related MSS (Bentsen et al., 1997; Deakin et al., 1994; Hagen et al., 1997; Palmer et al., 1999; Smith et al., 2005), and has been demonstrated to have good reliability and validity among several occupational groups (Burdorf & Zondervan, 1990; Dickinson et al., 1992; Kuorinka et al., 1987; Ohlsson et al., 1994). In addition, the SNQ is fast to administer and can accommodate diverse workforces and individuals (De Barros & Alexandre, 2003; Deakin et al., 1994; Smith et al., 2005). MSS were assessed for nine anatomical regions: neck, shoulders, upper back, elbows, wrists/hands, lower back, hips, knees, and ankles/feet. Initially, the following question in the SNQ was asked, for each anatomical region: “Have you at any time during the last 12 months had symptoms (ache, pain, stiffness, burning, numbness, or tingling) in <anatomical region>? A positive response led to subsequent questions, again from the SNQ, regarding the relevant anatomical region(s) and focusing on: whether or not the symptoms has been present for the last 7 days; any needs for medical treatment (contact with general practitioner, medical specialist, or physiotherapist, and use of medicines); and any interferences with daily activity including work leave, limitations in daily life, and work disability (total or partial). Positive responses to the latter of these (needs for medical treatment or MSS interfering with daily activity) were termed “adverse sequalae” here, and considered to be indicative of more serious musculoskeletal problems. For bilateral anatomical regions, symptoms were defined as present if MSS involved either or both sides. Note that this definition has been used in prior studies for the purpose of estimating prevalence (Allander, 1974; Andersson et al., 1993; Urwin et al., 1998).

Information regarding gender, age, load carriage frequency, work hours/day, and work experience (duration) was obtained, and individual stature and body mass were measured. Direct observation were used to obtain load mass and load size. The last question in the interview was an open question regarding workers' suggestions on possible improvements or interventions to the task.

The original English version of the assessment instrument (SNQ + additional questions) was translated into the Indonesian language (which is fluently spoken by the experimenter) and was pilot tested with six PLC workers. These participants were informed about the purpose of the research study, and asked to address any questions and provide suggestions concerning the questionnaire. Subsequently, relevant modifications were incorporated.

2.2.4 Data analyses

Descriptive statistics were obtained to summarize the types and prevalence of MSS (in terms of one-year period prevalences and point prevalences) and to summarize the adverse sequalae (interfering with daily activity or requiring medical treatment) for the nine anatomical regions. One-year period prevalence is defined as the number of participants who experienced MSS during the last 12 months divided by the total number of participants assessed during that period (Checkoway et al., 1989). Point prevalence refers to the number of participants who experienced MSS at the time of assessment (the last 7 days) divided by the total number of participants (Checkoway et al., 1989).

Multiple logistic regression was used to identify potential relationships between worker characteristics (age, body mass, and stature) and job demands (load mass, load size, carriage frequency, work duration, and work hours/day) as predictor variables, and MSS (one year prevalence = binary) as the dependent variable. Separate models were fit for each anatomical region. These regression models excluded interactions between predictor variables, given the relatively small sample size and since preliminary analyses found that they led to unstable parameter estimates. Where predictors were significant, associated odd-ratios (OR) are provided along with 95% confidence intervals (CI). Statistical significance was determined when $p < .05$ throughout all analyses, which were conducted using JMP 10 Pro (SAS Institute Inc., Cary, NC).

2.3 Results

2.3.1 Worker characteristics and job demands

Summary statistics regarding worker characteristics and job demands are presented in Table 2.1. Most PLC workers who participated were relatively young males, though a few were older and had been working in their current job for over 30 years. PLC was commonly used to carry industrial or agricultural products such as cement, fertilizer, rice, flour, etc., which are packed in standard units with masses ranging from 10 kg to 60 kg and with varied sizes. Ten different bag sizes were observed, and which ranged from 40 x 60 cm to 80 x 120 cm. Workers indicated that they typically carry as much load as they can handle for a given “trip”; these loads ranged from 30 to 100 kg, equivalent to roughly 50 - 175% of individual body mass. It was often observed that workers adopted a forward-leaning posture (Figure 2.1) and handled the load tightly using a power grip with bare hands.

Table 2.1. Workers information and job demands.

Work Variables	Percentile		
	5th	50th	95th
Age (years)	22.0	35.5	62.0
Stature (cm)	155.0	165.0	175.0
Body mass (kg)	48.4	57.0	72.0
Load carriage frequency (/min)	0.2	1.0	4.0
Load mass (kg)	30.0	50.0	80.0
Work duration (years)	1.5	8.5	30.0
Work hours (/day)	3.0	6.0	8.0

2.3.2 Musculoskeletal symptoms

MSS were reported to be present in all body parts that were assessed, though with varying prevalence and associated adverse sequalae (Table 2.2). Within the past year, MSS were most prevalent in the lower back, followed by the feet, knees, shoulders, and neck. The highest point prevalences were in the lower back and knees, followed by the feet, neck, and shoulders. Regarding adverse sequalae, MSS in the lower back most commonly interfered with workers' daily activity, followed by those in the shoulders, upper back, and feet. Though still relatively rare, medical treatment was most commonly sought for lower back symptoms.

Table 2.2. Prevalence of musculoskeletal symptoms by anatomical region and associated adverse sequalae.

Region	1 year prevalence		1 week prevalence		Interfered daily activity		Needed medical treatment	
	n	(%)[a]	n	(%)[a]	n	(%)[b]	n	(%)[b]
Neck	45	41.7	23	21.3	5	11.1	2	4.4
Shoulders	51	47.2	21	19.4	12	23.5	0	0.0
Upper back	37	34.3	13	12.0	8	21.6	2	5.4
Lower back	78	72.2	39	36.1	35	44.9	5	6.4
Hip	36	33.3	13	12.0	7	19.4	1	2.9
Knees	64	59.3	39	36.1	12	18.7	3	4.7
Feet	75	69.4	35	32.4	16	21.3	3	4.0
Elbows	37	34.3	17	15.7	2	5.4	2	5.4
Hands/wrists	39	36.1	20	18.5	5	12.8	2	5.1

[a] percentage of MSS or adverse sequalae cases relative to the total number of participants (n = 108)

[b] percentage of adverse sequalae per MSS case for each anatomical region.

Some MSS were significantly associated with worker characteristics and/or job demands. MSS in the lower back were significantly and positively associated with longer work hours/day (OR 1.72; CI 1.14 – 2.7; p = 0.0096), MSS in the hands were significantly and positively associated with higher load mass (OR 1.054; CI 1.004 – 1.11; p = 0.033), and MSS at the ankles/feet were significantly and negatively associated with stature (OR 0.9; CI 0.81 – 0.99; p = 0.033) and load carriage frequency (OR 0.59; CI 0.37 – 0.93; p = 0.024).

2.3.3 Improvements

Relatively few potential improvements were provided by the PLC workers. The most frequently suggested improvement, by 38 workers, was the use of a belt to tighten their “core” (such as a “back belt” or lumbar support). Some workers suggested other improvements that involve the use of assistive devices; these included use of a hook (n=6), a backpack/frame or cart for long distance carriage (n=4), and a soft (e.g., foam) layer to soften the load surface and increase friction (n=1). Four workers suggested improvements that involve a change in the carriage method, including carrying the load in a higher position on the back, head loading, and anterior loading. However, the workers thought that these improvements related to carriage methods were likely feasible only if the carriage distance was relatively short and the loads were relatively light.

2.4 Discussion

Most PLC workers in the current sample were relatively young males, though there were a few older workers who had done similar work for over 30 years. Some of these older workers suggested that they stay in their current job because of a lack of qualifications to work in other, less physically demanding, jobs. Interestingly, some older workers indicated not having any MSS during the prior year. Future work should examine this more closely, as such workers may have specific work strategies that are protective of musculoskeletal problems. These workers were also relatively "small" compared to, for example, the US adult male population; 95th percentile body mass in the former (80 kg) is lower than mean body mass (88 kg) in the latter (Fryar et al., 2012). In contrast, the observed PLC job demands can be considered as quite heavy manual labor, at least based on contemporary MMH guidelines. Specifically, the median (and mode) observed load (50 kg) was substantially higher than the NIOSH-recommended weight limit (23 kg) for tasks done under "optimal" conditions (Waters et al., 1993), and the median (44 kg) psychophysical value (maximum acceptable weight of carry) for the shortest distance (2.1 m) and the lowest frequency (1 carry/8 hours) (Snook & Ciriello, 1991). Workers need to carry load frequently, during relatively long daily working hours, both of which likely contribute to an increased risk for PLC workers (Scott, 2009). Though not formally quantified, PLC workers were observed to typically adopt a forward-leaning trunk posture (*cf.* Figure 2.1), which is consistent with several reports on postural changes among backpack users (David et al., 1997; Mackenzie et al., 2003; Talbott et al., 2009). A forward leaning posture is suggested as a mechanism to compensate for the posterior shift in system center of mass to maintain balance (Goh et al., 1998; Goodgold et al., 2002). However, this posture may cause a higher level of paraspinal muscle activation and delayed muscle activation (Kollmitzer et al., 2002; Slijper & Latash, 2000; Toussaint et al., 1997), both of which can be considered less efficient and effective aspects of motor control and potential contributors to low back injuries.

PLC workers reported experiencing MSS in several anatomical regions during the prior year. In particular, there was a relatively high prevalence of MSS in the lower back (72.2%), which is similar to the prevalence of low back pain (74.4%) associated with backpack use among adolescents (Sheir-Neiss et al., 2003) and among manual workers in the garment industry in China (74%: Jin et al., 2004). The next most common MSS were in the feet, knees, shoulder and neck. MSS in similar anatomical regions are also commonly reported among backpack users (Birrell & Hooper, 2007a; Korovessis et al., 2005; Sheir-Neiss et al., 2003; Skaggs et al., 2006). All of these MSS are likely related to the particular demands of PLC tasks, which involve transporting heavy loads (Deros et al., 2010) and direct contact of these loads with the upper back and neck. Specifically, MSS in the lower back were positively associated with longer work hours/day. Consistent with this finding, several studies have reported an association between MSS cases among backpack users with a longer duration of backpack use (Chiang et al., 2006; Negrini & Carabalona, 2002; Talbott et al., 2009). Interestingly, the well-known relationship between load mass and MSS in the lower back (Moore et al., 2007; Negrini & Carabalona, 2002; Talbott et al., 2009) was not observed in the present study. This might be explained as in Talbott et al. (2009), who noted that regardless of the load mass, a long duration of backpack use may result in back pain development. Another explanation could be that the sample size in the present study was insufficient to obtain a significant relationship. In addition, the loads observed in the present study were much heavier (50 - 175% of body mass) compared to those in the backpack studies (10-25% of body mass). This may account for why the relationship between load mass and lower back MSS in the present study was different from that in existing backpack studies.

MSS in the hands were positively associated with heavier load mass. This may be related to the load handling/holding method, which typically involved the use of a power grip with bare hands and without the use of an assistive device. The heavier the load, the tighter workers need to hold it, which likely contributes to pain development in the hands. An interesting association was found between MSS in the ankles/feet and worker stature and load carriage frequency. Specifically, MSS in the ankles/feet were higher among shorter workers and with a lower load carriage frequency. It may be that shorter workers need to take more steps in one load carriage trip compared to taller workers, leading to a greater cumulative impact from ground reaction forces to the ankle joints or feet during the day. Regarding the negative association with load carriage frequency, it may be that heavier loads are carried less frequently but that each carriage induces larger loads on the feet. However, the opposite was true (slight positive association), which make this relationship unclear. An alternative explanation is that only stronger workers are able to perform PLC tasks at a higher frequency, or that there is a health-worker survivor effect. Future studies are clearly needed to confirm such associations.

Cumulative load might also be a risk factor for MSS (Coenen et al., 2013; Gerr et al., 2013; Kumar, 1990). Here, cumulative daily loading could be estimated as the product of work hours x load carriage frequency. It was initially considered here as an interactive effect in the multiple linear regression models. Yet, as noted earlier, such interaction effects were excluded because of the relatively small sample size and since preliminary analyses found that they led to unstable parameter estimates. Future work should examine this issue, using large sample sizes and/or more direct measures of cumulative physical demands.

MSS in all the anatomical regions examined often interfered with workers' daily activity such as by leading to work leave, limitations to daily life, or work disability. For example, nearly half of the workers who experienced MSS in the lower back reported such interference. These results agree with studies reporting on students have limited their activity or left school due to MSS associated with the use of a backpack (Moore et al., 2007; Skaggs et al., 2006). Interestingly, only a few PLC workers indicated that they sought medical treatment for their MSS. Only 6% of those with MSS in the lower back sought treatment, and the percentage was even lower for those with MSS in other anatomical regions. Such a low use of medical treatment for musculoskeletal problems has also been reported for other developing countries in rural Africa (Belcher et al., 1976). Nevertheless, roughly 10 – 40% of PLC workers are still experiencing MSS in one or more anatomical regions, and the relative lack of seeking treatment may stem from a lack of awareness, limited access, and/or aspects related to the worker "culture".

Only few workers provided potential improvements for the PLC task. This might indicate limited access to the knowledge base of ergonomics and lack of awareness regarding the potential benefit of ergonomics to improve their task, which is a common condition in developing countries (Shahnavaz, 2009). The set of improvements that were suggested included the use of simple belt ("back belt"), hook, backpack/frame, cart, soft layer, and a change in carriage method for lighter loads and shorter distance. Use of a belt was the most popular suggestion, and workers indicated that this was offered due to an assumed ability (and benefit) to tighten the body core during carriage. However, there has been mixed and limited evidence in support of a beneficial effect of using a back belt to prevent low back pain (Ammendolia et al., 2005; Hodgson, 1996; NIOSH, 1994; Wassell et al., 2000). Though only a few workers suggested the use of a hook and backpack/frame, and several studies have related backpack use with MSS, the use of such assistive devices may help to reduce MSS in several anatomical regions for this particular task. Assistive devices could benefit workers in supporting and handling the load and could potentially improve their posture during load carriage. The use of a cart was also suggested by several workers to improve the task when longer carrying distances were required. However, in the work sites observed here no such carts were used. Use of this was actually not feasible, due to worksite limitations such as narrow aisles in the traditional markets and stairs in the warehouses. Lastly, if the standard load mass for most industrial products can be reduced, MMH workers might benefit from the use of alternative load carriage methods, other than PLC, such as head loading. Though the carriage capacity is smaller and the energy expenditure is bigger (Lloyd et al., 2010b), head loading has been shown to cause less discomfort compared to back loading (Lloyd et al., 2010a). Further studies are needed to investigate the benefits of these potential improvements for workers performing this specific task.

We acknowledge several limitations of the present study including the small sample size, use of a cross sectional design with self-report, and potentially limited generalization of the results. The sample size was constrained due to resource availability and the use of a structured interview. The latter was more time consuming and limiting off number of worker that could be reached, compared to questionnaire or follow up letters. However, a structured interview was chosen to better deliver and explain the questions and to obtain more in-depth information regarding worker characteristics, job demands, and potential improvements. In addition, since PLC workers usually have limited access to information and technology, a personal approach (e.g., versus a web-based one) was considered more appropriate to reach them. Nonetheless, the current findings, especially regarding the prevalence of MSS, were consistent with other studies of similar tasks, which suggests that the sample and sampling technique may not be substantially biased.

Perceptions of pain or discomfort associated with MMH have been used in the literature (Ghaffari et al., 2006; Sheir-Neiss et al., 2003; Smith et al., 2005) and considered to be consistent, valid, and reliable. It must be acknowledged, though that self-reported MSS here, which involved only participants' perceptions with no medical diagnoses, may not validly reflect workers current health status. In addition, since this was a cross-sectional study design, caution should be used when interpreting the current outcomes; causal relationship between factors cannot be made strongly. Further, though we asked the workers in the interviews if their symptoms were mainly influenced by their job, there are other potential factors in their daily life that could contribute to their musculoskeletal symptoms. This study only involved workplaces that represented the typical loading-unloading docks, warehouses, and traditional markets on Java Island, Indonesia. These may not be representative of all similar work places in other regions or developing countries, for example traditional MMH in African countries can involve head loading and PLC with straps (Ling et al., 2004; Lloyd et al., 2010a; Lloyd et al., 2010b; Maloiy et al., 1986). Therefore, the results of this study would be most applicable to similar work places that require PLC without the use of assistive devices and less applicable to those with different traditional MMH methods. Further studies may need to include other potential factors to better understand the mechanisms of MSS development among PLC workers and should include more regions/countries to extend generalizability.

In summary, the current study documented PLC workers characteristics, job demands, and associations of these with MSS. The results overall suggest relatively high job demands and a high prevalence of MSS among PLC workers in Indonesia. MSS in all the anatomical regions evaluated were reported to interfere with workers' daily activity. However, only few workers sought medical treatment. Some MSS were associated with particular worker characteristics and/or job demands; for example, MSS in the lower back was associated with work hours/day. Despite the high job demands and prevalence of MSS, unfortunately international guidelines are limited and/or often impossible to implement due to the unique characteristics of the PLC task. Existing guidelines on PLC include limiting the load mass and suggesting different method of carriage (Grimmer et al., 1999; Mackie et al., 2003; Moore et al., 2007; Negrini & Carabalona, 2002). However, these guidelines are intended for PLC with the use of a backpack and may not be relevant for the PLC tasks observed in this study. Therefore, further studies focusing on worksite assessments, laboratory/experimental studies, practical interventions, and specific local guidelines are needed to improve working conditions and occupational health and safety among PLC workers.

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Chapter 3: Ergonomic Evaluation of Traditional Posterior Load Carriage: Effects of Load Mass and Size on Torso Kinematics, Kinetics, Muscle Activity, and Movement Stability

Abstract

Traditional posterior load carriage (PLC), which is done without the use of an assistive device (e.g., backpack), has been associated with a high prevalence of low back pain (LBP). Existing studies of such tasks, however, have been limited to assessments of physiological cost and ratings of perceived discomfort. With a long-term goal of facilitating ergonomic guidelines and interventions, this study evaluated the effects of important task demands, related to load mass and size, on potential mechanisms linking traditional PLC to this higher risk of LBP. Nine healthy participants completed PLC tasks with all combinations of three load masses (20, 35, and 50% of individual body mass) and three load sizes (small, medium, and large). Torso kinematics, kinetics, muscle activity and slip risk were evaluated during PLC on a walkway, and torso movement stability was quantified during PLC on a treadmill. Increasing load mass caused increased torso flexion, L5/S1 flexion moment, abdominal muscle activity, and torso movement stability in the frontal plane. Increasing load size also caused higher torso flexion, peak torso angular velocity and acceleration, and abdominal muscle activity. Complex interactive effects of load mass and size were found on paraspinal muscle activity and slip risk. Specific task demands, related to load mass and size, may influence the risk of LBP during PLC.

Keywords: Traditional load carriage; spine; stability; kinematics; kinetics; slip risk

3.1 Introduction

Low back pain (LBP) is the leading work-related medical problem worldwide (Kent & Keating, 2005; Loney & Stratford, 1999; Volinn, 1997). LBP causes substantial societal and personal burdens, including loss of wages and productivity and interference with daily activities among industrial workers in both developed and developing countries (Galukande et al., 2006; Lubeck, 2003). An increased risk of LBP has been associated with occupational manual material handling (MMH), particularly tasks that involve repetitive lifting and transportation of heavy loads (Bigos et al., 1986; NIOSH, 1997; Snook, 1978). One particular type of MMH that has been associated with a high prevalence of LBP, and of interest here, is posterior load carriage (PLC: Chapter 2). PLC is common in developing countries, wherein this and other more traditional methods are commonly used when carrying heavy loads such as rice, flour, and diverse other industrial/commercial products (Datta & Ramanathan, 1971; Scott, 2009). Further, PLC is typically done without the use of any assistive devices (e.g., backpack), involves exposure to known risk factors for LBP such as heavy loads, non-neutral postures, and high levels of repetition, and PLC workers have a high prevalence of LBP (Chapter 2).

There is limited existing literature, however, that has addressed the effect of task demands on the mechanism linking PLC tasks without the use of an assistive device to the higher risk of LBP. Experimental studies on such PLC tasks have been limited to assessments of physiological cost (Datta & Ramanathan, 1971; Lloyd et al., 2010b) and ratings of perceived discomfort (Lloyd et al., 2010a). Several relevant investigations have been reported, though, regarding LBP risks related to PLC tasks using a backpack. Carrying a backpack alters the normal upright posture (Al-Khabbaz et al., 2008; Charteris, 1998; Chow et al., 2006; Grimmer et al., 1999), shifts the system's center of mass posteriorly, and causes a forward lean to maintain balance (Goodgold et al., 2002; Grimmer et al., 2002; Hong & Cheung, 2003). PLC with a backpack also causes an increase in back muscle activation (Bobet & Norman, 1984; Knapik et al., 1996), which may lead to muscular pain and fatigue (Chaffin, 1973). The effects of backpack use, however, appear to be dependent on the load being carried. For example, carrying a light load causes relatively small changes in back muscle activity (Al-Khabbaz et al., 2008; Cook & Neumann, 1987; Motmans et al., 2006), whereas heavier loads (i.e. ~20 – 40 kg) have been shown to substantially increase erector spinae muscle activity (Bobet & Norman, 1984; Knapik et al., 1996). Carrying a heavy backpack has also been shown to increase torso flexion angles and moments (Chansirinukor et al., 2001; Hong & Cheung, 2003; LaFiandra et al., 2002), and to affect both postural and movement stability (Heller et al., 2009; Palumbo et al., 2001).

PLC as done in developing countries (i.e., without the use of an assistive device), however, has different characteristics compared to backpack carriage. As examples, loads are typically held/stabilized with the hands at the top of the load, and the loads themselves are typically carried high on the dorsum of the torso. As such, existing evidence related to PLC using a backpack may not be applicable to more traditional PLC methods. Therefore, this study aimed to evaluate PLC task demands, with a specific emphasis on identifying potential mechanisms linking traditional PLC to higher LBP risk, and in the longer term to facilitate the development of ergonomic guidelines and interventions. Substantial variability in load mass and size was found in a recent survey of traditional PLC work sites (Chapter 2), and thus the effects of these factors were assessed. Risks of LBP development were estimated using intermediary measures derived from torso kinematics, kinetics, and muscle activity (Bobet & Norman, 1984; Knapik et al., 1996). Given the effects of PLC on stability noted earlier, measures of torso movement stability and slip risk were also obtained. We hypothesized that all of these measures of risk would increase with both load mass and load size, as results of inertial and/or postural differences between these load conditions.

3.2 Methods

3.2.1 Participants

Nine participants completed the study, all of whom reported being healthy and with no history of low-back pain or any current medical conditions that might have influenced the results. Participants were all males, with mean (SD) age, stature, and body mass of 22.6 (2.2) years, 1.81 (0.05) m, and 71.6 (5.8) kg, respectively. Males were used to match the typical population doing traditional PLC (Chapter 2), and a relatively young group of participants was included to avoid potential influences related to age. Prior to beginning the study collection, participants completed informed consent procedures approved by the Virginia Tech Institutional Review Board.

3.2.2 Experimental design and procedures

The experiment was composed of two sessions, in which PLC tasks were simulated in a laboratory environment, and done on both a walkway and on a treadmill; the two configurations were used to obtain two classes of outcome measures. PLC on a walkway facilitated measuring torso kinematics and kinetics, which required a force platform in the walkway, whereas PLC on a treadmill was used for measuring torso movement stability, which required multiple cycles of motion data. The two sessions were completed on separate days, with a minimum of two days between each, and in a random order.

3.2.2.1 PLC Task on a walkway

Each walkway session began with warm-up activities, several maximum voluntary contraction (MVC) trials, and a set of PLC practice trials. MVC trials were used to obtain maximum activity levels for select muscles in the lower torso (see below). MVCs were completed with the participant was standing upright and strapped to a rigid fixture, in which they performed several flexion and extension efforts to their maximum ability and using procedures described earlier (Jia et al., 2011). PLC practice trials were used to confirm that participants could complete load carriage tasks in all conditions, and to minimize subsequent learning effects within and between trials. Practice trials were also used to identify the proper starting position on the walkway to ensure proper foot placement (on a force platform described below).

Participants repetitively carried a load, using a traditional PLC technique, over ~5 m on a flat walkway. Participants handled the load using their bare hands at the upper two corners of the bag, without the use of an assistive device (Figure 3.1). A helper placed the load on the participant's back at the start and lowered the load at the end of each carry. Participants completed three trials of PLC using each of the nine load conditions at one carry per minute and with five-minute rest between load condition, and using a self-selected carrying pace. The order of the nine load conditions was counterbalanced across participants (using a 9 x 9 Latin Square). Loads were set based on individual body mass (BM), specifically 20% (20BM), 35% (35BM), and 50% (50BM) of individual body mass. Industrial products including rice, dog food, birdseed, sand, and metal pellets were used to fit the loads into small (S), medium (M), and large (L) sizes, with respective (unpacked) areas of 30 x 50, 40 x 60, and 55 x 80 cm. These ranges of load mass and size were selected to reflect distributions observed from a recent field study (Chapter 2).

Figure 3.1. Experimental set-up demonstrating a participant during PLC trials on the walkway (left) and on the treadmill (right).

Segmental kinematics data were recorded during PLC trials, using reflective markers attached bilaterally to the feet, shanks, hips, and torso, and largely based on anatomical landmarks described by Dumas et al. (2007). Marker positions were tracked at 120 Hz using a 6-camera system (Vicon Motion System, Inc., CA, USA). Ground reaction forces and moments, during a portion of one gait cycle, were sampled at 960 Hz using a force platform (OR6-1000, AMTI, Watertown, MA) embedded in the walkway. Marker and force platform data were low-pass-filtered (bi-directional, 2nd order Butterworth) with respective cut-off frequencies of 6 and 12 Hz, and force platform data were down-sampled to 120 Hz to be consistent with the marker data.

Raw electromyographic (EMG) activity of select paraspinal and abdominal muscles was recorded using Ag/AgCl disposable surface electrodes (Lynn Medical, MI, USA) that were placed as in earlier reports (Potvin et al., 1996; van Dieën, 1997). EMG was recorded bilaterally from the erector spinae, rectus abdominis, and external oblique muscles, to indirectly assess spinal loading during the PLC tasks. Erector spinae muscles were sampled using electrodes placed at the L1 (ES1) and L3 (ES3) levels, ~ 2 cm lateral to the midline. Electrodes for the rectus abdominus (RA) were at the level of the anterior superior iliac spine, ~ 2 cm lateral to the midline, while those for the external oblique (EO) were placed midway between the lateral aspect of the lowest rib and anterior superior iliac spine. Electrodes sites were shaved as needed, abraded, and cleaned with rubbing alcohol, and interelectrode impedance was verified as < 10 KΩ (Boone & Holder, 1996). Raw EMG signals were preamplified near the electrode sites, then amplified and bandpass filtered in hardware (TeleMyo 900, Noraxon, AZ) and sampled at 960 Hz. Root mean square (RMS) values were obtained from raw EMG.

Dependent measures were obtained to describe torso kinematics, kinetics, muscle activity, and slip risk. Kinematic and muscle activity measures were derived from windows of data that included one and a half complete gait cycles. These windows were centered on a foot being in contact with the force platform (Figure 3.2). Torso kinematics were characterized using lumbar angles (thorax relative to the pelvis), and were derived from the marker data (as in Winter, 2004). Triaxial torso angles were defined using Euler angles corresponding to the X (anterior-posterior = AP), Y (medial-lateral = ML), and Z (superior-inferior = SI) axes, and with an XYZ rotation sequence (Kingma & van Dieën, 2004). Five-point derivatives (of rotation matrices) were used to calculate angular velocities and accelerations (Kingma et al., 1998). Torso kinematics within each walkway trial were summarized using mean and peak angles, peak angular velocities, and peak angular accelerations. Means of RMS muscle activity were obtained from bilateral muscle pairs across the noted windows, and these are reported as percentages of MVCs. The total level of muscle activity was also obtained, as a summation of percentage MVCs across all muscles monitored.

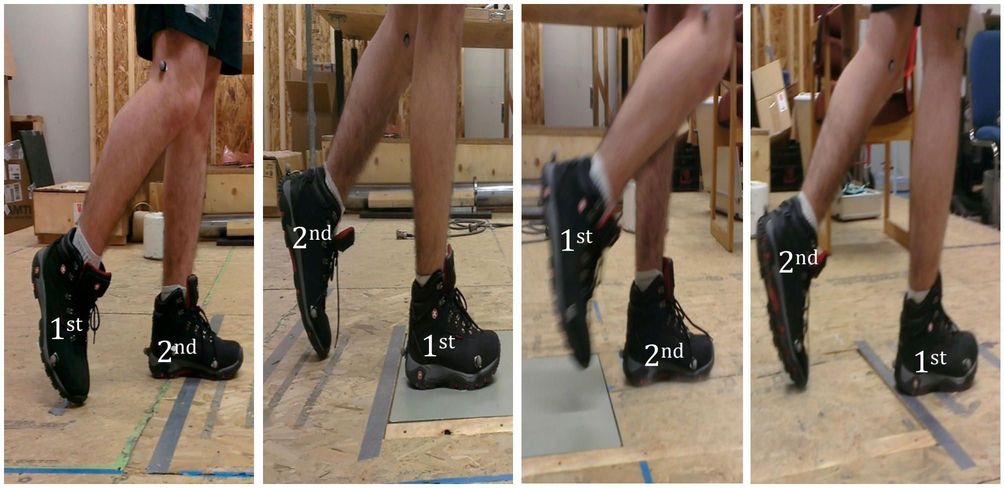

Figure 3.2. Illustration of data window during which kinematics and muscle activity were assessed. These windows comprised 1.5 complete gait cycles, starting when the 1st foot left the ground (far left) and ending when that foot contact the ground for the second time (far right).

Torso kinetics and slip risk were calculated using a subset of data from the noted windows (i.e., 1.5 gait cycles), specifically the time over which one foot was in contact with the force platform and the other was not in contact with the ground. Torso kinetics were described using mean and peak L5/S1 moments, and calculated using a "bottom-up" approach as described earlier (Kingma & van Dieën, 2004; Lee & Nussbaum, 2012). For this, a 3D, linked-segment model was used, consisting of seven body segments (i.e. feet, shanks, hips and torso) that was scaled using data from Dumas et al. (2007). L5/S1 moments were normalized to individual stature and body mass (Hof, 1996). Considering the low variability in torso lateral bending and twisting movement when performing symmetric load carriage similar to PLC (Pascoe et al., 1997; Yen et al., 2012), only peak values of sagittal-plane torso kinematics and kinetics were subsequently analyzed (positive values indicate torso flexion and an external flexion moment, respectively). Slip risk was measured from peak values of the required coefficient of friction (RCOF) obtained in each walkway trial. RCOF was computed as the largest instantaneous ratio of horizontal (resultant force in the AP and ML directions) to vertical ground reaction forces (Burnfield & Powers, 2006; Redfern & Andres, 1984).

3.2.2.2 PLC Task on a treadmill

Each participant performed PLC tasks on a treadmill that were similar to those on a walkway (i.e., nine loads in the same combinations of load masses and sizes, and in a counterbalanced order), and treadmill sessions included similar warm up activities and practice trials. However, in this session, only a 90-second trial was conducted on a treadmill (Figure 3.1) for each condition. This duration was considered sufficient to obtain data (gait) cycles for computing stability measures (Lockhart & Liu, 2008). Treadmill walking was done at each participant's preferred walking speed, which was determined using a protocol described earlier (Dingwell & Marin, 2006); this protocol also allowed participants to acclimate to walking on the treadmill (Wall & Charteris, 1980).

Segmental kinematics were recorded as in the walkway sessions. Torso movement stability was quantified using the largest Lyapunov exponent (Rosenstein et al., 1993). Detailed methods regarding the use of LLEs for biomechanics analyses are available elsewhere (England & Granata, 2007; Liu et al., 2008; Lockhart & Liu, 2008), and the same methods were employed here. Three LLEs were obtained as dependent measures, derived from torso angular time series about the AP, ML, and SI axes (Lee & Nussbaum, 2013), and using the TISEAN software package (Hegger et al., 1999) with the same number of data points (i.e., 10,000).

3.2.3 Statistical analyses

Separate repeated-measures analyses of variance (ANOVAs) were used to determine the effects of load mass and size on each dependent measure using the Restricted Maximum

Likelihood (REML) method. Several measures were log-transformed due to achieve normally-distributed residuals. As relevant, post-hoc pairwise comparisons were performed using Tukey's Honestly Significant Difference (HSD) test, and significant interaction effects were explored using simple effects analyses. Some data were excluded from analysis due to measurement errors, including all kinematics and kinetics measures from four trials (of four different participants), RA and EO muscle activity from 22 trials (of five different participants), and ES1 and ES3 muscle activity from four trials (of four different participants). Measurement errors in the kinematics and kinetics data were detected by visual inspection (i.e., missing markers). The same assessment was used to detect measurement errors for muscle activity, which were mainly caused by signal loss from the wireless EMG system. Outliers were detected and removed based on Grubbs' test (Grubbs, 1969), including one data point from mean torso angle, two data points from peak torso angular velocity, four data points from RCOF, three data points from ES1, one data point from ES3, four data points from RA and nine data points from EO. All statistical analyses were done using JMP™ (Version 10, SAS Institute Inc., Cary, NC), and significance was determined when $P < 0.05$. Summary statistics are reported as means (95% Confidence Interval) in the original units.

3.3 Results

Self-selected walking speeds on the walkway and treadmill are summarized in Table 3.1. Speeds on the walkway increased with load mass, in an effect that approached significance (P = 0.056). Treadmill walking speed also decreased with load mass (P = 0.0047). A summary of the statistical results, regarding the effects of load mass and size on each dependent measure, is presented in Table 3.2.

Table 3.1. Mean (SD) of self-selected walking speed (m/s) for each loading condition on the walkway (WW) and treadmill (TM).

Mass / Size	20BM		35BM		50BM		Mean	
	WW	TM	WW	TM	WW	TM	WW	TM
S	1.14 (0.14)	0.93 (0.12)	1.11 (0.15)	0.90 (0.12)	1.09 (0.17)	0.89 (0.11)	1.11 (0.15)	0.91 (0.11)
M	1.11 (0.13)	0.91 (0.11)	1.09 (0.15)	0.89 (0.11)	1.11 (0.16)	0.89 (0.11)	1.10 (0.15)	0.90 (0.11)
L	1.12 (0.12)	0.91 (0.09)	1.11 (0.15)	0.90 (0.09)	1.10 (0.13)	0.86 (0.12)	1.11 (0.13)	0.89 (0.10)
Mean	1.12 (0.13)	0.92 (0.10)	1.10 (0.15)	0.90 (0.10)	1.10 (0.15)	0.88 (0.11)	1.11 (0.14)	0.90 (0.11)

Table 3.2. The effects of load mass and size on all dependent measures. Bolded values indicate significant effects. Note that kinematic, kinetics, and EMG measures were obtained during walkway trials, whereas LLEs were obtained during treadmill trials.

Measure	Load Mass	Load Size	Mass x Size
Mean torso angle	**$F_{(2,213)}$= 100.65, *P*< 0.0001**	**$F_{(2,213)}$= 9.23, *P*= 0.0001**	$F_{(4,213)}$= 0.77, *P*= 0.54
Peak torso angle	**$F_{(2,214)}$= 13.82, *P*< 0.0001**	**$F_{(2,214)}$= 101.60, *P*< 0.0001**	$F_{(4,214)}$= 0.52, *P*= 0.72
Peak torso angular velocity	$F_{(2,212)}$= 0.96, *P*= 0.38	**$F_{(2,212)}$= 6.74, *P*= 0.0014**	$F_{(4,212)}$= 1.96, *P*= 0.10
Peak torso angular acceleration	$F_{(2,214)}$= 2.82, *P*= 0.062	**$F_{(2,214)}$= 5.79, *P*= 0.0035**	$F_{(4,214)}$= 1.017, *P*= 0.40
Mean L5/S1 moment	**$F_{(2,214)}$= 40.72, *P*< 0.0001**	$F_{(2,214)}$= 0.26, *P*= 0.77	$F_{(4,214)}$= 0.93, *P*= 0.45
Peak L5/S1 moment	**$F_{(2,214)}$= 37.88, *P*< 0.0001**	$F_{(2,214)}$= 0.36, *P*= 0.70	$F_{(4,214)}$= 0.43, *P*= 0.79
ES1 activity	**$F_{(2,211)}$= 20.77, *P*< 0.0001**	**$F_{(2,211)}$= 3.40, *P*= 0.035**	$F_{(4,211)}$= 2.36, *P*= 0.055
ES3 activity	**$F_{(2,213)}$= 31.55, *P*< 0.0001**	**$F_{(2,213)}$= 4.082, *P*= 0.018**	**$F_{(4,213)}$= 5.75, *P*= 0.0002**
RA activity	**$F_{(2,192)}$= 15.63, *P*< 0.0001**	**$F_{(2,193)}$= 14.45, *P*< 0.0001**	$F_{(4,197)}$= 1.36, *P*= 0.30
EO activity	**$F_{(2,187)}$= 8.10, *P*= 0.0004**	**$F_{(2,187)}$= 12.55, *P*< 0.0001**	$F_{(4,187)}$= 1.0042, *P*= 0.41
Total Muscle activity	**$F_{(2,182)}$= 59.52, *P*< 0.0001**	$F_{(2,182)}$= 2.90, *P*=0.057	**$F_{(4,182)}$= 3.26, *P*= 0.013**
RCOF	$F_{(2,208)}$= 2.69, *P*= 0.070	**$F_{(2,208)}$= 4.62, *P*= 0.011**	**$F_{(4,208)}$= 3.59, *P*= 0.0076**
LLE AP	$F_{(2,55)}$= 1.29, *P*= 0.28	$F_{(2,55)}$= 1.59, *P*= 0.21	$F_{(4,55)}$= 1.31, *P*= 0.28
LLE ML	**$F_{(2,52)}$= 5.39, *P*= 0.0075**	$F_{(2,52)}$= 0.69, *P*= 0.50	$F_{(4,52)}$= 2.10, *P*= 0.094
LLE SI	$F_{(2,53)}$= 2.17, *P*= 0.12	$F_{(2,53)}$= 0.12, *P*= 0.89	$F_{(4,53)}$= 1.69, *P*= 0.17

3.3.1 Torso kinematics and kinetics

Across all load conditions, mean and peak torso flexion angles were 15.9 (14.8-17.0)° and 17.6 (16.5-18.7)°, respectively. Both mean and peak torso angles significantly increased with load mass and size (Figure 3.3). Peak torso angular velocity increased with load size. Respective values of 7.76 (7.23-8.29), 8.29 (7.65-8.92), and 9.10 (8.43-9.77) °/s were found when carrying S, M, and L loads, and with significant pairwise differences between velocities using the S and L loads. Though the effect only approached significance, peak torso angular acceleration increased with load mass, with respective values of 51.18 (48.01-54.35), 54.62 (51.45-57.79), and 55.65 (51.60-59.70) $°/s^2$ when carrying 20BM, 35BM, and 50BM. Peak torso angular acceleration also increased with load size. These peak accelerations were approximately 52 $°/s^2$ with S and M loads, and significantly higher (~57.5 $°/s^2$) using the L load. Mean and peak L5/S1 moments, across all load conditions, were 1.11 (1.07-1.16) and 2.07 (1.99-2.15) Nm/kg.m, respectively, and both moments increased with load mass (Figure 3.4).

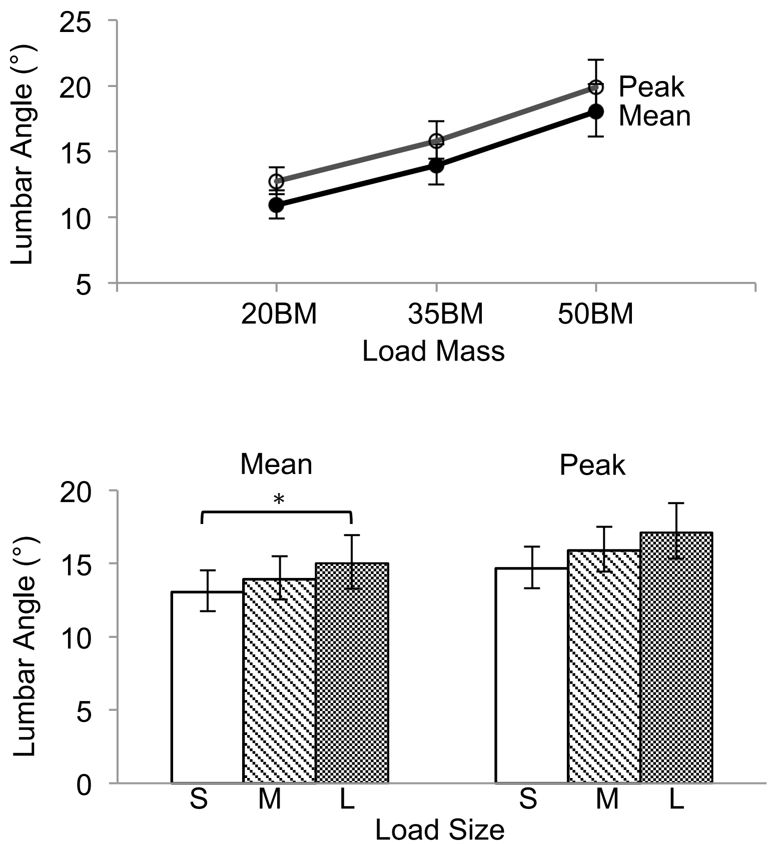

Figure 3.3. Effects of load mass (upper) and size (lower) on mean and peak torso angles. Error bars indicate 95% Confidence Intervals. Excepting the effect of load size on mean lumbar angle, all pairwise differences between factors levels were significant (* = significant difference between load sizes)

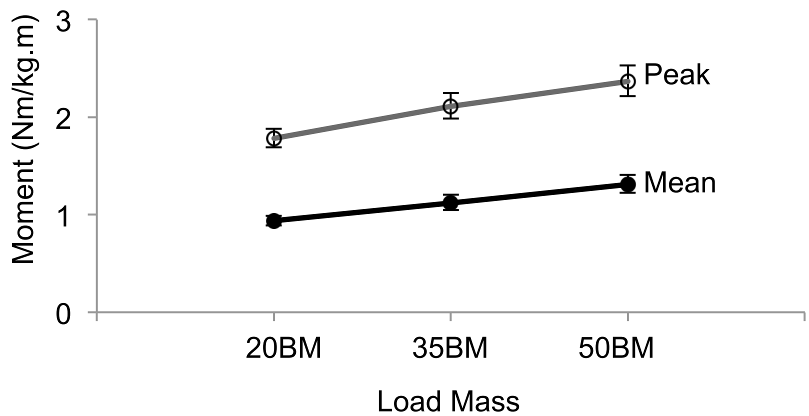

Figure 3.4. Effects of load mass on mean and peak L5/S1 moments (normalized to individual stature and mass). Error bars indicate 95% Confidence Intervals. All pairwise differences between levels of load mass were significant.

3.3.2 Muscle activity

There was an load mass x size interaction effect on ES1 that approached significance and a significant load mass x size interaction effect on ES3, with two evident patterns for both (Figure 3.5). First, the effect of mass was more substantial with larger loads. Second, the effect of load size depended on the load mass. With the lightest load (20BM), paraspinal muscle activity decreased as load size increased, whereas an increase in activity with load size was found for the heaviest load (50BM). Abdominal muscle activity (RA and EO) increased with both load mass and size, though the magnitudes of these effects were relatively small. Specifically, RA activities with the 35BM and 50BM loads (~4.5%) were significantly higher than when carrying the 20BM load (~3.5%), and RA activity using the L load (~5%) was significantly higher than that with both S and M loads (~3.5%). EO activity was approximately 8.5% using the 35BM and 50BM loads, significantly higher than with the 20BM load (~8%). EO activity when carrying the L load (~9%) was significantly higher than that with the two other sizes (~7.5%). There was a significant load mass x size interaction effect on total muscle activity, with two patterns evident that were the same as for paraspinal muscle activity (Figure 3.6).

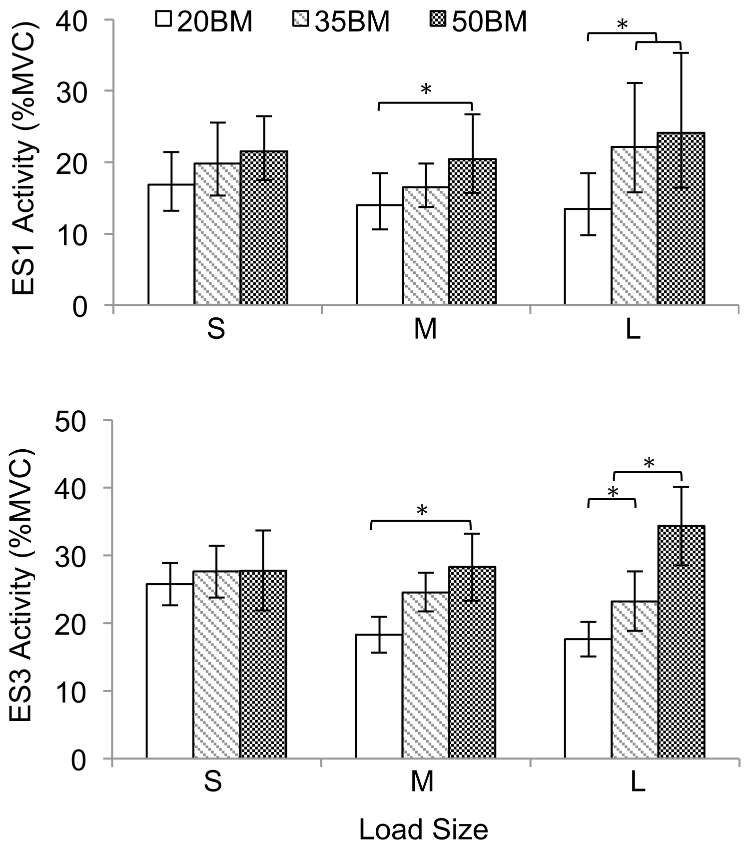

Figure 3.5. Effects of load mass and size on muscle activity of ES1 (upper) and ES3 (lower). Error bars indicate 95% Confidence Intervals. The effect of load mass was significant with larger loads (* = significant difference between load masses)

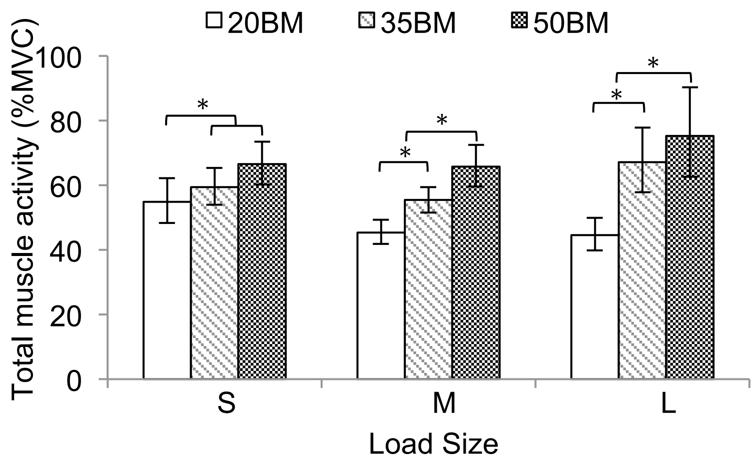

Figure 3.6. Effects of load mass and size on total muscle activity. Error bars indicate 95% Confidence Intervals, and * indicates significant pairwise differences between masses.

3.3.3 Slip risk and stability

Load mass and size had a significant interaction effect on RCOF. When carrying the 20BM and 35BM loads, there was a “U”-shaped relationship between load mass and RCOF, whereas RCOF decreased with load size when carrying the heaviest load (Figure 3.7). Further, the effect of increasing load mass qualitatively differed, depending on the specific load size. LLE ML decreased with increased load mass. Values of 1.10 (1.017-1.18), 1.086 (0.99-1.18) and 0.97 (0.87-1.07) were found when carrying loads of 20BM, 35BM and 50BM, respectively, with those during 50BM load carriage significantly lower than when using either of the smaller loads.

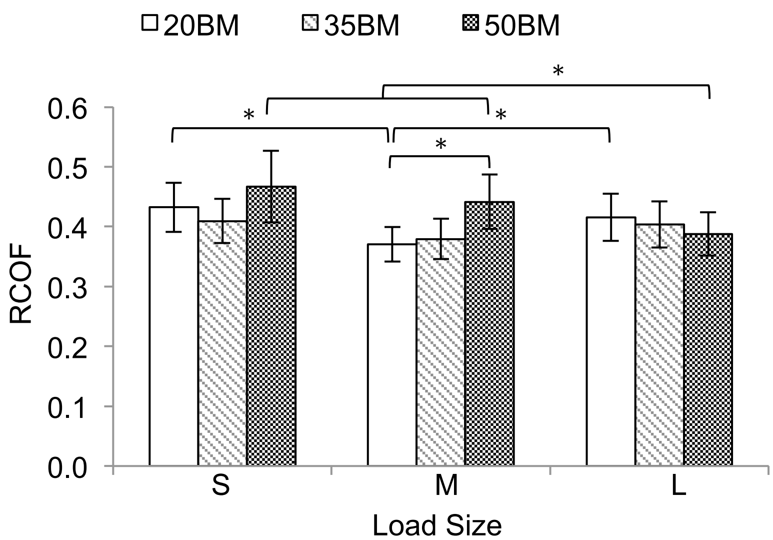

Figure 3.7. Effects of load mass and size on RCOF. Error bars indicate 95% Confidence Intervals, and * indicates significant pairwise differences.

3.4 Discussion

Self-selected walking speeds differed between load mass conditions, and these differences may have influenced walking kinematics and kinetics (Dingwell & Marin, 2006; LaFiandra et al., 2003). Self-selected walking speed were used here, however, to obtain more natural walking behaviors that are expected to be more similar to those in in the field (i.e., versus controlled speeds across loading conditions). As such, any effects of walking speed on the dependent measures in the present study are viewed as inherent results of the loading conditions.

3.4.1 Torso kinematics and kinetics

Mean and peak torso flexion angle increased with both greater load mass and size during PLC without the use of an assistive device. Earlier studies have reported similar forward leaning of the trunk during PLC when carrying heavier backpacks (Goh et al., 1998; Goodgold et al., 2002; Harman et al., 2000; Kinoshita, 1985; Martin & Nelson, 1986; Pascoe et al., 1997), and this behavioral response is suggested as a mechanism to compensate for the shift in system center of mass (COM). In other words, if a load is kept on the back in an upright posture, the COM of the body + load moves posterior relative to the body COM without a load. By leaning forward, the system COM can be returned to the original (unloaded) location. Increasing load size was also found here to increase torso flexion during PLC. This appeared to be caused by the load handling method used, which involved holding the load using the hands at the upper two corners of the bag and resting the load on the back area. Participants consistently placed the small load on the upper back and neck area (Figure 3.1, left), by which the COM of the body + load does not shift far posteriorly from the original unloaded body COM. Therefore, only small forward leaning was required to return the system COM to the unloaded body COM location. In contrast, participants could not place the larger load on the upper back and neck area because of the vertical dimension of the load. Instead, and using the same holding method, the load rested lower on the trunk (Figure 3.1, right), moving the system COM further posterior relative to the body COM original location. Thus, the increased forward leaning with load size was likely compensation for COM control, similar to that in response to load mass. Of note, these postural responses to load size correspond to actual methods observed in the workplace by PLC workers (Figure 3.8).

Figure 3.8. PLC workers using different postures when handling different load sizes. Smaller loads are typically placed on the upper back area using a more upright posture (left), whereas bigger loads are placed lower on the trunk and a more forward-leaning posture is adopted (right).

Torso angular velocity and acceleration also increased with load size, and there are several possible explanations for these increases. From a mechanical perspective, increases in angular velocity and acceleration may be a simple consequence of greater peak-to-peak torso angular range of motion (Harman et al., 2000). However, additional analysis was conducted, and which indicated that torso flexion/extension range of motion was not significantly affected by the load size ($P = 0.09$), and with a mean difference of < 0.5 degrees across the three levels. The larger load sizes were carried with increased torso flexion, and increased flexion is associated with additional challenges to maintain stability (Arjmand & Shirazi-Adl, 2006; Singh & Koh, 2009). To maintain stability, additional mechanical control may have been needed, and reflected in the higher angular velocity and acceleration (Kaya et al., 1998). This indirect relationship, however, needs further study for confirmation.

Both mean and peak L5/S1 moment increased with load mass. Existing studies on PLC with the use of a backpack reported a similar finding (Goh et al., 1998; LaFiandra & Harman, 2004). As argued above, participants appeared to minimize posterior shifts of the combined COM of the body + load by leaning forward with heavier loads. Such an adaptation should have reduced L5/S1 moment. But, this was apparently not the sole goal of postural adaptation, in that a positive (flexion) and increasing L5/S1 moment was found with heavier loads. This suggests that an additional (overcompensating) mechanism may be employed, perhaps to provide better stability and more effective forward progression during walking (Goh et al., 1998).

3.4.2 Muscle activity

Load mass and size had a complex interactive effect on paraspinal muscle activity (ES1 and ES3) during PLC. One pattern was that carrying heavier loads increased paraspinal muscle activity and that this increase was more substantial with larger loads. Increased paraspinal activity with load mass was likely a direct consequence of the larger low-back moments observed with higher load mass (Bobet & Norman, 1984; Harman et al., 2000). The main and interactive effect of load size, however, are more difficult to explain. Increasing load size increased paraspinal, abdominal, and total muscle activity, but did not affect L5/S1 moment in parallel, suggesting that muscle recruitment was driven by other factors. One potential cause is an increase in the lateral and rotational moments with increasing load size. Additional data analysis, however, indicated these moments were not affected by load size ($P > 0.5$). Alternatively, a higher level of muscle activity may be required with more flexed postures to maintain spinal stability (Granata & Wilson, 2001; Singh & Koh, 2009). The increase in paraspinal muscle activity due to load mass (equilibrium requirement) was more substantial when coupled with an increase in load size (stability requirement). In addition, activity in the abdominal muscles (RA and EO) also increased with greater load mass and size. Considering that there was an external flexion moment at the lower back, the abdominal muscles were thus acting as antagonists, further supporting that muscle recruitment is responding to differing spinal stability demands during PLC (Motmans et al., 2006; O'Sullivan et al., 2002).

The second pattern was that when carrying the lightest load paraspinal muscle activity decreased as load size increased, whereas an increase in activity with load size was found for the heaviest load. The former result is somewhat counterintuitive, but may be related to the method of load handling as described earlier. Recall that small loads were placed on the upper back and neck area, while the larger load was placed lower on the trunk and involved a more forward-leaning posture (Figure 3.1). Considering that the load was also held at the upper two corners of the bag and that the 20BM load was relatively light, participants may have supported a relatively larger proportion of the larger load using the arms. As such, a smaller load that was placed on the upper back area required higher paraspinal muscle activity to support and stabilize the trunk + load. Further, it may be that participants could not use the same method when handling heavier loads, as it would be too demanding on their hands. While speculative, these behaviors would account for a decrease in paraspinal muscle activity with increasing load size that was only found when carrying the lightest load. To confirm this relationship, future work is needed in which arm muscle activity is monitored.

3.4.3 Slip risk and stability

RCOF is often used as a measure/predictor for slip risk that may lead to falls (Grönqvist, 1995; Perkins, 1978). However, no existing reports, to the author’s knowledge, have addressed the effect of PLC on RCOF. Here, a complex interaction effect of load mass and size on RCOF was found. RCOF decreased with load size when carrying the heaviest load, whereas a “U”-shaped relationship to load size was found for the other two load masses. The effect of load size on RCOF may be related to its effect on torso angular acceleration. During normal walking, joint moments at the lower extremity contribute to torso angular acceleration (Nott et al., 2010). Thus, observed changes in torso angular acceleration imply that the gait patterns were also altered when carrying different load sizes. As the current kinematic data are limited (i.e., windows of 1.5 gait cycles), future work is needed to assess the specific relationships between load size, gait pattern, and RCOF.

RCOF increased with load mass overall (though this main effect only approached significance), but the relationship between the two differed substantially depending on the load size (*cf.* Figure 3.7). Prior evidence is mixed regarding the effect of load mass on RCOF. Myung and Smith (1997) found that anterior load carriage of a 10 kg load resulted in higher RCOF compared to normal (unloaded) walking. Kim and Lockhart (2008), however, reported that carrying 10% of body mass anteriorly did not increase RCOF. The latter study further noted that the use of relatively light loads in their study may have prevented them from identifying any differential increases in ground reaction forces (GRF) with increasing load mass reported in the earlier studies (Harman et al., 1992; Kinoshita, 1985; Tilbury-Davis & Hooper, 1999), and which may increase RCOF. Neither study, however, examined the effects of multiple levels of load mass. Increasing load mass may also affect the spatio-temporal characteristics of human gait, such as causing a shorter stride length and faster heel contact velocity, which can further increase peak horizontal and vertical GRF during gait (James, 1983; Lockhart et al., 2003; Myung & Smith, 1997; Palumbo et al., 2001). As above, such changes in gait characteristics could not be assessed here. The current findings, therefore, are considered to provide only preliminary evidence of important effects of load mass and size on slip risk during PLC, but that these effects may be substantially task dependent (i.e., specific to loads involved).

In contrast to the generally adverse changes in torso kinematics and kinetics, LLE about the AP and SI axes (flexion/extension and twisting, respectively) remained consistent across the levels of load mass and size studied, and there was a decrease in the ML direction with increasing load mass. The former consistency indicates that torso movement stability in the sagittal and transverse planes could be maintained during PLC, across a range of loads, while the decrease in the LLE ML suggests that carrying a heavier load can actually improve torso movement stability in the frontal plane. In general, spinal stability may have maintained as a result of the addition of an external load, which provides additional mass moments of inertia of the body + load system, so that small perturbations will cause relatively smaller angular displacements (Goh et al., 1998). In addition, as mentioned earlier, the increased paraspinal and antagonistic abdominal muscle with load mass and size likely stiffened the spinal structure and further contributed to maintaining torso stability. While an increased stability was only found in the ML axis, this may be related to the consistent lack of any lateral lean, in contrast to increased forward lean found with heavier loads (Pascoe et al., 1997). Of note, additional data analysis indicated that lateral bending angles remained consistent here across the levels of load mass ($P > 0.5$). Similar results regarding ML stability have also been reported earlier. A study on PLC with the use of an assistive device found that COM excursion in the ML direction decreased with increasing loads (Ling et al., 2004). In addition, Palumbo et al. (2001) found increased directional control and Qu (2012) reported increased motor performance in the frontal plane with backpack loading. Though stability was found here to be maintained (or improved) with increasing load mass and size, the positive values of LLE indicate that torso movement stability during PLC was, at least, challenged (Rosenstein et al., 1993), especially when compared to normal walking (Cholewicki et al., 2000; Heller et al., 2009; Palumbo et al., 2001; Rietdyk et al., 2005).

3.4.4 Implications and conclusions

PLC, a type of traditional manual material handling that is still commonly performed in developing countries, has been associated with high prevalence of LBP (Chapter 2). This risk may be related to specific task demands such as those imposed by load mass, size, carriage frequency, or work duration (Chapter 2). Our current findings, along with earlier work, suggest that load mass and size may influence the risk of LBP during PLC. As hypothesized, increasing load mass caused increased torso flexion, L5/S1 flexion moment, and abdominal muscle activity. Increasing load size also caused higher torso flexion, peak torso angular velocity and acceleration, and abdominal muscle activity. Effects on paraspinal muscle activity and total muscle activity were more complex, in that a heavier load mass coupled with a larger load size caused more substantial increases in both measures, while decreases in these were found when carrying a light and large load. An increase in torso kinematics and kinetics may increase mechanical stress, leading to a higher risk of LBP (Chaffin et al., 1999; Chaffin et al., 1977; Chansirinukor et al., 2001; Grimmer et al., 2002; Hong & Cheung, 2003; Kennedy et al., 1999; Knapik et al., 1996). In addition, higher levels of muscle activity may lead to localized muscle fatigue and further contribute to LBP risk (Hodges & Richardson, 1996; Roy et al., 1989; Roy et al., 1990). The effects of load mass and size during PLC on slip risk were more complex and may be substantially task dependent. Torso movement stability was maintained with increasing load mass and size, and even improved with heavier loads in frontal plane. As a whole, these results suggest that the use of smaller and light loads during PLC may be beneficial for reducing the risk of LBP. However, there may be practical barriers to this, particularly regarding productivity. Further, some complex interactive effects of load mass and size were found, suggesting that there may be optimal improvements that are specific to different load mass and size condition. Potential improvements, such as those suggested by PLC workers (e.g., use of a back belt or an assistive device; Chapter 2), should be addressed in the future studies.

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Chapter 4: The Effects of a Simple Intervention on Physical Exposures during Traditional Posterior Load Carriage

Abstract

Traditional posterior load carriage (PLC), which is without the use of an assistive device, is associated with a high prevalence of low back pain (LBP). However, there is a scarcity of studies that have evaluated potential interventions to reduce exposures to LBP risk factors. This work examined the effects of a simple intervention using an assistive device (i.e., carrying aid) on exposures to factors related to LBP risk during PLC. Toro kinematics and kinetics, slip risk, and ratings of perceived discomfort (RPD) were obtained during simulated PLC on a walkway. Consistent with earlier results, increasing load mass substantially increased torso flexion, L5/S1 flexion moment, and RPDs in all anatomical regions evaluated. Using the carrying aid with higher load placement resulted in substantially lower mean L5/S1 moments when carrying the heaviest load. In contrast, using the carrying aid with lower load placement resulted in substantially higher torso flexion angle, higher mean L5/S1 moment when carrying heavier loads, and higher peak L5/S1 moment across all load masses. With the use of the carrying aid, both higher and lower load placement resulted in significantly lower RPDs in the elbows and hands compared to the control condition. In summary, the use of a carrying aid with higher load placement may be beneficial in reducing the risk of LBP during PLC. Future studies are needed, though, to improve the device design and to enhance external validity.

Keywords: Traditional load carriage; assistive device; intervention; spine; kinematics; kinetics

4.1 Introduction

Traditional posterior load carriage (PLC), which is done without the use of an assistive device (e.g., backpack), has been associated with a high prevalence of musculoskeletal symptoms in several anatomical regions (Chapter 2), including the most common symptom of low back pain (LBP). LBP, in particular, was reported to interfere with daily activities among nearly half of PLC workers surveyed. Substantial societal and personal burdens, including loss of wages and productivity, may later impact workers, as these outcomes have been commonly reported among industrial workers experiencing LBP (Galukande et al., 2006; Lubeck, 2003). Further, LBP has become the leading work-related medical problem worldwide (Kent & Keating, 2005; Loney & Stratford, 1999; Volinn, 1997). Specific task demands, related to the loads being transported, have been shown to influence the risk of LBP during PLC (Chapter 3). For example, increasing load mass or size caused increased torso flexion, L5/S1 flexion moment, and abdominal muscle activity. The combination of a heavier load mass and a larger load size caused larger increases in paraspinal muscle activity. These changes likely increase mechanical stress and localized muscle fatigue, and in turn can lead to a higher risk of LBP (Chaffin et al., 1999; Chaffin et al., 1977; Chansirinukor et al., 2001; Grimmer et al., 2002; Hodges & Richardson, 1996; Hong & Cheung, 2003; Kennedy et al., 1999; Knapik et al., 1996; Roy et al., 1989; Roy et al., 1990). Load mass and size during PLC also affected slip risk, though with a more complex relationship that may be substantially task dependent.

In general, two strategies are used to reduce or eliminate the risk of work related musculoskeletal symptoms: 1) engineering controls, such as through task redesign, and 2) administrative controls, such as through management practices (NIOSH, 1997). Engineering control is suggested to be superior because it controls the hazard at its source and can be more effective in the long term (Goggins et al., 2008). Specific to traditional PLC, there has been limited effort to evaluate potential interventions to reduce the risk of LBP. Existing studies on PLC tasks have been limited to assessments of physiological cost (Datta & Ramanathan, 1971; Lloyd et al., 2010b) and ratings of perceived discomfort (Lloyd et al., 2010a). Several relevant guidelines have been offered, though, to reduce injuries related to PLC tasks using a backpack. As examples, backpack load is suggested to be limited to 10 - 30% of individual body mass depending on the limiting criteria and population (Hong & Cheung, 2003; Moore et al., 2007; Sander, 1979; Simpson et al., 2011), lower load placement should be avoided when carrying backpacks heavier than 15% body mass (Singh & Koh, 2009; Stuempfle et al., 2004), and others addressing specific aspects of backpack design (Harman et al., 2001; Harman et al., 2000; Xu et al., 2009). Our recent study also suggested that the use of light and small loads during PLC might be beneficial to reduce exposure to factors related to LBP risks (Chapter 3). However, there may be practical barriers to reducing load mass and size, particularly regarding productivity. Therefore, this study examined a potential control that involves only minimal (or no) loss of productivity, by improving the method of carrying the load.

A distinctive characteristic of traditional PLC, as noted above, is that loads are transported without the use of an assistive device. Loads, which are commonly bagged items, are instead typically held/stabilized with the hands at the upper two corners of the bag, and the loads themselves are typically carried on the posterior trunk area (Chapter 2). Using this method, varied load mass and size were found to have substantial postural changes (Chapter 3). For example, a more upright posture was adopted when carrying a smaller load, while a more forward leaning posture was adopted when carrying larger loads. This postural difference appeared to be related to different load placements used when carrying varied load sizes. A higher load placement, at the upper back and neck area, could be used when carrying smaller loads, though higher load placement is more difficult when carrying larger loads due to the vertical dimension. As such, redesigning the method to handle loads, by introducing the use of an assistive device, can potentially help by allowing users to hold and support loads in locations that reduce physical demands. In fact, several PLC workers also suggested the use of an assistive device, such as a carrying aid, to improve the task (Chapter 2). The specific purpose of this study was thus to examine the effects of a simple carrying aid during PLC, with different levels of load placement, on exposures to factors related to LBP risk. Risks of LBP were estimated using intermediary measures derived from torso kinematics and kinetics. In addition, slip risk was estimated along with perceived discomfort in several anatomical regions. It was hypothesized that the use of a carrying aid with higher load placement would lead to beneficial effects (decreases) in all of these measures.

4.2 Methods

4.2.1. Participants

Nine healthy male participants from the university and local community completed the study, whose respective mean (SD) age, stature, and body mass were 23.1 (3.0) years, 171.7 (5) cm, and 69.9 (7.2) kg. All participants reported being physically active and having no history of low-back pain or any current medical conditions that might have influenced the results. Males were used to match the typical population doing traditional PLC (Chapter 2), and a relatively young group of participants was included to avoid potential influences related to age. Prior to beginning the experiment, all participants completed informed consent procedures approved by the Virginia Tech Institutional Review Board.

4.2.2. Experimental design and procedures

A repeated measures design was used, in which each participant completed a single experimental session involving PLC simulated in a laboratory environment on a walkway. The session involved all combination of three loads and three PLC methods, as described below. The order of the conditions was counterbalanced across participants (using a 9 x 9 Latin squares). Torso kinematics, kinetics, slip risk, and ratings of perceived discomfort (RPD) were obtained during the session.

The session began with warm-up activities, RPD calibration procedures, and a set of PLC practice trials. Warm up involved light dynamic stretching involving the whole body. To calibrate participants to the RPD scale, each performed a wall-squat task; standing with back against a wall, feet on the floor, and knees bent at 90 degrees. Participants held this posture while intermittently rating their level of perceived discomfort using an existing 10-point Borg's scale (Borg, 1982), until they reach RPD = 9. The goal of this activity was to have participants experience nearly the whole range of RPDs (Sood et al., 2007). Practice PLC trials were used to confirm that participants could complete load carriage tasks in all conditions, and to minimize subsequent learning effects within and between trials. Practice trials were also used to identify a starting position on the walkway, to ensure complete foot placement on a force platform during subsequent experimental trials (see below).

Participants completed three trials of PLC in each of the nine conditions. These were completed at roughly one carry per minute, and using a self-selected carrying pace over ~5 m on a flat walkway. A helper placed the load on the participant's back or carrying aid at the start and lowered the load at the end of each carry. Rest periods of five minutes, or more as needed, were provided between conditions to minimize residual effects of fatigue or discomfort. Specific loads were set based on individual body mass (BM), at 20 (20BM), 35 (35BM), and 50% (50BM) of individual body mass. Industrial products including rice, dog food, birdseed, sand, and metal pellets were used to fit the 20BM, 35BM, and 50BM loads, into different bags with respective (unpacked) areas of 30 x 50, 40 x 60, and 55 x 80 cm. These ranges of load conditions were selected to reflect distributions observed from a recent field study (Chapter 2). Each load was carried with three different PLC methods, including the traditional PLC without the use of an assistive device (B0) and two "intervention" methods using a carrying aid with a higher load placement (B1) and with a lower load placement (B2: Figure 4.1). A commercial frame (Deluxe Freighter Aluminum Pack Frame 574-F, StanSport, Los Angeles, CA) was used in this study as a simple carrying aid (Figure 4.2), with the waist belt removed to simplify the design. The frame mass was 1.6 kg, with a width of 40 cm and a height of 86 cm. To set the two load placements, the bottom support was moved and pinned into the appropriate location on the frame. The higher placement was set such that the bottom support was roughly at the mid-thorax (T7/T8) and the lower placement such that the support was at roughly waist height (L5), with a distance between the two locations of 31 cm. Participants were instructed to hold the top part of the frame to facilitate marker recording for the torso segment (described below). This backpack frame was intended only as a model/prototype of a carrying aid. More specifically, it was expected that subsequent application in the field would be achieved using cheaper materials such as bamboo or wood, but with consideration of the results of design aspects evaluated here.

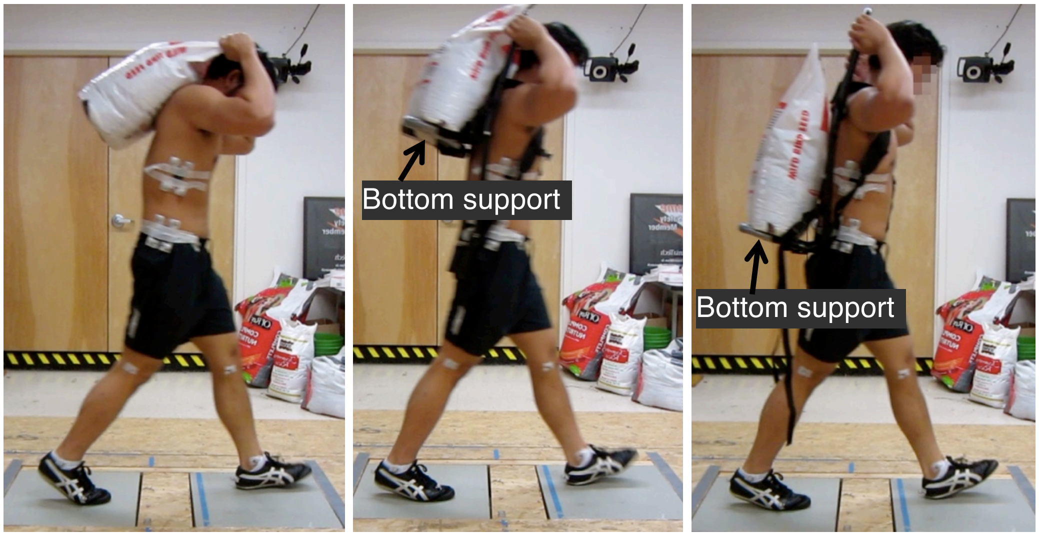

Figure 4.1. Experimental set-up demonstrating a participant during trials using traditional PLC (B0, left), a carrying aid with higher load placement (B1, middle) and carrying aid with lower load placement (B2, right).

Figure 4.2. Carrying aid used in the current study.

Segmental kinematics data were recorded during PLC trials, using reflective markers attached bilaterally to the feet, shanks, hips, and torso, and based on anatomical landmarks described by

Dumas et al. (2007). Marker positions were tracked at 120 Hz using a 6-camera system (Vicon Motion System, Inc., CA, USA). Ground reaction forces and moments were sampled at 960 Hz using two force platforms (OR6, 7-1000, AMTI, Watertown, MA) embedded in the walkway. Marker and force platform data were low-pass-filtered (bi-directional, 2nd order Butterworth) with respective cut-off frequencies of 6 and 12 Hz, and force platform data were down-sampled to 120 Hz to be consistent with the marker data. After completing the three trials in a given condition, participants provided RPDs for the neck, shoulders, upper back, lower back, hips, knees, ankles, elbows, and hands. For bilateral anatomical regions, single RPD measures were provided that reflected both sides. At the end of the session, participants provided their preferences regarding PLC methods for each load condition.

4.2.3. Dependent measures

Dependent measures used to evaluate the efficacy of the intervention included torso kinematics, kinetics, slip risk, and RPDs. Except for RPDs, these measures were derived from each of the three trials completed in each condition. Torso kinematics were characterized using mean and peak lumbar angles (thorax relative to the pelvis), and were derived from the marker data (as in Winter, 2004). Triaxial torso angles were defined using Euler angles corresponding to the X (anterior-posterior), Y (medial-lateral), and Z (superior-inferior) axes, and with an XYZ rotation sequence (Kingma & van Dieen, 2004). Kinematics were analyzed over a complete gait cycle (Figure 4.3).

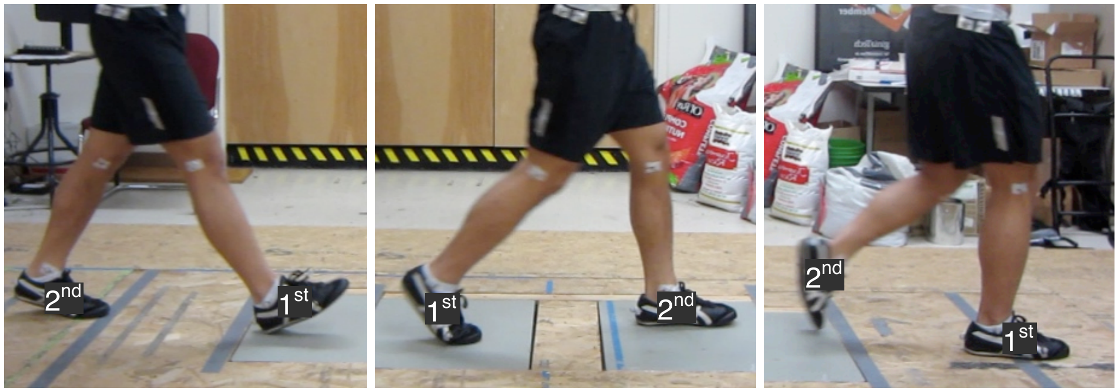

Figure 4.3. Illustration of data window during which kinematics were collected. These windows comprised a complete gait cycle, starting when the 1st foot contacted the ground (far left) and ending when that foot contact the ground for the second time (far right). Kinetic (force plate) data were obtained during a subset of these windows (see text).

Torso kinetics and slip risk were calculated using a subset of data from the noted windows, specifically the time between toe off of the 2nd foot (Figure 4.3) and heel strike of the 1st foot. This subset was used to avoid either foot being in contact with the floor other than on a force platform. Torso kinetics were described using mean and peak L5/S1 moments, and calculated using a “bottom-up” approach as described earlier (Kingma & van Dieen, 2004; Lee & Nussbaum, 2012). For this, a 3D, linked-segment model was used, consisting of seven body segments (i.e., feet, shanks, hips and torso) that were scaled using data from Dumas et al. (2007). L5/S1 moments were normalized to individual stature and body mass (Hof, 1996). Considering the low variability in torso lateral bending and twisting movement when performing symmetric load carriage similar to PLC with or without a backpack (Chapter 3; Pascoe et al., 1997; Yen et al., 2012), only peak values of sagittal-plane torso kinematics and kinetics were subsequently analyzed (positive values indicate torso flexion and an external flexion moment, respectively). Slip risk was measured from peak values of the required coefficient of friction (RCOF) obtained in each walkway trial. RCOF was computed as the largest instantaneous ratio of horizontal to vertical ground reaction forces (Burnfield & Powers, 2006; Redfern & Andres, 1984).

4.2.4 Statistical analyses

All statistical analyses were done using JMP™ (Version 10, SAS Institute Inc., Cary, NC), and significance was determined when $P < 0.05$. A preliminary multivariate analysis of variance (MANOVA) was conducted to determine if there were any differences in dependent measures across the three trials completed in each condition. No such differences were found for any of the measures ($P > 0.16$). Separate repeated-measures analyses of variance (ANOVAs) were used to assess the effects of load and PLC method on each dependent measure using the Restricted Maximum Likelihood (REML) method. As relevant, post-hoc pairwise comparisons were performed using Tukey's Honestly Significant Difference (HSD) test, and significant interaction effects were explored using simple effects analyses. Some data were excluded from analysis due to measurement errors, including all kinematics and kinetics measures from seven trials (of five different participants). Measurement errors on the kinematics and kinetics data were detected through visual inspection (i.e., missing markers). Outliers were detected and removed using Grubbs' test (Grubbs, 1969), including six data points from mean torso angle and peak torso angle. Summary statistics are reported as means (SD) in the original units.

4.3 Results

Walking speed differed significantly between PLC methods ($P < 0.0001$), with a faster walking speed used without vs. with a carrying aid. A summary of the statistical results, regarding the effects of load mass and PLC method on each dependent measure, is presented in Table 4.2.

Table 4.1. Mean (SD) of self-selected walking speed (m/s) for each task condition.

Method \ Mass	20BM	35BM	50BM	Mean
B0	1.10 (0.08)	1.10 (0.09)	1.10 (0.08)	1.10 (0.08)
B1	1.05 (0.10)	1.07 (0.09)	1.07 (0.10)	1.06 (0.10)
B2	1.05 (0.09)	1.06 (0.09)	1.03 (0.08)	1.05 (0.09)
Mean	1.06 (0.09)	1.08 (0.09)	1.07 (0.09)	1.07 (0.09)

Table 4.2. The effects of load mass and PLC method on the dependent measures. Bolded values indicate significant effects.

Measure	Load	PLC Method	Load x PLC Method
Mean torso angle	**$F_{(2,205)}$= 69.67, *P*< 0.0001**	**$F_{(2,205)}$= 13.80, *P*< 0.0001**	$F_{(4,205)}$= 0.76, *P*= 0.55
Peak torso angle	**$F_{(2,205)}$= 69.21, *P*< 0.0001**	**$F_{(2,205)}$= 15.078, *P*< 0.0001**	$F_{(4,205)}$= 0.78, *P*= 0.54
Mean L5/S1 moment	**$F_{(2,211)}$= 27.94, *P*< 0.0001**	**$F_{(2,211)}$= 7.53, *P*= 0.0007**	**$F_{(4,211)}$= 2.44, *P*= 0.048**
Peak L5/S1 moment	**$F_{(2,211)}$= 52.75, *P*< 0.0001**	**$F_{(2,211)}$= 10.28, *P*< 0.0001**	$F_{(4,211)}$= 2.028, *P*= 0.092
RCOF	$F_{(2,215)}$= 2.26, *P*= 0.11	$F_{(2,215)}$= 0.65, *P*= 0.52	$F_{(4,215)}$= 0.14, *P*= 0.97
RPDs Neck	**$F_{(2,56)}$= 14.86, *P*<0.0001**	$F_{(2,56)}$= 0.82, *P*= 0.45	$F_{(4,56)}$= 0.72, *P*= 0.58
Shoulders	**$F_{(2,56)}$= 26.52, *P*<0.0001**	$F_{(2,56)}$= 0.83, *P*= 0.44	$F_{(4,56)}$= 0.47, *P*= 0.76
Upper Back	**$F_{(2,56)}$= 32.59, *P*<0.0001**	$F_{(2,56)}$= 2.77, *P*= 0.071	$F_{(4,56)}$= 0.96, *P*= 0.45
Lower Back	**$F_{(2,56)}$= 23.22, *P*<0.0001**	**$F_{(2,56)}$= 3.69, *P*= 0.031**	$F_{(4,56)}$= 0.51, *P*= 0.73
Hips	**$F_{(2,56)}$= 15.28, *P*<0.0001**	**$F_{(2,56)}$= 3.24, *P*= 0.047**	$F_{(4,56)}$= 0.59, *P*= 0.67
Knees	**$F_{(2,56)}$= 14.79, *P*<0.0001**	$F_{(2,56)}$= 2.82, *P*= 0.068	$F_{(4,56)}$= 0.52, *P*= 0.72
Ankles	**$F_{(2,56)}$= 9.36, *P*=0.0003**	$F_{(2,56)}$= 1.35, *P*= 0.29	$F_{(4,56)}$= 0.89, *P*= 0.49
Elbows	**$F_{(2,56)}$= 10.51, *P*=0.0001**	**$F_{(2,56)}$= 23.28, *P*<0.0001**	$F_{(4,56)}$= 1.37, *P*= 0.26
Hands	**$F_{(2,56)}$= 13.22, *P*<0.0001**	**$F_{(2,56)}$= 24.89, *P*<0.0001**	$F_{(4,56)}$= 1.57, *P*= 0.20

Load and PLC method substantially affected torso flexion angle and L5/S1 moment. Specifically, increasing load mass substantially increased both mean and peak torso flexion angle and L5/S1 moment. When carrying 20BM, 35BM and 50BM, respective mean torso angles were 12.2 (4.2), 15.1 (4.1), and 17.4 (4.8)°, respective peak torso angles were 13.0 (4.3), 16.0 (4.1), and 18.6 (4.9)°, and respective peak L5/S1 moments were 1.75 (0.30), 1.91 (0.40), and 2.19 (0.42) Nm/kg.m. The B2 method resulted in higher mean and peak torso flexion angles compared to two other methods (Figure 4.4), and higher mean and peak L5/S1 moments compared to two other methods. Peak L5/S1 moments were 1.91 (0.37), 1.87 (0.38), and 2.06 (0.46) Nm/kg.m when using B0, B1, and B2 methods, respectively. The effects of a carrying aid use on mean L5/S1 moments were more complex, as there was a significant interaction effect between load x PLC method on this measure (Figure 4.5), and for which two patterns were evident. First, the effect of load mass was more substantial when using B0 or B2 method compared to when using B1 method. Second, the effect of a carrying aid use depended on the load mass. With heavier loads (35BM and 50BM), the use of a carrying aid with lower load placement resulted in higher mean L5/S1 moment, whereas there was no apparent difference in the mean moment when carrying the lightest load (20BM) using different methods. Though only approaching significance, an effect of load x PLC method was also observed on peak L5/S1 moment, and with a similar pattern of results as described for mean moment.

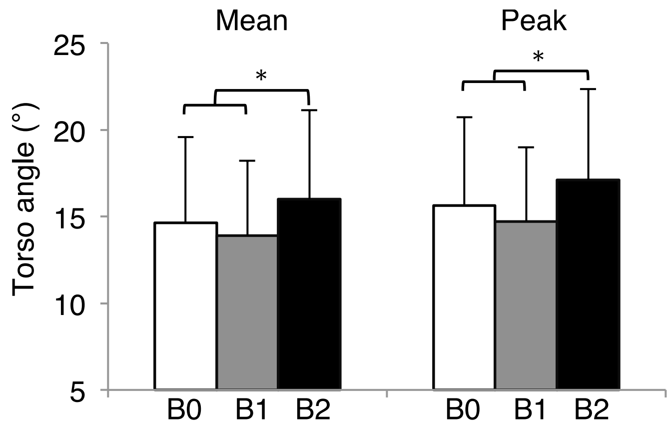

Figure 4.4. Effects of PLC method on mean and peak torso angles. Error bars indicate standard deviations, and significant differences between PLC method levels are indicated by *.

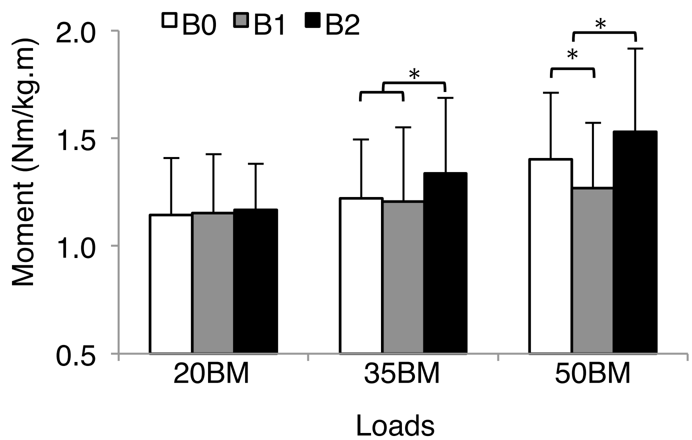

Figure 4.5. Effects of load mass and PLC method on mean L5/S1 moment. Error bars indicate standard deviations, and significant differences between factors levels are indicated by *.

Load and PLC method also affected RPDs in several anatomical regions (Figure 4.6). Specifically, increasing load mass substantially increased RPD in all anatomical regions. Both the B1 and B2 methods resulted in lower RPDs in the elbows and hands versus the B0 method. The B1 method resulted in lower RPDs in the lower back and hips than the B2 method. In addition, though only approaching significance, the B1 method resulted in lower RPDs in the upper back (*P* = 0.077) and lower back (*P* = 0.053) compared to the B0 method. All participants preferred using the B0 method to carry the 20BM load, and most participants (n = 7) preferred the B1 method to carry the 35BM load. When carrying the 50BM load, more than half of the participants (n = 5) preferred the B2 method and the remainder (n = 4) preferred the B0 method.

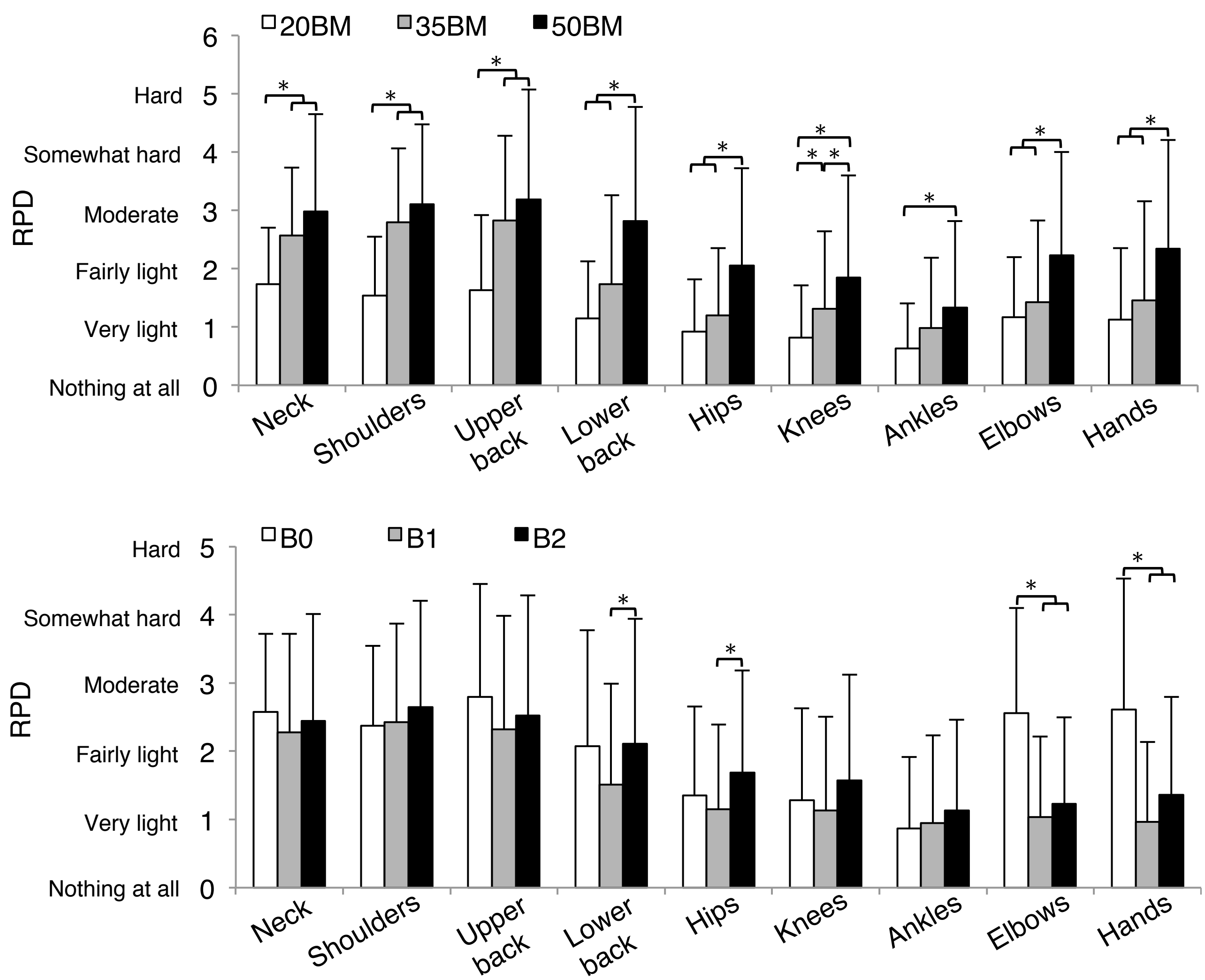

Figure 4.6. Effects of load (upper) and PLC method (lower) on RPD in several anatomical regions. Error bars indicate standard deviations, and significant differences between factors levels were indicated by *.

4.4 Discussion

PLC methods influenced self-selected walking speed, which may have contributed to the variability in walking kinematics and kinetics (Dingwell & Marin, 2006; LaFiandra et al., 2003). However, compared to controlled walking speed across task condition, self-selected walking speed was more preferable here to obtain more natural walking behaviors that are expected to represent those in the field. As such, any effects of walking speed on the dependent measures in the present study are viewed as inherent results of the task conditions.

Consistent with our previous findings (Chapter 3), increasing load mass increased all dependent measures except the RCOF. As discussed earlier (Chapter 3), the increase in torso flexion angle and L5/S1 moment likely function as mechanisms to compensate for the posteriorly shifted system center of mass (COM) and to provide better stability and more effective forward progression during walking while carrying heavier loads (Goh et al., 1998; Goodgold et al., 2002; Harman et al., 2000). Increased RPDs in all anatomical regions were similar to our earlier findings regarding the high prevalence of musculoskeletal symptoms in all regions among PLC workers in the workplace (Chapter 2). Increased RPDs also confirms that objective measures of LBP risk, such as increased torso kinematics and kinetics (Chapter 3), are consistent with subjective discomfort in the lower back area.

The use of a carrying aid was expected to lead to beneficial effects (decreases) in physical exposures, as measured by torso flexion angle, L5/S1 moment, RCOF, and RPD in several anatomical regions. The use of a carrying aid with higher load placement (B1 method), however, resulted in only small, and non-significant decreased in torso flexion angles compared to the control condition. In our previous study (Chapter 3), using a higher load placement when carrying smaller load without the use of an assistive device resulted in the smallest torso flexion angles. Participants consistently placed the small load on the upper back and neck area (*c.f.* Chapter 3: Figure 3.1, left), by which the COM of the body + load did not shift much posteriorly from the original unloaded body COM. Therefore, only small forward leaning was required to return the system COM to the unloaded body COM location. In the present study, however, the load could not be placed on the same area due to the carrying aid design and the large vertical dimension of the heavier loads. Since the load position was at about the same level as in the control condition (Figure 4.1), this likely explains why the use of a carrying aid with higher load placement resulted in comparable flexion angles as the traditional PLC method.

In contrast with the higher load placement when using the carrying aid, the lower placement resulted in higher torso flexion. This effect of load location is consistent with some previous studies (Bloom & Woodhull-McNeal, 1987; Devroey et al., 2007), but is in contrast with other studies that indicated that a lower load placement caused less forward leaning (Grimmer et al., 2002; Singh & Koh, 2009). However, these latter studies only use lighter loads (< 20% body mass) with a school backpack. In the present study, participants may have adopted a more forward-leaning posture to keep the load in place, because there was no strap/belt that secured the load on the carrying aid. In addition, the lower load position itself may require more forward leaning to maintain system stability (Bloom & Woodhull-McNeal, 1987). Adding a load strap/belt might be beneficial, but it would require more time to prepare the load on the carrying aid prior to actual load carriage. A longer preparation time may not be preferable or practical in the workplace, since the frequency of PLC can be fairly high (Chapter 2) and any loss of productivity unacceptable.

Though not significantly decreasing torso flexion angle, the use of a carrying aid with higher load placement did decrease mean L5/S1 moment when carrying the heaviest load (50BM) as compared to the control condition. An increased L5/S1 moment during load carriage has been suggested as an additional (overcompensating) mechanism that may provide better stability and more effective forward progression during walking (Goh et al., 1998). The reduced L5/S1 moment found here using the heaviest load, therefore, may imply that the use of a carrying aid with higher load placement provide better inherent stability during PLC. The use of a carrying aid with higher load placement appeared to be beneficial only when carrying the heaviest load (i.e. 50% of body mass). However, since the maximal loads examined here are lighter than those found at actual PLC worksites (Chapter 2), this result suggests a more substantial potential benefit of using a carrying aid with higher load placement in the field (i.e., with heavier loads). Future studies using such heavier loads, though, are clearly needed to confirm this speculation. In contrast to the higher load placement, the lower load placement (B2 method) caused higher mean L5/S1 moments when carrying heavier loads and higher peak L5/S1 moment for all loads. This increase in L5/S1 moments may be related to higher torso flexion angle when using this method. Higher torso flexion angles may require more compensation to provide stability during walking while carrying loads (Granata & Wilson, 2001).

Effects of load placement using the carrying aid were most clearly evident from the subjective measures. The higher load placement was better than the lower placement as indicated by lower RPDs in all anatomical regions, especially in the lower back and hips. Using the carrying aid with lower load placement did not seem to offer much improvement over traditional PLC, and RPDs in several anatomical regions, including the shoulders, hips, knees, and ankles, were actually slightly higher compared to the control condition. Though not significant differences, they may indicate a shift in the loading pattern. Specifically, the lower position of the load moved the loading/pressure toward the lower extremities, and the straps of the carrying aid increased the loading on the shoulders area. Using a carrying aid with higher load placement may also be better than traditional PLC. Though not significant, the use of a carrying aid with higher load placement resulted in lower RPDs in most anatomical regions, with more prominent improvements in the upper back, lower back, elbows and hands. Lower RPDs in most anatomical regions may be caused by reduced direct contact between load and skin. For example, when using the traditional PLC, loads directly rested on the neck and upper back. The use of a carrying aid with higher load placement reduced this direct contact and change likely resulted in lower RPDs in these regions. Lower RPDs may also be related to the decrease in torso kinematics and kinetics when using the carrying aid with higher load placement. For example, lower RPD in the lower back is consistent with lower L5/S1 moment when using the carrying aid with higher load placement.

There are several limitations to the current study that should be considered. First, it was assumed that the requirement that participants hold the upper part of the frame (Figure 4.1), necessary to accommodate marker tracking, would not induce substantial changes in PLC performance. However, there was indication that this arm position induced some discomfort in the hands and elbows (Figure 4.6), and without this requirement such discomfort levels could have been lower (or nonexistent). Restricting the arms may also have affected gait kinematics, kinetics, and energetics, though prior work suggests these effects would be relatively small (Umberger, 2008). Thus, despite the requirement the current findings regarding the effects of carrying aid use are still considered practically relevant. Second, the findings of this study only assessed short-term effects of the current intervention, and such effects may differ over a long-term period due to adaptation. Third, the study results may not be applicable to other traditional PLC tasks. Although designed to evaluate an intervention in relatively realistic conditions, the current study involved only a single, controlled PLC task. Finally, generalization to the actual population of PLC workers is unknown, given that they can be expected to have distinct levels of physical activity and experience versus the current sample. Future work should thus evaluate this intervention for longer periods, with actual workers, and under a range of simulated or actual PLC tasks in the field.

Despite the limitations, the present study shows that the use of a carrying aid with higher load placement may be beneficial to reduce physical factors associated with LBP risks. To build a realistic carrying aid for use in developing countries, several design aspects should also be considered. For example, the frame should be made more comfortable for longer use, perhaps by adding padding between the frame and the body. The frame should also be strong enough to handle heavier loads, affordable by workers, and avoid any adverse effects on productivity. Future studies are clearly needed to refine and evaluate the carrying aid design to improve traditional PLC tasks.

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Chapter 5: Conclusions

Work-related musculoskeletal symptoms (MSS) cause substantial economic burden and adverse effects on workers worldwide (Galukande et al., 2006; Lubeck, 2003). Many studies have associated manual material handling (MMH) tasks with the development of diverse MSS (Kuiper et al., 2005; Marras, 2000; NIOSH, 1997). However, limited investigations have been undertaken among one large group of workers using a particular MMH method called "traditional" posterior load carriage (PLC). Such load carriage is typically done without the use of an assistive device (e.g., backpack) in developing countries, and involves exposure to known risk factors for MSS such as heavy loads, non-neutral postures, and high levels of repetition. Therefore, the current work aimed to: 1) investigate the types and prevalence of MSS related to PLC among workers in a developing country; 2) assess the effects of important task demands, related to load mass and size, on torso kinematics and kinetics, muscle activity, trunk dynamic stability, and slip risk; 3) evaluate the efficacy of a potential intervention to reduce exposure to factors related to low back pain (LBP) risk associated with PLC.

5.1 Musculoskeletal symptoms associated with posterior load carriage

The present study suggests relatively high job demands and a high prevalence of MSS among PLC workers in Indonesia (Chapter 2). MSS were reported in all anatomical regions evaluated, with symptoms most commonly reported at the lower back (72.2%), feet (69.4%), knees (64%), shoulders (47.2%), and neck (41.7%). MSS in all regions evaluated were reported to interfere with workers' daily activity. However, only few workers sought medical treatment. Substantial variability in task demands such as work hours/day, load mass and size was found in the survey of traditional PLC work sites. Some MSS were associated with particular worker characteristics and/or job demands; for example, MSS in the lower back were associated with work hours/day.

Workers suggested possible improvements including the use of a belt, hook, or backpack/frame, and changes in the carriage method. Despite the high job demands and prevalence of MSS among PLC workers, existing guidelines are limited and/or often difficult to implement due to the unique characteristics of the traditional PLC task and the environment in which it is typically performed. Therefore, further study is warranted focusing on worksite assessments, laboratory/experimental studies, practical interventions, and specific local guidelines to improve working conditions and occupational health and safety among PLC workers.

5.2 Effects of load mass and size on physical exposures during posterior load carriage

Similar to several earlier studies regarding PLC tasks using a backpack, the present study showed that specific task demands related to load characteristics influenced the risk of LBP during PLC (Chapter 3). Increasing load mass caused increased torso flexion, L5/S1 flexion moment, and abdominal muscle activity. Increasing load size also caused higher torso flexion, peak torso angular velocity and acceleration, and abdominal muscle activity. Effects on paraspinal muscle activity and total muscle activity were more complex, in that a heavier load mass coupled with a larger load size caused more substantial increases in both measures, while decreases in these were found when carrying a light and large load. An increase in torso kinematics and kinetics may increase mechanical stress, leading to a higher risk of LBP (Chaffin et al., 1999; Chaffin et al., 1977; Chansirinukor et al., 2001; Grimmer et al., 2002; Hong & Cheung, 2003; Kennedy et al., 1999; Knapik et al., 1996). In addition, higher levels of muscle activity may lead to localized muscle fatigue and further contribute to LBP risk (Hodges & Richardson, 1996; Roy et al., 1989; Roy et al., 1990). The effects of load mass and size during PLC on slip risk were more complex and may be substantially task dependent. Torso movement stability was maintained with increasing load mass and size, and even improved with heavier loads in frontal plane. These results suggested that the use of smaller and light loads during PLC may be beneficial for reducing the risk of LBP. However, there may be practical barriers to this, particularly regarding productivity. Potential improvements, such as those suggested by PLC workers (e.g., use of a back belt or an assistive device; Chapter 2), should be addressed in future studies, and one such approach was evaluated in the third study.

5.3 Effects of a simple intervention on physical exposures during posterior load carriage

Improving the PLC task by introducing the use of a carrying aid was hypothesized to be beneficial in reducing the risk of LBP (Chapter 4). The present results indicated that using a carrying aid with higher load placement substantially lowered mean L5/S1 moment when carrying heavier loads. In contrast, using a carrying aid with lower load placement resulted in substantially higher mean L5/S1 moment. In addition, higher torso flexion angle was observed when using the latter method. Effects of load placement using the carrying aid were most clearly evident from the subjective measures. The higher load placement was better than the lower placement as indicated by lower rating of perceived discomfort (RPDs) in all anatomical regions, especially in the lower back and hips. Though not statistically significant, using a carrying aid with higher load placement was also found to be better than traditional PLC, as seen in the lower RPDs in most anatomical regions and with more prominent improvements in the elbows and hands. As a whole, this study suggested that the use of a carrying aid with higher load placement may be beneficial to reduce exposures to physical factors associated with LBP risk.

5.4 Future directions

Several limitations were present in the current work, and should be addressed in future research. The first study, which was focused on the prevalence of MSS among PLC workers, was conducted using a cross-sectional study design. As such, strong support for causal relationships between MSS prevalence and PLC task demands was not obtained. In addition, and though workers confirmed if their symptoms were mainly influenced by their job, there are other potential factors in their daily life that could have contributed to their musculoskeletal symptoms. This study also only involved workplaces that represented the typical loading-unloading dock, warehouses, and traditional markets on Java Island, Indonesia. These may not be representative of all similar work places in other regions or developing countries. For example traditional MMH in African countries can involve head loading and PLC with straps (Ling et al., 2004; Lloyd et al., 2010a; Lloyd et al., 2010b; Maloiy et al., 1986). Therefore, the results of this study would be most applicable to similar work places that require PLC without the use of assistive devices, and less applicable to those with different traditional MMH methods. Future studies should use a prospective approach to better understand the mechanisms and causes of MSS development among PLC workers and should include more regions/countries to extend generalizability.

The second study investigated only two important factors, related to load mass and size, that may contribute to LBP development associated with PLC tasks, and did so only for a limited experimental duration. Future studies may need to address other MSS that are common among PLC workers such as MSS in the feet, knee, neck, etc., and include other potential factors such as frequency of carry or work duration.

The third study was considered an initial step toward developing simple and effective intervention that could be feasibly applied to PLC tasks in the workplace. Although the use of a carrying aid with higher load placement was found to improve the PLC task, the findings of this study only assessed short-term effects of the current intervention. Future work should assess whether alternative device designs can provide additional benefits, and evaluate such an intervention in field to improve to enhance external validity.

Finally, the participants in the two experimental studies were all young, healthy individuals with no experience in traditional PLC. Future studies are needed to investigate whether the current findings would be present among actual PLC workers.

5.5 Overall conclusions

Overall, this dissertation contributes to the limited extant research on the physical impacts of traditional PLC task among workers in a developing country, and evaluated a practical intervention that may help improve this task. The findings suggest that PLC workers incur a relatively high MSS burden, which were reported to interfere with daily activity, though only few workers sought medical treatment. Specific to the most common symptom of LBP, increasing load mass and size substantially increase physical exposure to the risk factors. As such, using light and small load may be recommended to reduce LBP risk. Since reducing load mass and size can decrease productivity, the use of a carrying aid with higher load placement may be a more feasibly applied intervention to improve the PLC task, as shown by reduced torso kinematics and kinetics, and RPD. Future studies are needed, though, to refine and evaluate the carrying aid design that suits the needs, capabilities, and/or limitations of workers in developing countries.

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APPENDIX

Appendix A: Verbal Consent Scripts (translated to Indonesian) for Study 1

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Good morning/afternoon. My name is Khoirul Muslim. I am a student of Industrial and System Engineering, Virginia Tech, USA. I am here to conduct a survey to better understand the physical health and work experiences among workers like you whose job involves posterior load carriage. Before we start, I will provide you with consent information regarding your participation in this study.

The main purpose of this study is to investigate the types and prevalence of musculoskeletal problems that are present among manual material handling workers using posterior load carriage methods in Indonesia. We will ask you several questions in a brief interview, which requires only about 10-20 minutes.

The risks involved in participating in this study are minimal. Your personal information and other responses that you provide will be kept confidential. Permission for you to participate in this study has been obtained from your foremen/supervisors, though these individuals will not be given any of your individual data or responses.

You will receive no direct benefit from participating in this study. However, by participating in this study, you will help us in obtaining the first formal examination of the extent of musculoskeletal problems and associated factors in a worker population using posterior load carriage. Furthermore, the results of this study may benefit many workers in the long term, by reducing and preventing musculoskeletal problems. We do not guarantee or promise that you will receive any of these benefits, and no promise of benefits has been made to encourage your participation. You will receive compensation for participating in this study (i.e. $3.00 (the Indonesian equivalent will be indicated)).

Your participation is voluntary. Refusal to participate will involve no penalty or loss of benefits, and you may discontinue participation at any time without penalty or loss of benefits.

Should you have any questions in the future, you can contact me by phone 540 257 9108 or email: khoirul@vt.edu.

Do you have any questions regarding this study?
Do you agree to participate in this study?

Appendix B: Informed Consent Form for Study 2 and 3

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: **Posterior Load Carriage: Ergonomic Assessment and Guideline Development II**

Investigator(s):

- Maury A. Nussbaum

- Khoirul Muslim

I. Purpose of this Research

The goal of our study is to better understand potential causes of injury of the lower back due to performing manual material handling tasks. Of particular interest are posterior load carriage (PLC) tasks, which involve carrying loads on the upper part of the back and shoulder. We are investigating how load size and weight and the use of assistive devices during PLC affect the loading of the trunk and associated muscle responses.

II. Procedures

An experimental session is expected to last about 2-3 hours and you may be requested to return for repeated testing. All experiments will be performed in the Industrial Ergonomics and Biomechanics Laboratory located on the fifth floor of Whittemore Hall. We will prepare you for the session by taping adhesive reflective markers on your skin, around your legs and trunk, and these will passively measure your postures and how you move. Also, we will put sensors on your skin around your abdomen and back to measure the responses of your muscles. These sensors detect the electrical activity generated by contracting muscles, a process called electromyography (EMG). We may need to clean the skin area where we put the sensors, by removing body hair with a disposable razor, abrading it with soft sand paper, and cleaning it with rubbing alcohol. These preparations will require about one hour.

After some preliminary warm up activities, we may ask you to push and/or pull as hard as you can against a resistance to record your maximum muscle responses (or, strength). We may also ask you to carry a weight on your upper back for up to 30 times on a walkway or on a treadmill, during which muscle responses and trunk movements will be recorded. Each load carriage task will last up to one minute. You will be given rest periods between tasks. We may obtain your heart rate using a heart rate monitor watch after you complete each task. Finally, we may ask you to provide a rating of your perceived level of effort and/or discomfort in different body parts.

III. Risks

The risks of this study are minor. However, they include a potential skin irritation to the adhesives used in the tape and EMG electrodes. You may also feel some temporary muscle soreness such as might occur after exercising. To minimize these risks you will be asked to warm-up before the tasks and tell us if you are aware of any history of skin-reaction to tape, musculoskeletal injury, or cardiovascular limitations. During prolonged testing, you may feel dizzy or light-headed, and there is a small risk that you could faint. To minimize these risks, you will be asked several times if you are experiencing such symptoms; if so, you will be asked to walk around or sit down as appropriate. In addition, hunger may exacerbate such risks, so you will be asked to not come to experimental sessions hungry, and small snacks will be made available should you become hungry.

IV. Benefits
By participating in this study, you will help to increase our understanding of musculoskeletal injury mechanisms of the lower back due to posterior load carriage. We do not guarantee or promise that you will receive any of these benefits, and no promise of benefits has been made to encourage your participation.

V. Extent of Anonymity and Confidentiality
Experimental data collected during your participation will be coded and matched to this consent form so only members of the research team can determine your identity. Your identity will not be divulged to unauthorized people or agencies. Digital video recorded during the experimental trials will be used to track the movement of sensors by means of computer analyses and is sufficient video quality to observe individual participant characteristics. Sometimes it is necessary for an investigator to break confidentiality if a significant health or safety concern is perceived or the participant is believed to be a threat to himself/herself or others.

VI. Compensation
You will be paid $10/hour for your participation in this study. Each session will last in 2-3 hours. If you should withdraw in the middle of a session or if a session is finished earlier, you will be partially compensated for your time (rounded up to the nearest full hour completed). Participants participating in experiments as part of course or laboratory procedures will receive appropriate credit for analysis of specified data as described in the course syllabus but not for personal performance during the experimental session.

VII. Freedom to Withdraw
You are free to withdraw from a study at any time without penalty. If you choose to withdraw, you will be compensated for the portion of the time of the study (if financial compensation is involved). You are free not to answer any questions or respond to experimental situations that you choose without penalty. There may be circumstances under which the investigator may determine that you should not continue as a subject. If so, you will be compensated for the portion of the project completed.

VIII. Approval of Research
This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech.

IX. Subject's Responsibilities
I voluntarily agree to participate in this study. I have the following responsibilities:

- Inform the investigators of all medical conditions that may influence performance or risk
- Comply to the best of my ability with the experimental and safety instructions
- Inform the investigator of any physical and mental discomfort resulting from the experimental protocol
- Inform the investigator of any feelings of dizziness, light-headedness, or fainting

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

Subject Name (Print):____

Subject signature:___________________________________ Date____________

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Investigator: Khoirul Muslim E-mail: khoirul@vt.edu Phone 394-1532

Faculty Advisor: Maury A. Nussbaum E-mail: nussbaum@vt.edu Phone 231-6053

IRB Chair: David M. Moore

Office of Research Compliance
Research & Graduate Studies
540-231-4991 / moored@vt.edu

Subjects must be given a complete copy (or duplicate original) of the signed Informed Consent

Appendix C: Interview Scripts (translated to Indonesian) for Study 1

VIRGINIA TECH

Posterior Load Carriage: Ergonomic Assessment and Guideline Development

(Note: the interview will be in a "semi-structured" format. Material below indicates specific questions that will be asked, but additional follow-up questions will be posed to solicit additional information depending on the responses given)

Participant Information

Participant No._____

Gender: Male/Female

Age: _____ years old

Height and weight: _____ cm and _____ kg

Work experience in MMH jobs: _____ year(s)

Work exposures

Lifting frequency: _____/minute

Weights handled: _____ kg

Load size: _____ cm x _____ cm x _____cm

Working schedules: _____ hour(s)/day

Work duration at the current job: _____ month(s)

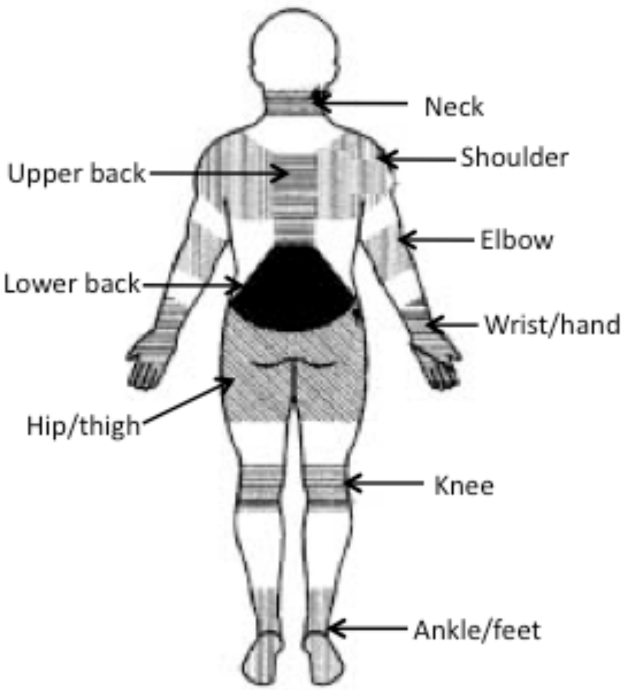
Possible improvements or interventions to the task

What kind of improvements to the current task do you think may reduce discomfort, fatigue, or musculoskeletal problems? (Please select all that applied or add below)

1. The use of handle (support aid)
2. Lower the load position
3. The use anterior load carriage method
4. Others:____
____
____

Musculoskeletal Problems

Please answer by putting a mark in the appropriate box for each question. The picture below shows different body areas to help you with the questions.



	Have you at any time during the last 12 months had problems (ache, pain, stiffness, burning, numbness, or tingling) in:		Have you had the troubles for the last 7 days in:		During the last 12 months have you been prevented from carrying out normal activities (job, housework, hobbies) because of the troubles in:		During the last 12 months have you seen a physician for this condition?	
Neck	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes
Shoulder	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes
Upper Back	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes
Elbows	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes
Wrist/hands	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes
Lower back	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes
Hips/thighs	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes
Knee	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes
Ankles/feet	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes	☐No	☐Yes