Kneeling, knee kickers and kneepads: a study of ergonomic exposures and interventions for floor coverers

BY

XIAOLU JING

B.S CHINA UNIVERSITY OF GEOSCIENCES (2003)

M.S. CHINA UNIVERSITY OF GEOSCIENCES (2006)

M.S. UNIVERSITY OF MASSACHUSETTS LOWELL (2008)

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF DOCTOR OF SCIENCE

IN WORK ENVIRONMENT

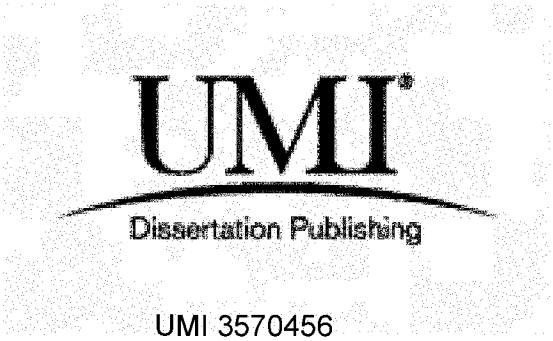
UNIVERSITY OF MASSACHUSETTS LOWELL

Signature of Author _____ Date 3/21/2013

Signature of Dissertation Advisor: _____

Signature of Other Dissertation

Committee Members: _____



ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

Kneeling, Knee Kickers and Kneepads: a Study of Ergonomic Exposures and Interventions for Floor Coverers

by

XiaoLu Jing

ABSTRACT OF A DOCTORAL DISSERTATION SUBMITTED TO

THE FACULTY OF THE DEPARTMENT OF WORK ENVIRONMENT

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF DOCTOR OF SCIENCE IN WORK ENVIRONMENT

UNIVERSITY OF MASSACHUSETTS LOWELL

2013

Dissertation Supervisor: Bryan Buchholz

Professor, Department of Work Environment:

ABSTRACT

This dissertation discussed ergonomic exposures and interventions for floor coverers.

Study I evaluated whole body ergonomic exposures for floor coverers by specific tasks, and collected other work-related factors using an observational exposure assessment approach. In this study, kneeling was observed 56.0% of the time. Floor coverers spent more time kneeling than in neutral leg postures. VCT and hardwood floor tasks had a relatively high combination of kneeling and MMH (26% for VCT and 20% for hardwood floor).

Study II was a biomechanical evaluation of the carpet knee kicker. A typical kicking action was divided by four phase: windup (I), kick (II), recoil (III), and release and adjustment (IV) in order to discuss the time consequence among muscle activities, body postures and impact forces. A typical impact contact only lasts about 0.08 seconds, and it takes less than 0.04 second for the impact force to reach the peak from the baseline. The peak impact force, minimum hip and knee extension appears almost simultaneously. On average, subjects exerted an impact force 1.32 times as much as their body weight.

Study III compared the muscle activities and segment motions between the kicker and the air stretcher for the kicking/stretching and the in-between phase. For both the kicking/stretching phase, there were significant differences for the leg muscles (BF and

RF) with a higher %MVC from the kicker. However, for the in-between phase, there were no significant differences for the leg muscles (BF and RF), except BF at 90th level. These finding indicated that the new tool did not create more leg muscle strain at the in-between phase while dramatically decreasing leg muscle activities for the kicking/stretching phase. For postural data, the stretcher significantly decreased range of motion (90th -10th) for both knee and hip extensions for both phases, and it eliminated several extreme extensions (10th and 90th). The new tool changed users' body postures: workers tended to keep higher knee extension and lower hip extensions for both phases. Based on the above results, the air stretcher significantly decreased major muscle activities during the kicking/stretching phase; it also decreased range of motion for the knee and hip.

Study IV compared contact areas, mean and peak pressures in kneeling while wearing an advanced (Pro Knee) kneepad, a regular kneepad, and no kneepad. Both kneepads increased the contact area, and the advanced kneepad had a much larger contact area than the regular one. Sitting on heels led to less contact area than kneeling, and more trunk flexion resulted in more contact area. The bare knee was associated with much higher mean and peak pressure than either kneepad. Leg posture had a significant impact on contact area and mean pressure, but no impact on peak pressure. Trunk posture only had an impact on contact area. Arm posture had no significant impact on any of these three dependent variables.

Work-related factors (Good Pressure Distribution, Improving Work Performance) had high importance scores. Some usability factors, such as Well Attached to the Knee, Durability, Easy to Get on and Take off, Not Getting Sweaty, also received importance scores greater than three. Workers were less interested in factors such as Good Customer Service, Low Cost, Light Weight and Good Aesthetic Factors. The advanced kneepad was rated higher on all factors with an importance score over three over the regular pad. The regular kneepads gained the advantage for factors that had importance scores less than three.

ACKNOWLEDGEMENTS

I am grateful for the guidance given by Dr. Bryan Buchholz, the thesis advisor of the Committee. Dr. Buchholz has been extremely patient and taught me numerous research skills hand by hand. I thank Dr. Punnett and Dr. Dennerlein for their contribution to this dissertation during data collection, data analysis and manuscript writing stage. Both Dr. Punnett and Dr. Dennerlein provided so many wonderful suggestions. One of the project was conducted at Dr. Dennerlein's lab.

I thank Scott Fulmer, Rebecca Gore for their assistance in their expertise. Thanks to Adam Luce, Brad Schugardt and Pranav J. Parikh for their help with data collection. I want to thank Dr. Samuel Paikowsky from civil engineering who lent me the pressure sensors. Thank Ken Soltz and Jack Albani from Tekscan for their technical support. I also want to thank my "Anything But Dissertation" group for their support, including Miriam Weil, Jamie Tessler, and Gabi Kernan. I want to thank many students who helped me, Alicia Kurowski, Homero Harari, Priya Dasgupta, Chuan Sun, Yuan Zhang.

I thank my parents, and my, Jun Pang, John Wang, Yun Yang, Liang Fang and FanHai Yang.

My special thanks goes to local floor coverers union #2168 (The New England Regional Council of Carpenters) for their cooperation, especially to their business agent Mynor Perez.

Funding for the research presented in this dissertation was provided by the National Institute for Occupational Safety and Health (NIOSH) though the Harvard ERC (Grant No. 2 T42 OH008416). Parts of data collection were also supported by the NIOSH (Grant No. R01-OH008254).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ABBREVIATIONS

AS – AIR STRETCHER

BF – BICEPS FEMORIS

ERC– EDUCATION RESOURCE CENTER

KK– KNEE KICKER

LD– LEFT ANTERIOR DELTOID

NIOSH–NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

OSHA- OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

PATH– POSTURES, ACTIVITIES, TOOLS, AND HANDLING

PDA– PERSONAL DIGITAL ASSISTANT

RD– RIGHT ANTERIOR DELTOID

RF– RECTUS FEMORIS

1 INTRODUCTION

1.1 BACKGROUND

1.1.1 Floor coverers and their occupational injuries and disorders

The New England Regional Council of Carpenters defines floor coverers as a specific class of construction workers, who install various materials, such as carpets, hardwood floors, baseboard and vinyl floors in commercial and residential buildings (The New England Regional Council of Carpenters, 2009). In New England, they belong to the carpenters union.

The Standard Occupational Classification (SOC) has different classifications for floor coverers. Carpet installers have SOC code 47-2041; while SOC code 47-2031 belongs to carpenters who construct, erect, install, or repair hardwood floors. Workers who deal with vinyl are not mentioned in the SOC. In this series of studies, floor coverers are defined as a group of workers including carpet installers and other carpenters, who construct, erect, install, or repair hard wood, baseboard and vinyl floors. There were 25,580 carpet installers in the US according to the Bureau of Labor Statistics (BLS) database in 2010 (Bureau of Labor Statistics, 2010b). There were 620,410 carpenters in the US from BLS database in 2010 (Bureau of Labor Statistics, 2010a).

1.1.1.1 Knee disorders and injuries among floor coverers

The floor covering task involves a combination of posture, force, acceleration, and repetition that are biomechanically demanding and leads to increased occurrence of knee disorders and injuries. Three common kinds of knee disorders and injuries are knee osteoarthritis (OA), bursitis and meniscal disorders.

Yuan et al. used an administrative database from the New England Carpenters Benefit Funds to identify cases of knee disorders and examined the distribution of specific disorders among floor coverers during a 16-year period (1990-2006) (Yuan et al., 2009). They found that the incidence of knee disorders was approximately 286 per 10,000 person-years. Of those cases, the most frequently occurring single knee disorder was meniscal injuries (33.1), followed by bursitis (24.3%) and osteoarthritis (OA) (21.1). Similar results were found for the St. Louis area; bursitis (32.1%) was the most common disorders, followed by meniscal injuries (26.9) and OA (15.3) for floor coverers journeymen (Yuan et al., 2011). Both the Carpenters' Health and Welfare Trust Fund of St. Louis and the Carpenters' Combined Benefits Fund of Massachusetts funds have strict requirement for members to use them, such as working 500 hours in a consecutive 6-month period. Therefore, the prevalence of injuries and disorders were smaller than results from other self-report surveys.

Kivimaki et al. found that the prevalence of osteoarthritis of the knee was 58% among floor coverers (Kivimaki et al., 1992). Jensen and Kofoed did a survey for 102 carpet installers and found that 56% of them reported knee complaints during previous 12

months (Jensen and Kofoed, 2002). A higher frequency of bursitis, arthritis, skin infections over the knee and other knee symptoms have been found in floor coverers compared to millwrights and bricklayers (Tanaka et al., 1989).

The average cost for claims involving the knee is $19,785, which is lower than those involving the head or central nervous system, multiple body parts, the neck, leg, hip/thigh/pelvis, lower back and arm/shoulder (National Safety Council, 2008).

1.1.1.2 The association between the occupation and knee disorders and injuries

A carpet installer spends 75% of his time in the kneeling posture that sometimes requires near maximum knee flexion (Bhattacharya et al., 1985). This job regularly requires kneeling, crawling, moving and kicking with the knee. Other floor coverers who deal with hardwood floor, baseboard and vinyl share similar work characteristics with carpet installers.

Epidemiologic studies have shown that prolonged kneeling has a moderate association with knee disorders and injuries such as knee osteoarthritis, bursitis and meniscal disorders. Jensen et al. did a systematic review of epidemiological studies on this topic published between 1986 and 2006. This review indicated that there was a moderate relationship between OA of the knee and kneeling/squatting, and a strong relationship between OA of the knee and the jobs including kneeling/squatting with heavy lifting simultaneously (Jensen, 2008). Another comparison study showed that knee disorders, knee symptoms, and radiographic changes of the patella were more common among floor coverers than among painters (Kivimaki et al., 1992). Also, long time knee-

straining positions may be a risk factor for the development of knee OA above the age of 50 years (Jensen et al., 2000).

Increased frequency of bursitis, needle aspiration of knee fluid, skin infections of the knee, and other knee symptoms were noticed in floor coverers, tile terrazzo and marble setters as compared to that in millwrights and bricklayers (Tanaka et al., 1989).

The relationship between meniscal disorders and occupation has not been discussed for floor coverers. However, this issue has been studied for many years in the mining industry. In 1965, Atkins and others did a study to examine the high risk of meniscal disorders among miners and concluded that kneeling at work was the main factor of meniscal disorders (Atkins, 1957). This relationship has also been found by other researchers (Sharrard and Liddell, 1962) (Baker et al., 2002).

1.1.2 Assessing ergonomic exposures to the lower extremities

1.1.2.1 Methodologies for assessing ergonomic exposures

There are three major methods to assess ergonomic exposure: self-reports, direct measurements and observational methods.

Self-reporting includes dissection of information from worker diaries, interviews and questionnaires. Questionnaires are one of the most commonly used types of self-report. A questionnaire collects data from a large sample cohort in a short period of time at comparatively low cost. A questionnaire could not only collect current data, but also

retrospective data such as ergonomic exposures a couple of years ago. In addition, a questionnaire could also collect information, such as psychosocial status and social support, which could be hard to be collected by other methods. A questionnaire, however, can be inaccurate if poorly designed, or because of limited worker literacy or poor comprehension of questions asked.

Direct measurements provide large quantities of highly accurate data on a range of exposure variables. Direct measurements have disadvantages such as they are invasive, time consuming and comparatively expensive. Invasion of participants comes from the attachment of the sensors or other equipment. Some equipment is expensive and requires appropriate training to be used. Equipment, such as electromyography (EMG) and motion tracking systems, need to be calibrated before each trial to receive accurate data.

Observational methods include simple and advanced techniques. Simple observational techniques, such as Rapid Upper Limb Assessment (RULA) (Lynn, 1993), Rapid Entire Body Assessment (REBA) (Hignett and McAtamney, 2000) and the strain index (Moore and Garg, 1995), are suited to the assessment of static or repetitive jobs; they come with a hypothetical scoring system. Advanced observational methods are based on time sampling or real time video recordings, these methods are suitable for non-repetitive jobs; however, their reliability is directly proportional to the length of time of data collection.

1.1.2.2 PATH

The PATH (Posture, Activities, Tools, Handling) (Buchholz et al., 1996) observational method will be used in this study.

Tasks for floor coverers have some characteristics that make assessment difficult. First, floor coverers have a bigger work area than others, e.g. cashiers in a grocery store who work within a limited area. Floor coverers frequently need to fetch materials or shared tools in different places, and they are also required to move from one working room or building to another due to their work process or schedule. Therefore, some traditional methods such as fixed position cameras are not practical in assessing their ergonomic exposures.

Secondly, the work of floor coverers is variable from day by day. Their tasks include measuring, cutting, installing, manual material handling, supervising, leveling, housekeeping and others. Floor coverers might focus on one task one day and switch to the other task the next day following the instructions of their employers.

Thirdly, it is not easy to define a clear work circle for floor coverers since their works may not repetitive. Additionally, as floor coverers work in groups, the size of the group ranging from 2 to 6 depending on the size of the project. It is common for floor coverers to stop doing their current tasks in order to help their coworkers. Therefore, their own work would be broken, and this makes it even harder to quantify their exposures.

PATH is an observational method based on work sampling, and is designed for the construction industry with specific focus on body posture, activity, tools, and handling (Buchholz et al., 1996). PATH is flexible and could be customized for different jobs. In order to study floor coverers, the PATH template would need to be revised to give more emphasis to the lower extremities in order to capture postures such as kneeling, squatting and others. Many observation methods do not address lower extremities movements (Armstrong and Foulke, 1982) or pay limited attention to them (Lynn, 1993) (Hignett and McAtamney, 2000).

PATH allows researchers to analyze ergonomic exposures at a detailed level, such as tasks, in order to identify and target specific tasks and activities that pose large ergonomic hazards (Buchholz et al., 1996).

1.1.3 The knee kicker

Carpet installers are exposed to ergonomic hazards due to frequent kicking a knee kicker. The knee kicker (Figure 1) is used to stretch the carpet; so the carpet could be hooked by the tack strip secured on the floor. The knee kicker has a toothed end, which is used to hold the carpet, and a padded end, which absorbs the impact force from the knee when the worker kicks it with the knee to produce a driving force.

The knee kicker is small and easy to manipulate, and it is a necessary tool for carpet installers. To stretch a piece of carpet, vigorous kicks are required by the suprapatellar region of the knee on the padded end of the tool with the worker's body aligned with the

long axis of the tool. In the process, the suprapatellar region of the knee is often traumatized, and this often leads to bursitis and osteoarthritis (Bhattacharya et al., 1986).

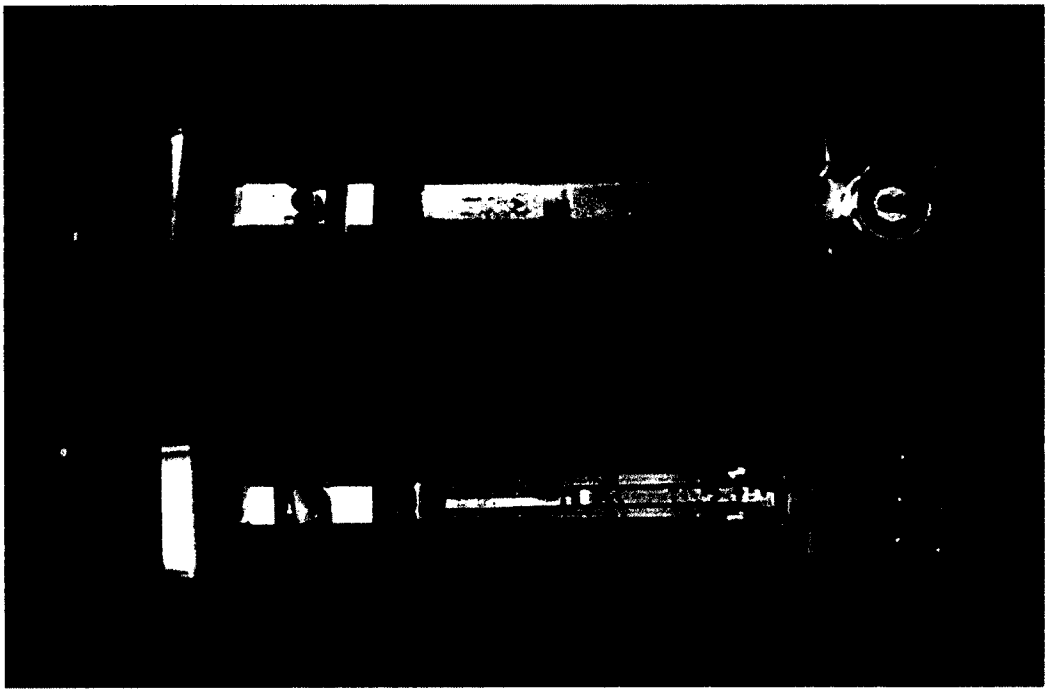


Figure 1 A knee kicker with the teeth, the pad, and the length adjustment (Roberts Deluxe Knee Kicker 10-412, Mexico, MO, USA)

The peak impact force while executing the hardest kicks was reported to be about four times the body weight (Bhattacharya et al., 1985) (Village et al., 1993). Animal studies simulating this phenomenon suggest that the repetitive impacts to the knee could explain the high level of knee morbidity found among carpet installers (Radin and Paul, 1971) (Liu et al., 1988).

A former professional carpet layer has developed a pneumatic powered carpet stretcher (Figure 2) with a view to decreasing the occurrence of knee-related disorders. The toothed part of the stretcher is movable and holds the carpet similar to the knee kicker. The frame at the front catches the tack strip to secure the tool. The air stretcher uses compressed air as the power source to drive the toothed part forward to stretch the carpet. So, this tool does not require kicking and does not have a padded end.

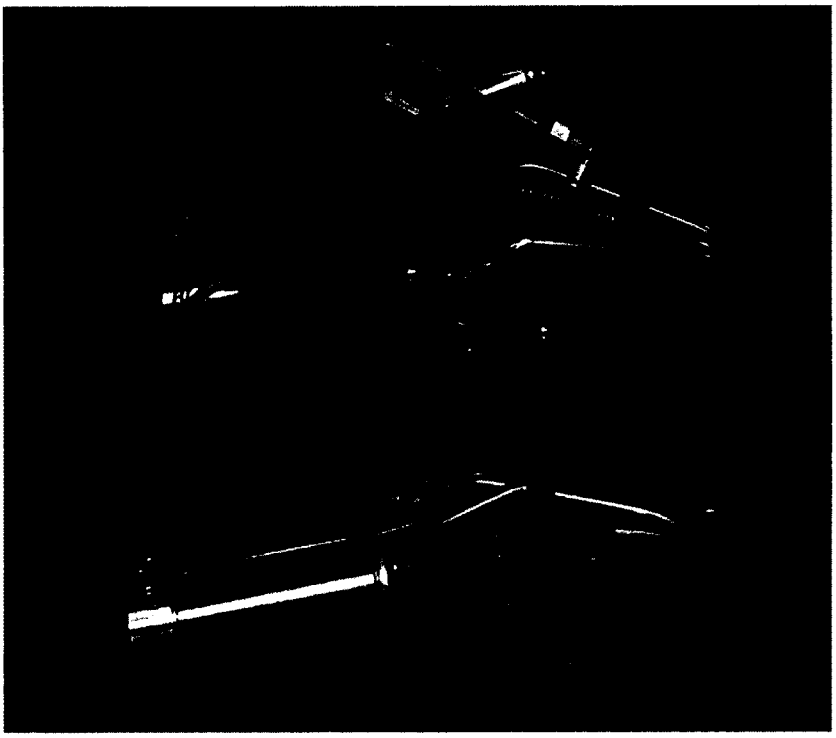


Figure 2 an Air Stretcher (Lee's Custom Floors, British Columbia, Canada)

1.1.4 Kneepads as a protective device

Despite significant changes in technology, the work of floor coverers has not changed very much. The major materials have remained the same (vinyl, hardwood, baseboard and carpet), as well as tools, protective devices and the installation process.

Floor coverers have traditionally used knee pads to protect their knees. Kneepads are widely used not only by workers in many different industries, but also by homeowners who do their own home improvement projects. Between 1887 and 2009, the United State government has issued more than 400 patents related to kneepads. Despite this, limited research has been conducted to study the effectiveness of protection that the kneepad confers

Moore et al. designed an experiment to determine the pressure applied to the knee during static postures used in low seam mining while not wearing knee pads and while wearing knee pads. They found that, in the majority (60%) of cases, the pressure was on the patellar tendon (PT) and the tibial tubercle (TT) during full flexion when kneeling at ninety degrees on one knee. They found that the presence of the kneepad significantly reduced the mean of the maximum pressure applied to the combined PT and TT, but the major part of the pressure still being on the patellar tendon and the tibial tubercle (Moore et al., 2009). Another paper from the same team indicated that one type of kneepad tested decreased the maximum pressure experienced at the combined patellar tendon and tibal tubercle. Nevertheless, peak pressures of greater than 25 psi were still experienced over knee structures commonly injured in mining (Porter et al., 2010).

These two studies focused on miners who work in confined areas with a high frequency of back bending. As such, these findings may not precisely fit the situation of floor coverers or other workers who do not work in confined areas with highly constrained postures. Additionally, their study focused on the landmarks of knee joint, which received the pressure.

Porter (Porter et al., 2010) suggested that novel kneepad designs were needed to redistribute the stresses at the knee across a greater surface area and to other regions of the leg away from key structures of the knee. Pro Knee (Figure 3) is an advanced kneepad, and it covers the whole leg from the ankle to the knee. A Pro Knee kneepad requires personal measurements, such as the circumference of the calf and the length of the leg, so that it can be built to fit its user. In the great Boston area, this kneepad dominates the professional pad market among floor coverers. However, no formal testing has been conducted to quantify to which extent the Pro Knee kneepads distribute contact pressure over the knee structures. An experimental study will be conducted to compare pressure distribution pattern, size of the contact area and mean and peak pressures among wearing Pro Knee, wearing a regular kneepad, and no kneepad. Pro Knee kneepads (over $200) cost ten times higher than regular one (around $20).

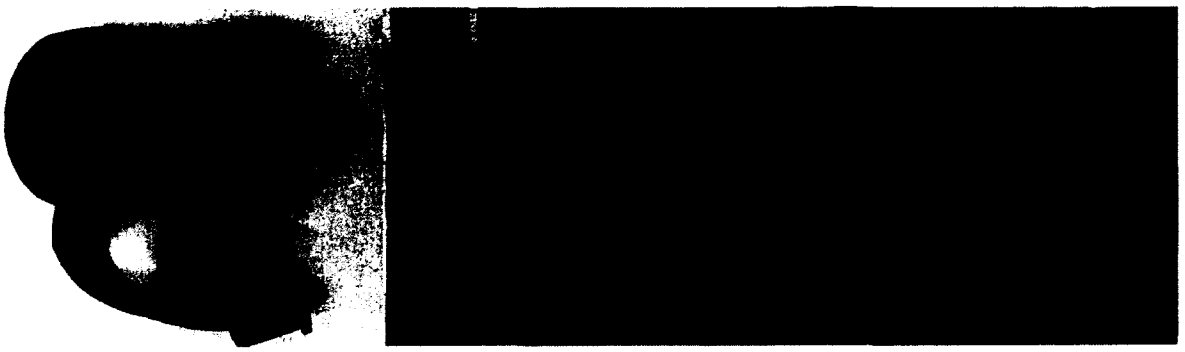


Figure 3 Regular kneepad (left) and the Pro Knee (right)

1.2 OBJECTIVE AND SPECIFIC AIMS

This dissertation is to discuss ergonomic exposures and interventions for floor coverers especially carpet installers. On-site observations will be utilized to collect ergonomic exposure data. Laboratory studies will be conducted to evaluate a common carpet installation tool (the knee kicker), and to compare it with an alternative. Another laboratory study will evaluate different kneepads for their mechanism and effectiveness in decreasing the impact of ergonomic exposures.

The specific aims of three studies are:

Study I: An assessment of quantitative ergonomic exposures for floor coverers in the Greater Boston area

- To quantify the ergonomic hazards in floor covering job tasks, using PATH (posture, activity, tools and handling)
- To collect other work-related information about the work environment that may have an impact on workers' health, e.g. tasks, materials, and others.

Study II: A biomechanical evaluation of the carpet knee kicker

- To describe the biomechanics of knee kicking during carpet installation
- To record the kicking durations and the average impact force.

Study III: A kinematic and kinetic comparison between the carpet knee kicker and the air stretcher

- To create a method to divide the entire movement to several phases
- To compare the muscle activity and segment motions between the kicker and the air stretcher among different phases

Study IV: A quantitative analysis of the pressure on the knee among carpet installers and a questionnaire for choosing kneepads

- To compare contact areas, mean and peak pressures on the knee among the bare knee and wearing two different kinds of kneepads
- To identify other reasons apart from pressure distribution in order to explain why workers prefer one specific type of knee pads

1.3 LITERATURE CITED

Armstrong, T.J., Foulke, J.A., 1982. Investigation of cumulative trauma disorders in a poultry processing plant. American Industrial Hygiene Association Journal .

Atkins, J.B., 1957. Internal derangement of the knee joint in miners. Br. J. Ind. Med. 14, 121-6.

Bhattacharya, A., Ramakrishanan, H., Habes, D., 1986. Electromyographic patterns associated with a carpet installation task. Ergonomics 29, 1073-1084.

Bhattacharya, A., Mueller, M., Putz-Anderson, V., 1985. Traumatogenic factors affecting the knees of carpet installers. Appl. Ergon. 16, 243-50.

Buchholz, B., Paquet, V., Punnett, L., Lee, D., Moir, S., 1996. PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. Appl. Ergon. 27, 177-87.

Bureau of Labor Statistics, 2010a. Occupational Employment and Wages, May 2010, 47-2031 Carpenters. 2011, 1.

Bureau of Labor Statistics, 2010b. Occupational Employment and Wages, May 2010,47-2041 Carpet Installers. 2011, 1.

Dennerlein, J.T., Johnson, P.W., 2006. Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. Ergonomics 49, 45-61.

Hignett, S., McAtamney, L., 2000. Rapid entire body assessment (REBA). Appl. Ergon. 31, 201-5.

Jensen, L.K., 2008. Hip osteoarthritis: influence of work with heavy lifting, climbing stairs or ladders, or combining kneeling/squatting with heavy lifting. Occup. Environ. Med. 65, 6-19.

Jensen, L.K., Mikkelsen, S., Loft, I.P., Eenberg, W., Bergmann, I., LÃ¸gager, V., 2000. Radiographic knee osteoarthritis in floorlayers and carpenters. Scand. J. Work Environ. Health 26, 257-62.

Jensen, L.K., Kofoed, L.B., 2002. Musculoskeletal disorders among floor layers: is prevention possible? Appl. Occup. Environ. Hyg. 17, 797-806.

Kivimaki, J., Riihimaki, H., Hanninen, K., 1992. Knee disorders in carpet and floor layers and painters. Scand. J. Work Environ. Health 18, 310-316.

Liu, Y., Huston, R., Bhattacharya, A., 1988. Modelling of a carpet installer knee-kicker. Int. J. Ind. Ergonomics 2, 179-182.

Lynn, M., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. Appl. Ergon. .

Moore, S.M., Porter, W.L., Mayton, A.G., 2009. Pressures applied to anatomical landmarks of the knee while in kneeling postures. 2009 ASB Annual Meeting Program .

Moore, J.S., Garg, A., 1995. The Strain Index: a proposed method to analyze jobs for risk of distal upper extremity disorders. Am. Ind. Hyg. Assoc. J. 56, 443-458.

National Safety Council, 2008. Injury Facts 2008. National Safety Council.

Porter, W.L., Mayton, A.G., Moore, S.M., 2010. Pressure distribution on the anatomic landmarks of the knee and the effect of kneepads. Appl. Ergon. 42, 106-13.

Radin, E.L., Paul, I.L., 1971. Response of joints to impact loading. I. In vitro wear. Arthritis Rheum. 14, 356-362.

Sharrard, W.J., Liddell, F.D., 1962. Injuries to the semilunar cartilages of the knee in miners. Br. J. Ind. Med. 19, 195-202.

Tanaka, S., Lee, S.T., Halperin, W.E., Thun, M., Smith, a.B., 1989. Reducing knee morbidity among carpetlayers. Am. J. Public Health 79, 334-5.

The New England Regional Council of Carpenters, 2009. Affiliated Trades of the Carpenters Union. 2010, 1.

Village, J., Morrison, J.B., Leyland, A., 1993. Biomechanical comparison of carpet-stretching devices. Ergonomics 36, 899-909.

Yuan, L., Buchholz, B., Dale, A.M., 2011. Knee Disorders Among Carpenters in the St. Louis Area. The Open Occupational Health & Safety Journal 3, 31-38.

Yuan, L., Buchholz, B., Fulmer, S., Jing, X.L., 2009. Knee Disorders among Union Carpenters.

2 A QUANTITATIVE ASSESSMENT OF ERGONOMICS EXPOSURES IN FLOOR COVERING IN COMMERCIAL CONSTRUCTION

2.1 INTRODUCTION

Floor coverers are a specific class of construction workers, who install various materials, such as carpets, hardwood floors, and vinyl floors in commercial and residential buildings. In New England, they belong to the carpenters union.

Floor coverers have a high prevalence of knee disorders and injuries. Three common kinds of knee disorders and injuries are knee bursitis, osteoarthritis (OA), and meniscal disorders (Yuan et al., 2009). Kivimaki et al. found that the prevalence of osteoarthritis of the knee was 58% among floor coverers (Kivimaki et al., 1992). A higher frequency of bursitis, arthritis, skin infections over the knee has been found in floor coverers compared to millwrights and bricklayers (Tanaka et al., 1989). Other researchers have also found that floor coverers have relatively high prevalence of knee pain (O'Reilly et al., 2000), knee complaint (Jensen and Kofoed, 2002) and other knee disorders and symptoms (Kivimaki et al., 1992).

Epidemiologic studies have shown that prolonged kneeling has a moderate association with knee disorders and injuries. Jensen et al. did a systematic review of epidemiologic studies published between 1986 and 2006. This review indicated that there

was a moderate relationship between OA of the knee and kneeling/squatting, and a strong relationship between OA of the knee and the combination of kneeling/squatting with heavy lifting (Jensen, 2008). In addition, long time knee straining positions may be a risk factor for the development of knee osteoarthritis for those above the age of 50 years (Jensen et al., 2000). The relationship between occupational meniscal disorders and occupation has not been discussed for floor coverers. However, this issue has been studied for many years in the mining industry. In 1957, Atkins et al. found that kneeling at work was the main factor for these injuries (Atkins, 1957). This relationship has been confirmed by other researchers (Sharrard and Liddell, 1962)(Baker et al., 2002).

Current studies discussed overall awkward leg posture using video tapes observation and other methods, and presented the approximate percentage of time spending on awkward leg postures in order to emphasize the magnitude of problems among floor coverers for their knee. However, when practitioners move to interventions to help floor coverers, more detailed data are needed to identify which specific tasks lead to more awkward body postures in order to tailor practical intervention approach. Meanwhile, other body segment postures and other work-related factors such as tool usage and manual material handling (MMH) would be useful to explain strain on the knee from the whole body perspective and to provide more information for floor coverers' work environment. The objective of this study is to quantify whole body ergonomic exposures for floor coverers by specific tasks, and to collect other work-related factors.

2.2 METHODS

The PATH (Posture, Activities, Tools, and Handling) observational method was used in this study (Buchholz et al., 1996). PATH is a validated observational ergonomics exposure assessment based on work sampling, and is designed for non-repetitive job such as construction work (Paquet et al., 2001), (Paquet et al., 2005). The main types of exposure observed for this study were body postures (trunk, legs and arms), tasks, activities, and tools and equipment used (Table 1). PATH employs a taxonomy, or a hierarchical system of classification, that subdivides construction work into the categories of stage, operation, task, and activity (Moir et al., 2003). The taxonomy for floor-covering work was developed from information obtained through on-site interviews and literature reviews, and the taxonomy was used to define trade-specific tasks and activities. General activities, as in prior studies (Tak et al., 2009), include manual material handling (MMH), tool use, and housekeeping. PATH definitions were shown below (Table 1).

Four major tasks were defined as fitting/installing baseboard, fitting/installing carpet, fitting/installing hardwood floor, and fitting/installing vinyl composite tile (VCT). Installing meant to secure materials to their permanent locations. Fitting included all kinds of preparations, such as measuring and cutting. Additional tasks included leveling (make the ground level in order to be covered with materials), housekeeping and other.

The template was installed in four PDAs that were used to record PATH data on-site. Inspect Write ^{TM} software (Penfact Inc., Boston, USA) was installed on these PDAs to

load templates and to transfer data. The "authoring" of Inspect Write ™ software was installed on a laptop to design templates, edit templates, and transfer data.

All observers were trained by other experienced trainers. The trainees were evaluated by coding the same tasks together with the trainers. Inter-observer agreements were calculated by dividing the number of observations for which observers agreed by the total number of observations. If the percentage of concordant observations between the trainee and the trainer was at least 0.8, the trainee was allowed to collect data.

Table 1 PATH definitions including body segments and weight in hands

Body Segments	PATH Definitions
Trunk – Refers to the position of the upper body above the hips in relation to the lower body below the hips, where the axis of rotation is considered to be the hips.	Neutral (<20) – Trunk flexion, twist or bending in any direction, less than 20 degrees. Mild flexion (≥20 - <45) – Forward trunk flexion of at least 20 degrees and less than 45 degrees. Severe flexion (≥45) – Forward trunk flexion of at least 45 degrees Bend or Twist – Can be either: 1. Trunk rotation about the long axis of the trunk of at least 20 degrees and/or 2. Side bending in the frontal plane of at least 20 degrees Bend/Twist AND Flex – Any combination of: a.) Lateral bend or twisting and b.) At least 20 degrees of sagittal flexion
Legs – Stand and Squat refer to the degree of flexion of either one or both knees. Walk, kneel, sit and kick refer additionally to whole-body activity and support surface.	Stand (flex < 35) – The feet support both legs and the knee joint flexion angle is less than 35 degrees. Shallow squat (both knees ≥ 35 - < 80) – The feet support both legs and the knee joint angle is at least 35 degrees and less than 80 degrees. Deep squat (both knees ≥ 80) - The feet support both legs and the knee joint angle is at least 80 degrees. Walk – Worker is in bipedal locomotion. Kneeling (One or both knees) – Worker has one or both knees on supporting surface.
Arms – Refer to the angle (either flexion or abduction) of the humerus in reference to the trunk.	Arms down (Both arms < 60) – The humerus of both the left and right arms are elevated less than 60 degrees from the trunk. 1 arm ≥ 60 – One arm, either the left or right, is elevated at least 60 degrees in any plane. 2 arms ≥ 60 – Both arms are elevated at least 60 degrees in any plane.
Weight in hands – Refers to weights of MMH loads exclusively.	No weight in hands – 0lbs Very light – (>0 - ≤5lbs) Light – (>5 - ≤15lbs) Medium – (>15 - ≤50lbs) Heavy – (>50lbs)

2.2.1 Study site and subjects

Researchers from the UMass Lowell Work Environment Department contacted the New England Regional Council of Carpenters to gain access to construction work sites and the workers there. At each construction site, a group of potential subjects was pre-selected if workers would keep working on the same site for at least two more weeks, and if workers have no knee-related diseases and injuries. Then researches randomly selected a subject in this group to obtain her/his permission for the observation. Participants were asked to sign a consent form to indicate their agreement with established policy. The consent form, authorized by UMass Lowell institutional review board, provided contact information of the project investigator if participants wanted to talk with him to know more about the project. The consent form also pointed out each participant's rights, including the right to stop the observation if participants did not feel comfortable to continue.

2.2.2 Data collection, management and analysis

Participants were observed from an appropriate distance that would disrupt their work performance. Each subject was observed by one observer at the same time. It is common that several observers were present at the same construction site. Both subjects and observers were given id numbers. It was randomly selected for an observer to observe a specific subject for any given observation day. Observers tried to cover the entire shift from the beginning to the end.

Once every 60 seconds, observers mentally recorded the individual worker and entered each exposure item, in the fixed sequence provided by the PATH template, into

the PDA. The researchers also made notations of unexpected or unusual activity observed during each session of study. Unexpected issues included unusual posture, new tools, and unusual materials.

A coversheet was completed with the assistance of the participant after each observation. The coversheet included general information about the individual and the work shift observed, such as gender, height, any personal protective equipment (PPE in use), observation durations and other descriptive data. At the end of each day of the observation, data from the PDA were transferred to the authoring laptop.

All recorded data were later transferred to a single spreadsheet. Both subjects and observers were not stratified for the analysis. Descriptive statistics for specific postures, activities, tools, MMH, and weight in hands were collected to provide task-specific estimations of the proportion of time when workers were exposed to these factors (Statistical Package for the Social Sciences, Version 18.0, IBM Corporation, Endicott, New York). Chi-square tests were performed to determine which exposures varied among tasks.

2.3 RESULTS

A total of 6059 observations (about 100 hours of data) were made on 49 floor coverers by 7 trained observers at 8 construction sites. Observation lasted from February 2007 to September 2009. Data were collected on 31 different days. Fitting/Installing hardwood floor and carpet were observed most frequently, representing almost three-fourths of the work time observed (Table 2).

Table 2 Frequency and percentage for tasks data collected from 49 workers at 8 sites

Task	Frequency	Percent
Fitting/Installing Hardwood floor	2,612	43.1
Fitting/Installing Carpet	1,627	26.9
Fitting/Installing Baseboard	509	8.4
Leveling	501	8.3
Fitting/Installing VCT	484	8
Housekeeping	222	3.7
Other	104	1.7
Total	6059	100

Awkward leg postures were common. Overall, kneeling was observed 56.0% of the time, which was more frequent than a neutral posture (36.5%) by one and half times. Kneeling (Figure 4) was observed in more than half of the observations during four major tasks. Overall, crawling was observed much less frequently than knelling for all tasks. Leg postures were significantly different among all job tasks (chi-square on 20 degree of freedom (d.o.f.), $p < 0.01$).

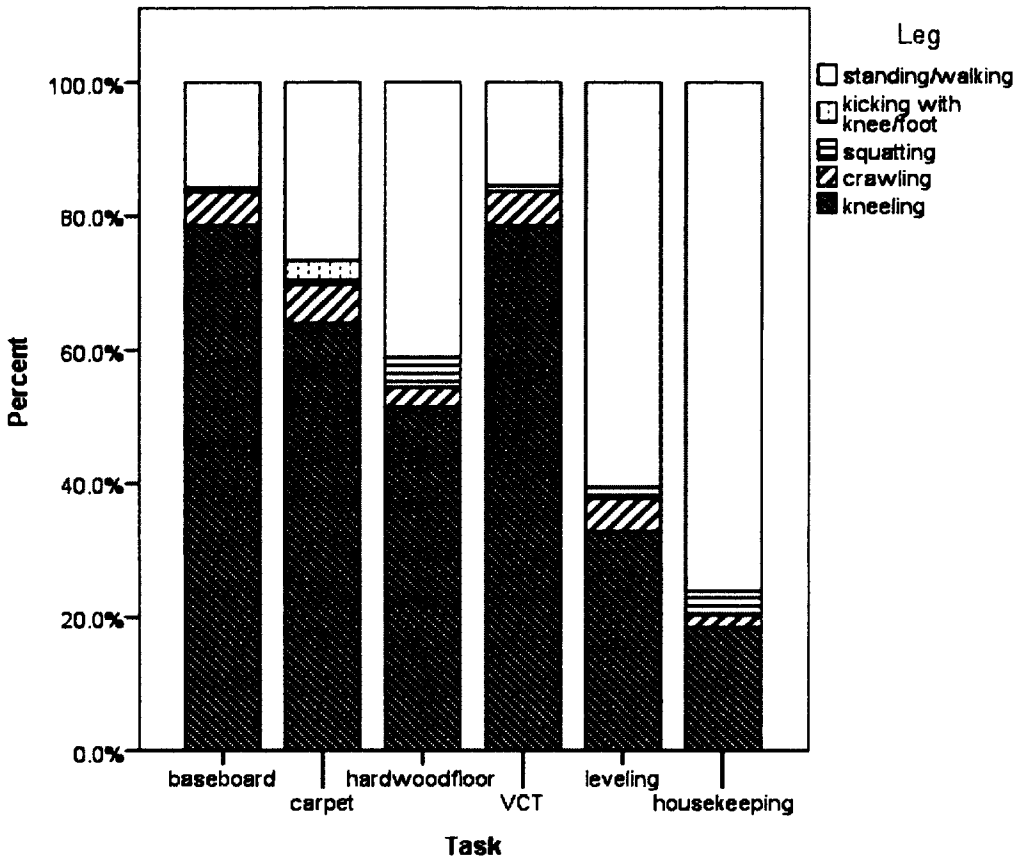


Figure 4 Estimate of the proportion of time that floor coverers were observed in various leg postures during different job tasks.

Overall, non-neutral trunk postures occurred frequently. Severe trunk flexion was observed as much as neutral posture (40.0%). Mild trunk flexion was observed 13.1%, and bend and/or twist was 9.6%. Severe trunk flexion was observed frequently among all four major tasks, especially for VCT (47.7%) (Figure 5). Trunk postures were significantly different among job tasks (chi-square on 15 d.o.f., $p < 0.01$).

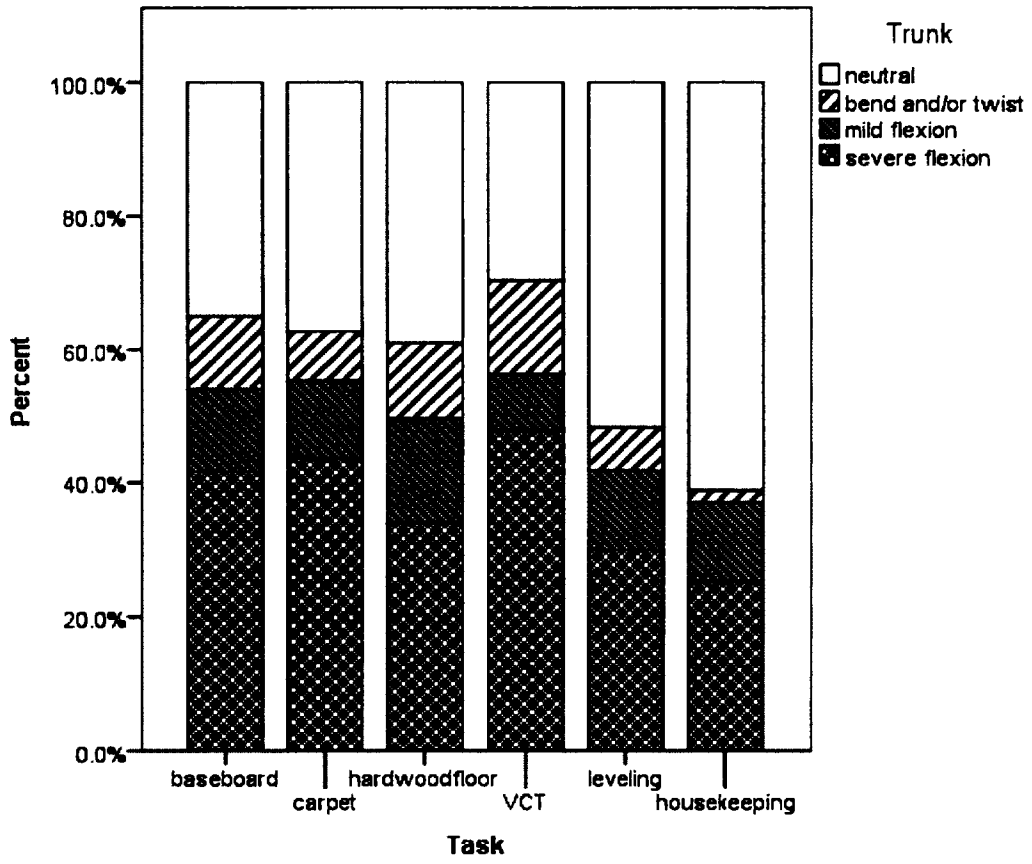


Figure 5 Estimate of the proportion of time that floor coverers were observed in various trunk postures during different job tasks.

Non-neutral trunk posture and kneeling occurred together often (Figure 6). For kneeling, crawling or kicking with knee/foot, severe trunk flexion was observed more than 50% of the time. For squatting, mild trunk flexion occurred more frequently than sever trunk flexion. For standing/walking, neutral trunk position was observed the most frequently (77.6%). Trunk posture was significantly different between leg postures (chi-square on 12 d.o.f., $p < 0.01$).

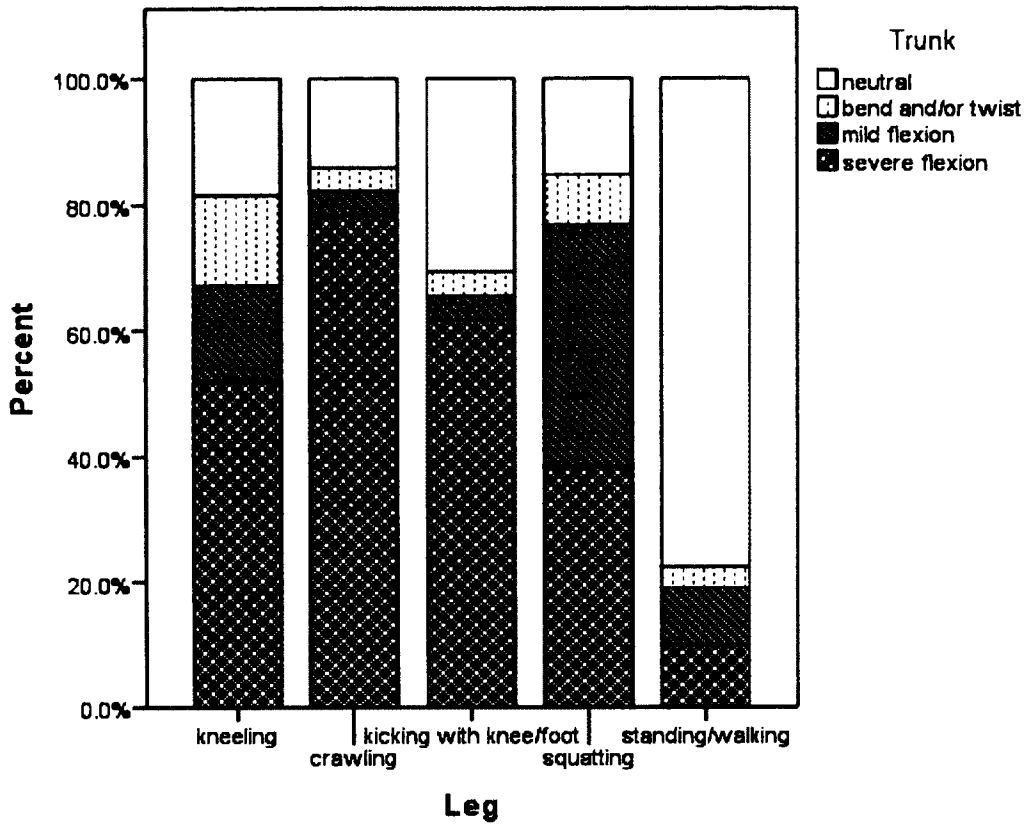


Figure 6 Estimate of the proportion of time that floor coverers were observed in various trunk postures during different leg postures.

Overall, two arms over 60 degrees was observed 37.8% of the time, one arm over 60 degree was 15.1%. Two arms over 60 was observed in more than 40% of the observation for VCT, carpet and baseboard (Figure 7). Arm postures were significantly different between job tasks (chi-square on 10 d.o.f., $p < 0.01$).

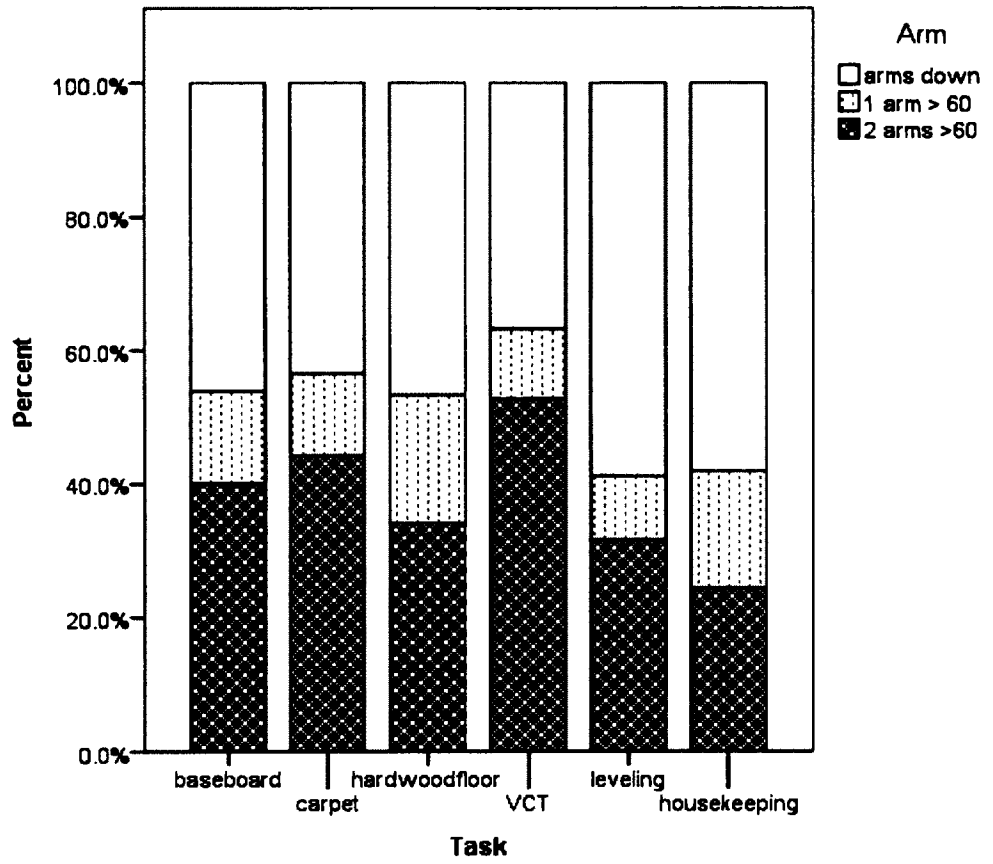


Figure 7 Estimate of the proportion of time that floor coverers were observed in various arm postures during different job tasks.

For kneeling, crawling, and kicking with knee/foot, two arms over 60 degrees were observed more than 50% of the time, especially for crawling (78.5%) (Figure 8). For squatting, two arms over 60 degrees and one arm over 60 degrees were observed at similar level. For standing/walking, arms were down most of the time. Arm postures were significantly different between job tasks (chi-square on 8 d.o.f., $p < 0.01$).

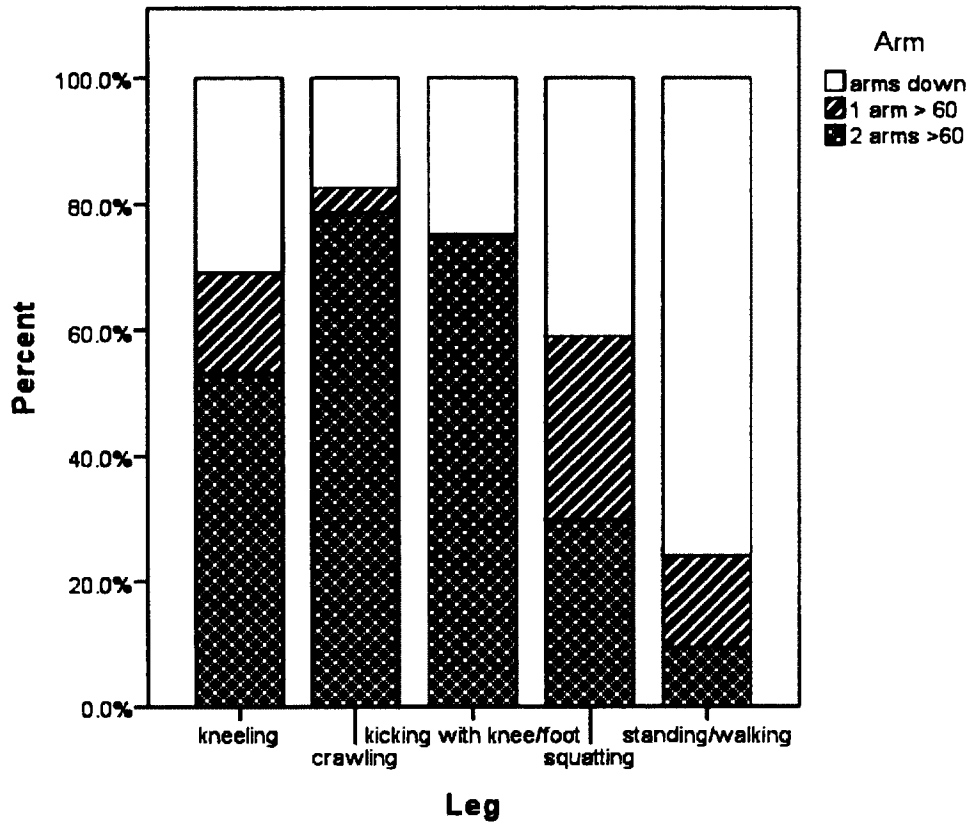


Figure 8 Estimate of the proportion of time that floor coverers were observed in various arm postures during different leg postures.

MMH was observed 26.9% of the time. Among all types of MMH, moving/placing occurred the most frequently (10.9%), carrying was observed 8.1%, and lifting/lowering 4.9%. Moving/placing was observed most frequently during VCT and hardwood floor tasks (Figure 9). Both carrying and lifting/lowering occurred most frequently during housekeeping and hardwood floor. MMH was significantly different between job tasks (chi-square on 20 d.o.f., $p < 0.01$).

the trainee was allowed to collect data

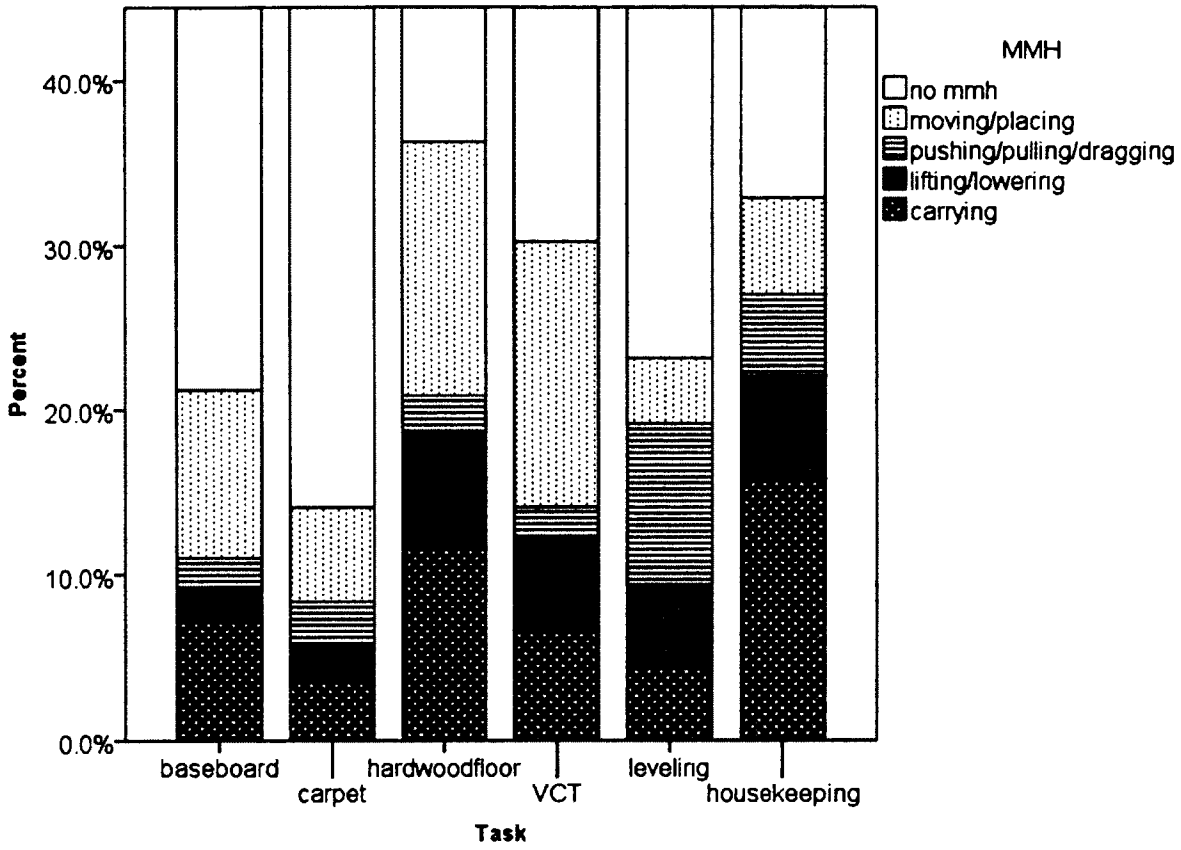


Figure 9 Estimate of the proportion of time that floor coverers were observed in various MMH activities during different job tasks. No MMH took the rest of the bar, but was displayed partially.

For kneeling and crawling, moving/placing was the most frequently observed type of MMH (Figure 10). For standing/walking, carrying was the most observed of (Figure 10). MMH was significantly different between leg postures (chi-square on 16 d.o.f., $p < 0.01$).

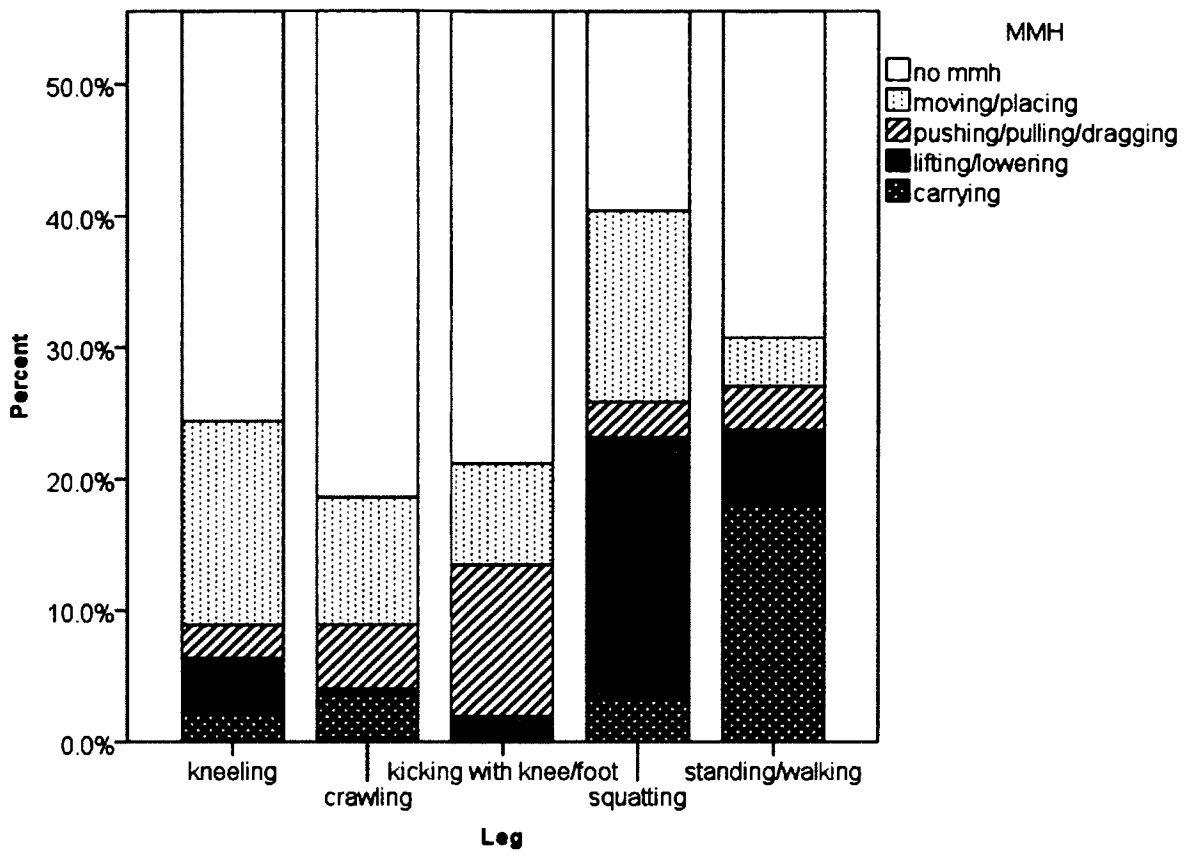


Figure 10 Estimate of the proportion of time that floor coverers were observed in various MMH activities during different leg postures. No MMH took the rest of the bar, but was displayed partially.

Overall, loads were handled 27.4% of the time. While heavy loads and medium loads were handled infrequently (under 4%), light loads and very light loads were handled more frequently (around 10%). For heavy and medium weight, top two tasks were not one of the four major tasks. For both light and very light, the top three tasks were hardwood floor, housekeeping, and VCT (Figure 11). Weight in hands was significantly

different between job tasks (chi-square on 20 d.o.f., $p < 0.01$).

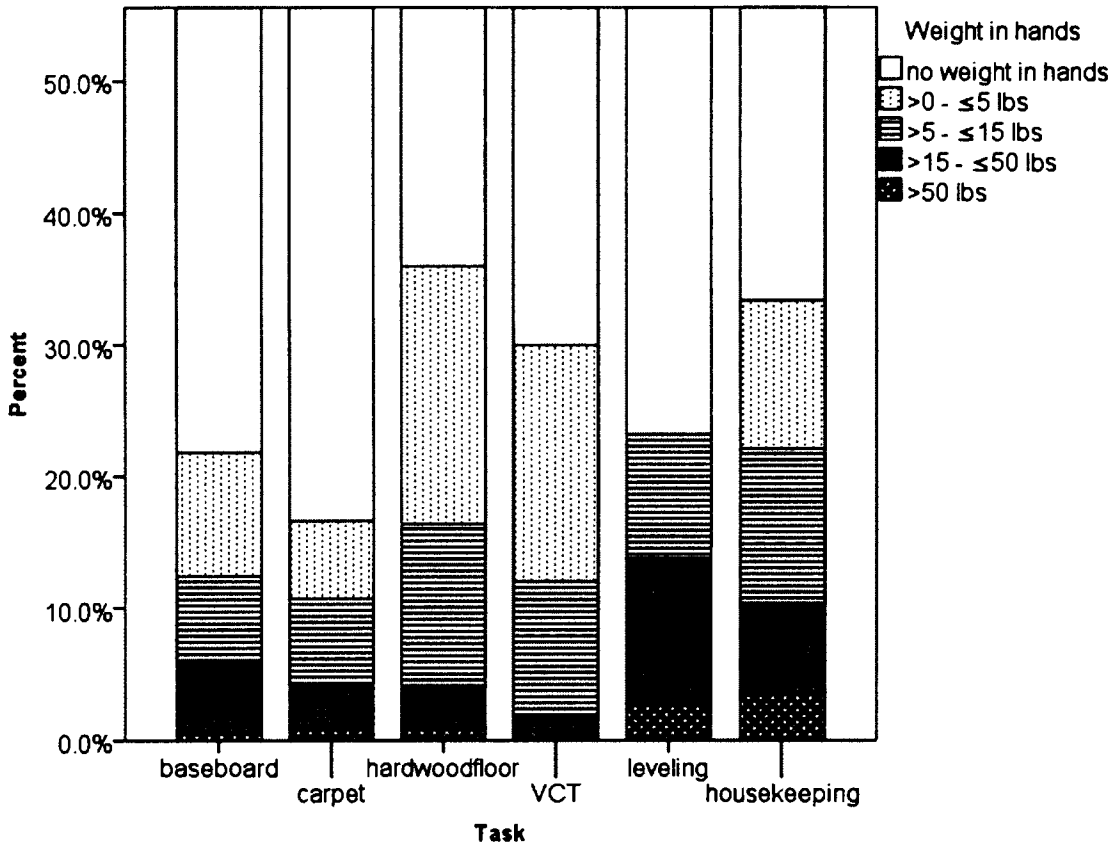


Figure 11 Estimate of the proportion of time that floor coverers were observed handling loads in various weight categories in hands during different job tasks. No weight in hands took the rest of the bar, but was displayed partially.

For all leg postures, heavy weight in hand was not observed frequently. Medium weight in hands was observed more frequently for squatting and standing/walking than other leg postures (Figure 12). For all leg postures, light weight in hands was observed at a narrow range between 8% and 15%. Very light weight in hands was observed frequently (above 10%) for kneeling, squatting, and standing/walking (Figure 12).

Weight in hands was significantly different between leg postures (chi-square on 16 d.o.f., $p < 0.01$).

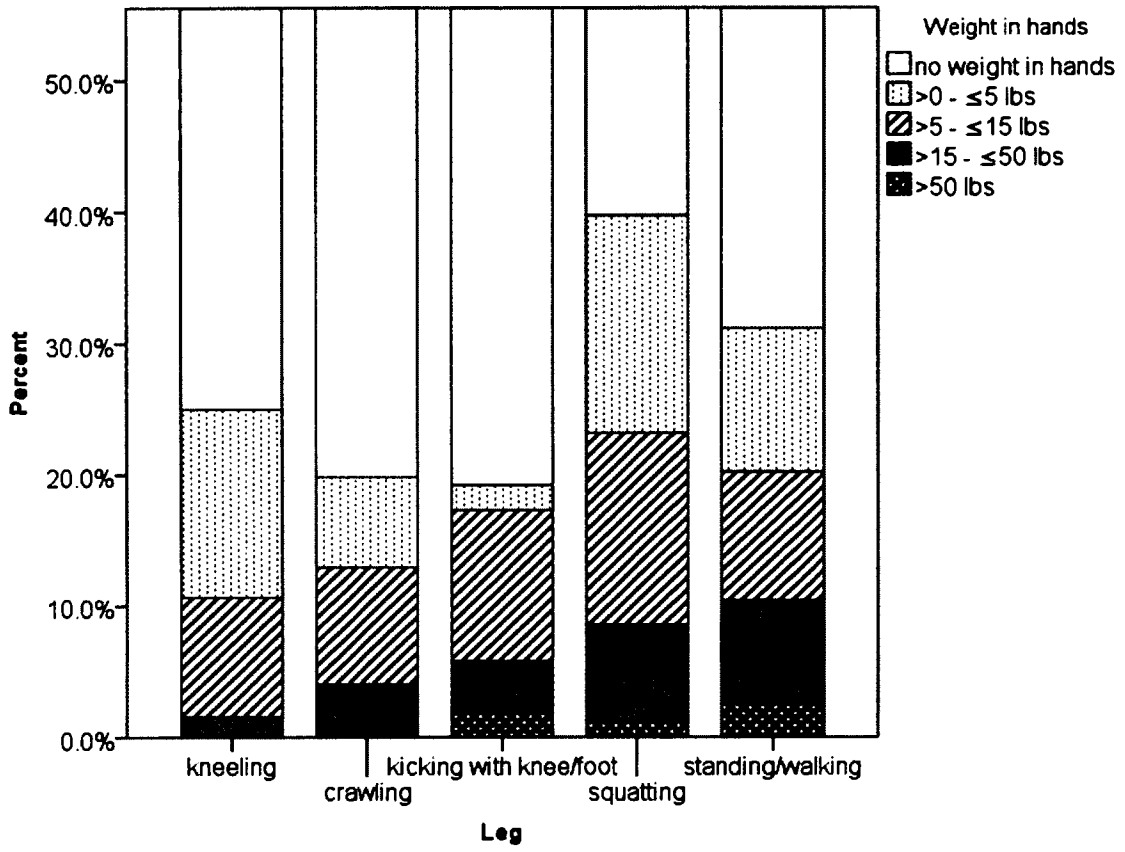


Figure 12 Estimate of the proportion of time that floor coverers were observed in various leg postures while handling objects of different weight categories. No weight in hands took the rest of the bar, but was displayed partially.

Overall, knives, trowels, hammers, and chop saws were the top tools used frequently (7.4%, 5.7% 2.4% and 2.1%) (Table 3). For about half of the time (49.8%), there were no tools in use.

Table 3 Frequently observed tools for floor coverers

Tools	Frequency	Percent
Knife	454	7.3%
Trowel	348	5.6%
Rag	227	3.7%
Hand	161	2.6%
Hammer	148	2.4%
Stair Tool	151	2.4%
Chop Saw	134	2.2%
Putty Knife	113	1.8%
Kicker	105	1.7%
Mallet	105	1.7%
Table Saw	86	1.4%
Tape Measure	88	1.4%
Pencil	71	1.1%

For different tasks, frequently used tools were different (Table 4). There were only three tools, which were observed more than 10% of the observations: knives for Fitting/installing carpet, knives and trowels for Fitting/installing VCT.

Hand tools were used more frequently (33.3%) than power tools (5.2%). Workers spent additional time to adjust/prepare tools (3.0%) and hold but not operate tools (7.0%).

Table 4 Frequently used tools for major tasks

Major tasks	Key tools	Percent
Fitting/installing baseboard tasks	putty knives	8.1%
	wall trimmers	3.7%
	framing squares	1.7%
Fitting/installing carpet	knives	12.1%
	stair tools	8.6%
	knee kickers	6.5%
	hammers	5.3%
	trowels	4.7%
Fitting/installing hardwood floor	rag	5.7%
	chop saws	4.8%
	rubber mallets	4.0%
	trowels	3.9%
	table saws	3.3%
Fitting/installing VCT	knives	11.2%
	trowels	10.7%
	tile cutters	6.0%
	propane torches	5.2%
	pencils	4.8%

2.4 DISCUSSIONS

These data represent the largest set of observations reported to date on the ergonomic features of floor laying at tasks level, and the first analysis of the extent of MMH while the knee is loaded. These findings could be useful to explain the previously reported high prevalence of knee-related injuries and disorders among floor coverers. This study also provide valuable information for interventions used to eliminate the knee-related ergonomics exposures for floor coverers.

Two previous studies found the duration of time spent in kneeling was 65% (Jensen et al., 2009), and 75% (Bhattacharya et al., 1985). In this study, kneeling was observed 56.0% of the time. This number is lower than the previous studies, but still very high. For four major tasks, especially for fitting/installing VCT and baseboard, workers spent more time kneeling than in neutral leg postures. For floor coverers, the majority of activities (cutting, measuring, fitting and installing) happened near or on the ground. Sometimes they could have stood up and walked to obtain materials or tools nearby, but they chose to crawl. This may because they preferred to avoid the repetition of getting up and down, or because they wanted to save time and energy.

VCT and hardwood floor tasks had a relatively high combination of kneeling and MMH (26% for VCT and 20% for hardwood floor). When floor coverers were doing MMH while kneeling or crawling, their knee suffered burdens from not only the kneeling but also from the weight of the materials they were handling. This stress may lead to knee-related disorders or injuries after high cumulative exposures.

Tools usage collected in this study could be used to give further explanation for awkward body posture. Take trunk flexion for example, hardwood floor required lower frequency of severe flexion than VCT and carpet. Because chop saws, rubber mallets, and table saws, which were the main tool in hardwood floor task, did not require much severe bending of the trunk. However, during VCT or carpet tasks, knives, trowels, tile cutters, stair tools, knee kickers and pencils, as key tools, required workers to kneel on the ground frequently and bend their trunk severely at the save time.

One kind of intervention is to provide alternative tools. For carpet installers, for example, the power stretcher and the air stretcher are two alternatives for the knee kicker. The power stretcher uses leverage and cogs, while the air stretcher uses compressed air. Both of them could decrease the frequency of awkward body postures and especially decrease impact forces on the knee by eliminating the kicking action.

This study used an observational method to quantify ergonomics exposures such as awkward postures. Awkward postures and joint loads could be different concepts and awkward postures might not always lead to heavy load on certain joints. For example, kneeling with severe trunk flexion is an extreme awkward posture, which may lead to high joint loads to knee and back. But if workers use their hands to support their body, then the weight of their body will be distributed through both their knees and hands, so there will be less joint loads. In this case, awkward postures did not provide enough information for joint loads. There is a need to create an approach to assess knee related exposures combining posture data with biomechanics modeling (Reid et al., 2010).

There are potential sampling concerns in this study. For example, data in Table 2 is just descriptive analysis of this data sample and does not represent the task distribution for general floor coverers since only 100 hours data have been obtained.

In this study, the proportion of time for operating/holding/adjusting the knee kicker was 6.5%, but the high impact forces due to its usage has been noticed and discussed (Reid et al., 2010) (Bhattacharya et al., 1985). Further biomechanical research could be done to collect both muscle activity data and body postures data in order to figure out the pattern of ergonomics exposure. Floor coverers suffer longtime kneeling; therefore, the protection efficiency and principles of the kneepad need to be studied to discuss whether they have special needs for kneepads.

It is practical to decrease work time on tasks with high ergonomics exposure by redesigning the work. It is also efficient to reduce negative effects on the body by using alternative tools or protection devices. However, both interventions require cooperation from the management level. During the study, it is learned that local unions have been working a long time to get employers to pay for alternative tools and professional protection equipment.

This study analyzed ergonomics exposure for floor coverers at the task level, and provided detailed information for body posture, tool usage and other. Data can be used to understand the floor-covering job, and design new interventions to decrease the high knee-related injuries and disorders.

2.5 LITERATURE CITED:

Atkins, J.B., 1957. Internal derangement of the knee joint in miners. Br. J. Ind. Med. 14, 121-6.

Baker, P., Coggon, D., Reading, I., Barrett, D., McLaren, M., Cooper, C., 2002. Sports injury, occupational physical activity, joint laxity, and meniscal damage. J. Rheumatol. 29, 557-557.

Bhattacharya, A., Mueller, M., Putz-Anderson, V., 1985. Traumatogenic factors affecting the knees of carpet installers. Appl. Ergon. 16, 243-50.

Buchholz, B., Paquet, V., Punnett, L., Lee, D., Moir, S., 1996. PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. Appl. Ergon. 27, 177-87.

Jensen, L.K., 2008. Hip osteoarthritis: influence of work with heavy lifting, climbing stairs or ladders, or combining kneeling/squatting with heavy lifting. Occup. Environ. Med. 65, 6-19.

Jensen, L.K., Mikkelsen, S., Loft, I.P., Eenberg, W., Bergmann, I., LÃ¸gager, V., 2000. Radiographic knee osteoarthritis in floorlayers and carpenters. Scand. J. Work Environ. Health 26, 257-62.

Jensen, L.K., Rytter, S., Bonde, J.P., 2009. Exposure assessment of kneeling work activities among floor layers. Appl. Ergon. .

Jensen, L.K., Kofoed, L.B., 2002. Musculoskeletal disorders among floor layers: is prevention possible? Appl. Occup. Environ. Hyg. 17, 797-806.

Kivimaki, J., Riihimaki, H., Hanninen, K., 1992. Knee disorders in carpet and floor layers and painters. Scand. J. Work Environ. Health 18, 310-316.

Moir, S., Paquet, V., Punnett, L., Buchholz, B., Wegman, D., 2003. Making sense of highway construction: a taxonomic framework for ergonomic exposure assessment and intervention research. Appl. Occup. Environ. Hyg. 18, 256-67.

O'Reilly, S.C., Muir, K.R., Doherty, M., 2000. Occupation and knee pain: a community study. Osteoarthritis Cartilage 8, 78-81.

Paquet, V.L., Punnett, L., Buchholz, B., 2001. Validity of fixed-interval observations for postural assessment in construction work. Appl. Ergon. 32, 215-24.

Paquet, V., Punnett, L., Woskie, S., Buchholz, B., 2005. Reliable exposure assessment strategies for physical ergonomics stressors in construction and other non-routinized work. Ergonomics 48, 1200-1219.

Reid, C.R., Bush, P.M., Cummings, N.H., McMullin, D.L., Durrani, S.K., 2010. A review of occupational knee disorders. J. Occup. Rehabil. 20, 489-501.

Sharrard, W.J., Liddell, F.D., 1962. Injuries to the semilunar cartilages of the knee in miners. Br. J. Ind. Med. 19, 195-202.

Tak, S., Paquet, V., Woskie, S., Buchholz, B., Punnett, L., 2009. Variability in risk factors for knee injury in construction. J Occup Environ Hyg 6, 113-120.

Tanaka, S., Lee, S.T., Halperin, W.E., Thun, M., Smith, a.B., 1989. Reducing knee morbidity among carpetlayers. Am. J. Public Health 79, 334-5.

Yuan, L., Buchholz, B., Fulmer, S., Jing, X.L., 2009. Knee Disorders among Union Carpenters.

3 A BIOMECHANICAL EVALUATION OF THE KNEE KICKER

3.1 INTRODUCTION

Carpet installers install carpets in commercial and residential buildings (The New England Regional Council of Carpenters, 2009). They are exposed extensively to ergonomic hazards due to frequently kicking a knee kicker with their knee in order to stretch the carpet installers (Bhattacharya et al., 1985) (Radin and Paul, 1971) (Liu et al., 1988).

The knee kicker (Figure 1) has a toothed end which is used to hold the carpet, and a padded end which absorbs the impact force from the knee when the worker kicks it with their knee to produce a driving force.

To stretch a piece of carpet, vigorous kicks are needed by the suprapatellar region of the knee on the padded end of the tool with the worker's body aligned with the long axis of the tool. In the process, the suprapatellar region of the knee is often traumatized, and this often leads to bursitis and osteoarthritis (Bhattacharya et al., 1986). Previous studies discussed the repeated patterns for kicking (Bhattacharya et al., 1986, Village et al., 1993), but none associated knee/hip angles with muscle activities and impact forces. Little is known about the nature of the kicking movement, and the temporal relationship among knee/hip angles, muscle activities and impact forces. This paper describes these patterns of motion, muscle activity, and force while floor coverers are using the knee kicker.

3.2 METHODS

Professional carpet installers were recruited from local floor coverers union #2168 (The New England Regional Council of Carpenters) for this study with the assistance from the business agent of the union. This group of floor coverers were doing a project where was close to the laboratory. Every day, the foreman sent one subject to the laboratory to participate the experiment. EMG electrodes and optical markers were attached to subjects after finishing the consent form (IRB No.: 07-110-BUC-XPD). Then subjects were required to perform three trials each comprising of five work cycles of carpet stretching using the knee. Subjects took a 1-minute break between subsequent trials and 5 minutes break after the completion of three trials. In the lab, a big piece of carpet was fixed on a wooden platform (6 feet by 4 feet) using nails on one end while the other side was kept unsecured; so it could be stretched in the opposite direction. Each subject received 150 dollars cash incentive.

A load cell (Model: SM-500, Interface Inc., Scottsdale, Arizona, USA) fitted in the knee kicker was used to measure the impact force (Figure 13). Force signals were amplified using a strain gauge amplifier (Force Monitor, Model: ST-1, Prototype Design & Fabrication Company, Ann Arbor, MI, USA). Average peak impact force for subjects was calculated. The ratio between peak impact force and body weight was also provided with a standard deviation.

Figure 13 The load cell was fitted in the knee kicker

Activities from right knee-flexors/hip-extensors (right biceps femoris), right knee-extensors/hip-flexors (right rectus femoris), and shoulder flexors (left and right anterior deltoid) were recorded by surface electromyography electrodes (Bhattacharya et al., 1986). Standard differential electrodes were placed parallel to the muscle fiber direction with an inter-electrode distance of 2cm. The EMG signals were amplified using custom-built pre-amplifiers and then amplified (Delsys DE-3.1 Surface EMG Sensors, Delsys Inc. Boston, MA, 02215) before being digitized using a twelve-bit analog-to-digital (A/D) converter and stored on a personal computer. Data acquisition was controlled by using LabVIEW software (version 8.0). The sampling rate for EMG signals was 1000 Hz.

Maximum voluntary contractions (MVC) and the baseline activities of each muscle were recorded by surface electromyography for five seconds after the experimental trials.

Kinematics of the kicking motion were recorded using the Optotrak Certus Motion capture system (Northern Digital Inc., Ontario, Canada). Infrared light emitting diode markers (IREDs) were placed on each of three body segments: pelvis; right thigh; and right lower leg. The IREDs were pulsed at high frequencies and viewed by three cameras. In order to prevent excessive movement of these markers in relation to the skin during the kicking motion, markers were first attached to a thermoplastic splint made of Omega Max (North Coast Medical Inc., USA) molded according to the contour of the three body segments, and then this split was attached to the skin using double-sided tape. Displacement data of the knee kicker and the air stretcher were obtained by an IRED marker placed on the shaft of the knee kicker, and on the movable portion of the air stretcher. The viewing field of the cameras was calibrated in three dimensions using a standard calibration cube supplied with the motion analysis system. Motion analysis data were sampled at 250 Hz. Motion analysis and EMG data were synchronized. Figure 14 shows a person with all IRED markers and EMG electrodes attached to the body. Postural data were synchronized with muscle activities and impact force data.

For EMG data, the baseline was subtracted from both the MVC and trial data, prior to analysis. An RMS algorithm with a 0.1 second time constant was implemented in software to normalize and smooth the EMG data. For each trial, only the middle work cycle was chosen to calculate an EMG average.

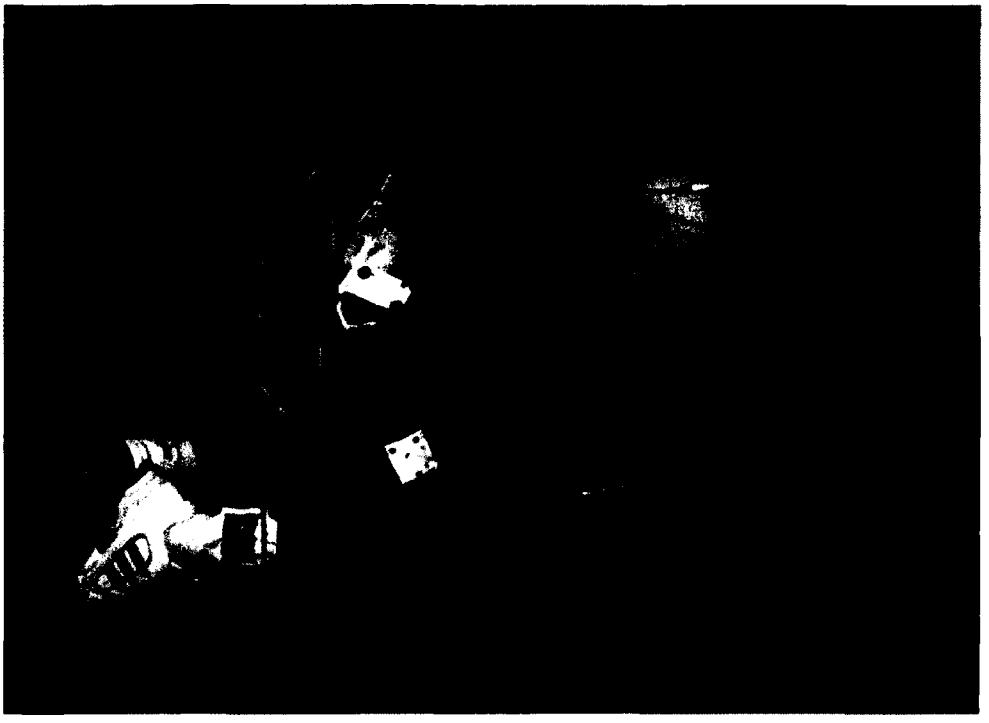


Figure 14 One participant with electrodes and markers.

Original data from the motion capture system only include positions of markers. A MatLab (MatLab Version 2009, MathWorks, Natick, MA) script was adapted from other scripts available from the Harvard Occupational Biomechanics and Ergonomics Laboratory in order to calculate knee and hip angles (Dennerlein and Johnson, 2006).

3.3 RESULTS

Nine professional carpet installers (8 male and 1 female) agreed to participate. Their mean body weight was 797.5 N (SD 148.6 N) and mean height was 173.1 cm (SD 10.5 cm). One subject (subject 3) did not finish the entire experiment, so his data were omitted from the results.

Example plots of muscle activities, impact force, and knee and hip angle versus time demonstrate the four phases of a typical kicking action (Figure 15) : windup (I), kick (II), recoil (III), and release and adjustment (IV). Similar methods were used to identify distinct phases in a keystroke contact force history (Rempel et al., 1994).

Windup (I) begins (Line A) when biceps femoris becomes active to increase hip extension (Point A) and ends (Line B) when both hip and knee reach their maximum extension (Point B). During phase I, rectus femoris and right deltoid are not active. Hip flexion initiates the kick phase (II) (Line B) just as the rectus femoris becomes active. Impact (Line E) occurs just prior to the end of phase II as the leg drives the kicker (Point E).

The recoil phase (III) starts when the knee and hip reach maximum flexion (Point C). The knee bounces off the kicker, causing knee and hip extension. Both biceps femoris and rectus femoris have activities, that though they are decreasing, cause the knee and hip to flex slightly. During the recoil phase, the knee leaves the kicker (Line F, Point F). The release and adjustment phase (IV) starts (Line D) at the end of the recoil phase, ends

(Line A^1) with the beginning of the next windup phase when biceps femoris starts to become active again (Point A^1).

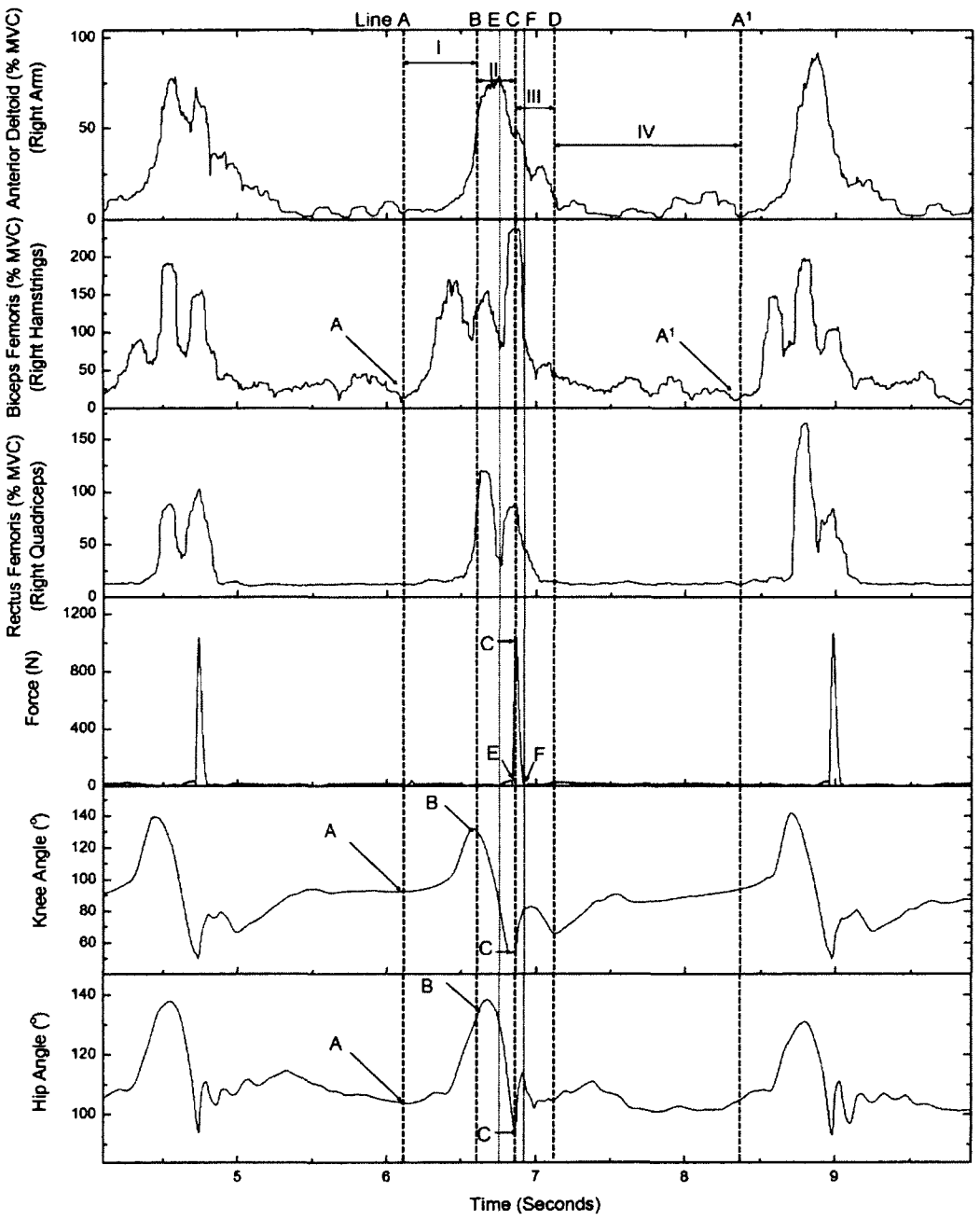


Figure 15 An example of EMG-time curve, force-time curve, and angle-time curve to demonstrate four phases of a typical kicking action: windup (I), kick (II), recoil (III), and release and adjustment (IV). Line A, B, C, D and A^1 indicate either the beginnings or the ends of difference phases

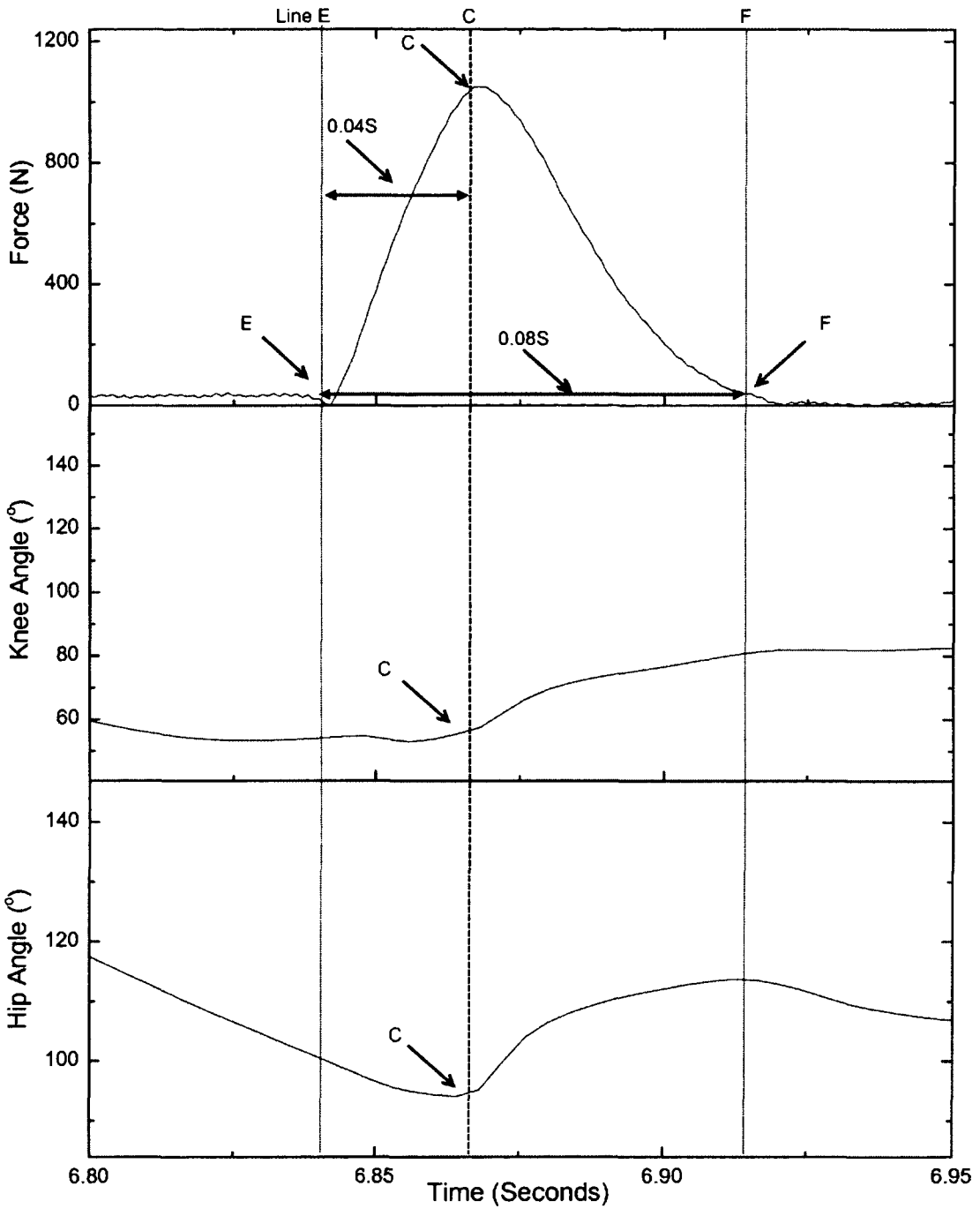


Figure 16 An example of the force-time curve, and angle-time curve for the impact phase (phase III)

A typical impact contact between the knee and the kicker, including both parts from the kick (II) and the recoil phase (III), only lasts about 0.08 seconds (Figure 16), and it

takes less than 0.04 second for the impact force to reach the peak (Point C) from the baseline (Point E). The peak impact force (Point C), minimum hip (Point C) and knee extension (Point C) appears almost simultaneously. Then the knee leaves the kicker (Point F).

The mean impact force of eight subjects was 1047.2 N (Table 5). For all subjects except subject 9, the impact force was greater than subject's body weight. On average, subjects exerted an impact force 1.32 times as much as their body weight.

Table 5 Impact force and ratio between the impact force and the body weight for each subject

Subject ID	Average impact force (N)	Subject's body weight (N)	Average impact force/body weight
1	1289.4	767.7	1.68
2	1168.2	1048.4	1.11
4	975	761.5	1.28
5	1164.9	877.6	1.33
6	768.3	648.1	1.19
7	1044.7	640.1	1.63
8	1318.3	951	1.39
9	649.1	685.9	0.95
Average	1047.2 (SD: 239.7)	797.5 (SD:148.6)	1.32 (SD: 0.25)

3.4 DISCUSSION

The presented methodology integrated quantitative muscle activities, accurate impact force and quantitative postural data to characterize four phases during the use of a knee kicker. Two previous investigations have attempted to characterize the kicking movement; however, the video recorder (Bhattacharya et al., 1986, Bhattacharya et al., 1985) used in these two studies provided less accurate quality of data than this study. This paper discussed the nature of the kicking movement, and the temporal relationship among knee/hip angles, muscle activities and impact forces.

The impact force averaged at 1047.2 N, which was much smaller than findings from previous studies (3000 N) (Village et al., 1993, Bhattacharya et al., 1985). One explanation may be the setup of the experiment environment. As described in the methods section, the experiment was conducted in a lab with a motion tracking system, and a piece of carpet was secured on a piece of plywood with one edge open. This setup was different with that of the two previous studies which occurred in real work situations (without a motion tracking system). All these markers and electrodes may change workers' performance by decrease their kicking force, because workers worried about whether their intensive kicking may toss these markers off. In addition, in real work condition, the carpet is either glued to the floor or has a large fraction from the underlay that is placed underneath the carpet. Nevertheless, in this experiment, no glue was applied and friction was limited since a relatively small size of the carpet was directly secured on the plywood without any underlay. Therefore, less force was required to stretch the carpet.

The impact only lasted about 0.08 second, and it took less than 0.04 second for the impact force to reach the peak. The result confirmed findings from previous studies (Village et al., 1993, Bhattacharya et al., 1985). The impact stops the forward leg motion. During the kicking, relative movements between the skin and the electrodes (Bhattacharya et al., 1986) could cause spikes of biceps femoris. Then biceps femoris helps extend the knee to resting position after impact.

There were several scenarios when the EMG RMS went beyond the measured MVC with the %MVC exceeded 100%. One explanation was that the MVC was measured during static tasks, but kicking was a dynamic activity; thus, the added force and velocity factor may produce EMG spikes. In addition, relative movements between the muscles and the electrodes during the kicking could also cause the spikes. Motion artifacts during knee kicking were also found by other researchers (Bhattacharya et al., 1986).

More than this, there were relative movements between the skin and the bones during the kicking. These movements led to errors in the measured segment angles. It is unknown to what extent these errors will be, but latest studies discovered that the influence of these movements could be significantly large (Stagni et al., 2005).

In summary, the loading on the knee of floor coverers was characterized by high impact force, short impact duration, and high frequency of exposure from kicking using their knee. Therefore, the cumulative exposure to the knee could be a significant concern for workers' health. The maximum compressive strength of the knee joint is 7300N (Bargren et al., 1978) and the average impact force is about 40 percent of this maximum

compressive strength (Bhattacharya et al., 1985). It has been shown that osteoarthritis lesions will be induced if articular stresses frequently exceeded the resistance capacity of bone and cartilage tissues (Radin and Paul, 1971). Animal studies simulating this phenomenon also suggested that the repetitive impacts to the knee could explain the high level of knee morbidity found among carpet installers (Radin and Paul, 1971, Liu et al., 1988).

The timing of specific muscle contractions provides insight into the kicking movements. The peak impact force, minimum hip and knee extension occurs simultaneously. Hip flexion initiates the kick phase just as the rectus femoris becomes active. The mechanisms of the kicking movement may be helpful to design a more efficient knee kicker. These data could also be used to develop biomechanical model to describe the kicking movements.

3.5 LITERATURE CITED:

Bargren, J.H., Day, W.H., Freeman, M.A., Swanson, S.A., 1978. Mechanical tests on the tibial components of non-hinged knee prostheses. J. Bone Joint Surg. Br. 60-B, 256-261.

Bhattacharya, A., Ramakrishanan, H., Habes, D., 1986. Electromyographic patterns associated with a carpet installation task. Ergonomics 29, 1073-1084.

Bhattacharya, A., Mueller, M., Putz-Anderson, V., 1985. Traumatogenic factors affecting the knees of carpet installers. Appl. Ergon. 16, 243-50.

Dennerlein, J.T., Mote Jr, C., Rempel, D.M., 1998. Control strategies for finger movement during touch-typing the role of the extrinsic muscles during a keystroke. Experimental brain research 121, 1-6.

Dennerlein, J.T., Johnson, P.W., 2006. Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. Ergonomics 49, 45-61.

Jing, X., Buchholz, B., Punnett, L., Dennerlein, J., 2013. A kinematic and kinetic comparison between the carpet knee kicker and the air stretcher. Dissertation (UMass Lowell).

Liu, Y., Huston, R., Bhattacharya, A., 1988. Modelling of a carpet installer knee-kicker. Int. J. Ind. Ergonomics 2, 179-182.

Radin, E.L., Paul, I.L., 1971. Response of joints to impact loading. I. In vitro wear. Arthritis Rheum. 14, 356-362.

Rempel, D., Dennerlein, J., Mote, C., Armstrong, T., 1994. A method of measuring fingertip loading during keyboard use. J. Biomech. 27, 1101-1104.

Stagni, Rita, et al. "Quantification of soft tissue artefact in motion analysis by combining 3D fluoroscopy and stereophotogrammetry: a study on two subjects." Clinical Biomechanics 20.3 (2005): 320-329.

The New England Regional Council of Carpenters, 2009. Affiliated Trades of the Carpenters Union. 2010, 1.

Village, J., Morrison, J.B., Leyland, A., 1993. Biomechanical comparison of carpet-stretching devices. Ergonomics 36, 899-909.

4 A KINEMATIC AND KINETIC COMPARISON BETWEEN THE CARPET KNEE KICKER AND THE AIR STRETCHER

4.1 INTRODUCTION

Carpet installers install carpets in both commercial and residential buildings (The New England Regional Council of Carpenters, 2009). In 2010, there were 25,580 carpet installers in the U.S., according to the Bureau of Labor Statistics (BLS) database (Bureau of Labor Statistics, 2010) (code 47-2041 in the Standard Occupational Classification system).

The carpet installation task involves a combination of posture, force, acceleration, and repetition that is biomechanically demanding and thus leads to increased occurrence of knee injuries and disorders. Kivimaki et al. (Kivimaki et al., 1992) found that the prevalence of osteoarthritis of the knee was 58% among floor coverers. Jensen et al. (Jensen and Kofoed, 2002) surveyed 102 carpet installers, of whom 56% reported knee complaints during the previous 12 months. A higher frequency of bursitis, arthritis, skin infections over the knee, and other knee symptoms was found in floor layers compared to millwrights and bricklayers (Tanaka et al., 1989).

Yuan et al. (Yuan et al., 2009) used an administrative database from the New England Carpenters Benefit Funds to identify cases of knee disorders and examined the distribution of specific disorders among floor coverers during a 16-year period (1990-2006). The incidence of knee disorders was approximately 286 per 10,000 person-years.

Of those cases, the most frequently occurring single disorder was meniscal injuries (33.1%), followed by bursitis (24.3%) and osteoarthritis (OA) (21.1). Similar results were found for floor coverers in the St. Louis area: bursitis (32.1%) was the most common disorders, followed by meniscal injuries (26.9) and OA (15.3) for floor coverers journeymen (Yuan et al., 2011). Both the Carpenters' Health and Welfare Trust Fund of St. Louis and the Carpenters' Combined Benefits Fund of Massachusetts have strict requirements for case coverage, such as members having worked 500 hours in a consecutive 6-month period. Therefore, the prevalence of injuries and disorders in these data sets were smaller than results from other surveys.

A carpet installer spends 75% of his time in the kneeling posture that sometimes requires near maximum knee flexion (Bhattacharya et al., 1985). In addition to ergonomic exposure from kneeling, carpet installers are frequently exposed to impact forces that arise during use of the device called a knee kicker. The knee kicker, an essential tool in this trade, is used to stretch the carpet, allowing the carpet to be hooked to the tack strip secured on the floor edges. The knee kicker has a toothed end used to hold the carpet and a padded end that is intended to absorb the impact force from the knee (Figure 1).

The knee kicker is small and easy to manipulate. To stretch a piece of carpet, vigorous kicks are administered with contact by the suprapatellar region of the knee on the padded end of the tool, with the worker's body aligned with the long axis of the tool

(Bhattacharya et al., 1986). In the process, the suprapatellar region of the knee is often traumatized, and this may lead to bursitis and osteoarthritis (Bhattacharya et al., 1986).

A former professional carpet layer has developed a pneumatic powered carpet stretcher (Figure 2) with the goal of decreasing the occurrence of knee disorders. The toothed part of the stretcher is movable and holds the carpet in a manner similar to the knee kicker. The frame at the front catches the tack strip to secure the tool. The air stretcher uses compressed air as the power source to drive the toothed part forward to stretch the carpet; therefore, this tool does not require kicking and does not have a padded end surface.

The objective of this study was to compare the muscle activities and segment motions between the kicker and the air stretcher.

4.2 METHODS

Carpet installers (8 male and 1 female) from Massachusetts Carpenters' union Local #2168 were recruited for this study (Chapter 3.2).

Subjects were introduced to the air stretcher and given enough time to become familiar with the new tool. During this process, subjects learned the mechanics of the air stretcher, and tried to use it to stretcher the carpet for at least 10 times. EMG electrodes and optical markers were attached to subjects after they provided informed consent (Chapter 2.2). Then subjects were required to perform three trials each comprising of five work cycles of carpet stretching. Subjects were asked to choose either the knee kicker or the air stretcher, then perform the three trials. Subjects took a 1-minute break between subsequent trials and 5 minutes break after the completion of three trials with each tool. In the lab, a big piece of carpet was fixed on a wooden platform (6 feet by 4 feet) using nails on one end while the other side was kept unsecured so that it could be stretched in the opposite direction.

Muscle activity from the right knee-flexors/hip-extensors (right biceps femoris), right knee-extensors/hip-flexors (right rectus femoris), and shoulder flexors (left and right anterior deltoid) were recorded by surface electromyography electrodes (Bhattacharya et al., 1986). Standard differential electrodes were placed parallel to the muscle fiber direction with an inter-electrode distance of 2cm. Before the placement of electrodes, the skin was rubbed with a rough material and cleaned with isopropyl alcohol to reduce the skin resistance. If necessary, the skin was shaved. The electrodes were placed

approximately on the most prominent portion of the muscle belly. After placement, the electrodes were secured onto the skin using a micropore tape to minimize relative movement between the electrode and the skin. The EMG signals were amplified using custom-built pre-amplifiers and then amplified (Delsys DE-3.1 Surface EMG Sensors, Delsys Inc. Boston, MA, 02215) before being digitized using a twelve-bit analog-to-digital (A/D) converter and stored on a personal computer. Data acquisition was controlled by using LabVIEW software (version 8.0). The sampling rate for EMG signals was 1000 Hz.

Maximum voluntary contractions (MVC) and the baseline activities of each muscle were recorded by surface electromyography for five seconds after the experimental trials. Following are details for MVC measurement:

Right biceps femoris: The subject lay down in the prone position on a wooden platform with 90-degree flexion at the knee joint. The subject then was instructed to flex the knee maximally against resistance and hold for 5 seconds.

Right rectus femoris: The subject sat in a chair with slight flexion at the hip joint and 90-degree flexion at the knee joint. The subject was instructed to extend the knee maximally against resistance and hold for about 5 seconds.

Left anterior deltoid: The subject sat in a chair maintaining 90-degree flexion at both the hip and the knee joints. The left upper arm was hanging vertically and the elbow was

flexed 90 degrees. The subject was instructed to abduct and slightly flex the left shoulder maximally against resistance and hold for 5 seconds.

Right anterior deltoid: The subject sat in a chair maintaining 90-degree flexion at both the hip and the knee joints. The right upper arm was hanging vertically and the elbow was flexed 90 degrees. The subject was instructed to abduct and slightly flex the right shoulder maximally against resistance and hold for 5 seconds.

4.2.1 Motion analysis

Kinematics of the kicking motion were recorded using the Optotrak Certus Motion capture system (Northern Digital Inc., Ontario, Canada). Infrared light emitting diode markers (IREDs) were placed on each of three body segments: pelvis, right thigh, and right lower leg. The IREDs were pulsed at high frequencies and viewed by three cameras. In order to prevent excessive movement of these markers in relation to the skin during the kicking motion, markers were first attached to a thermoplastic splint made of Omega Max (North Coast Medical Inc., USA) molded according to the contour of the three body segments, and then this split was attached to the skin using double-sided tape. Displacement data of the knee kicker and the air stretcher were obtained by an IRED marker placed on the shaft of the knee kicker, and on the movable portion of the air stretcher. The viewing field of the cameras was calibrated in three dimensions using a standard calibration cube supplied with the motion analysis system. Motion analysis data were sampled at 250 Hz. Motion analysis and EMG data were synchronized. Figure 17 shows a subject with all IRED markers and EMG electrodes attached to the body.

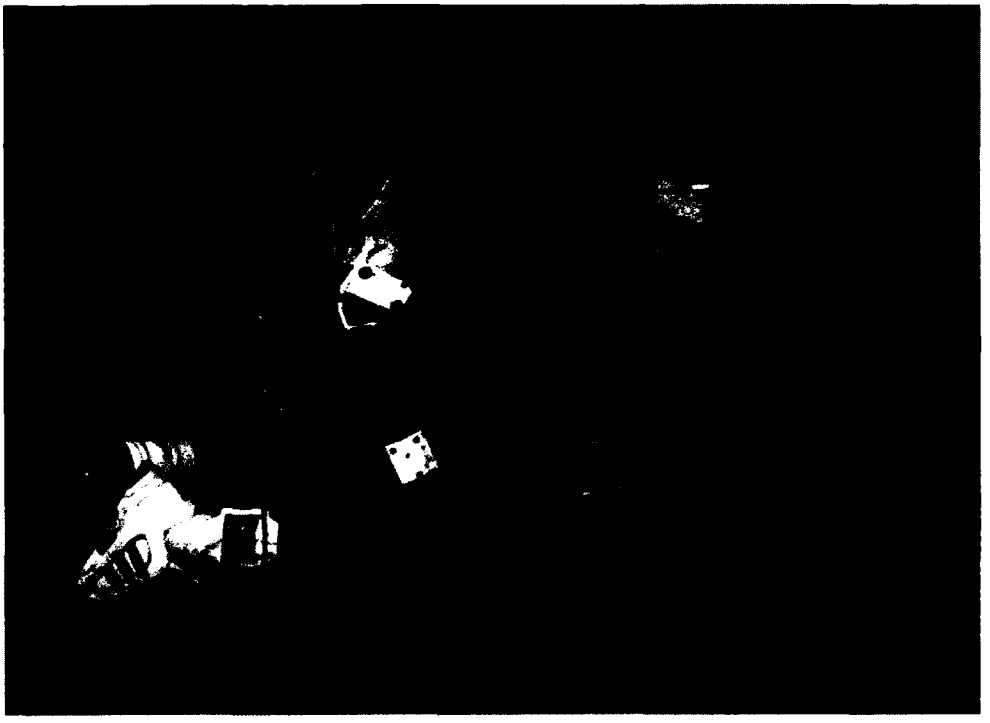


Figure 17 One study participant with electrodes and markers in position for data collection.

4.2.2 Definition of two phases

In order to make a detailed comparison between the kicker and the stretcher, both muscle and postural data were divided into two phases: the kicking/stretching and the in-between phase (Figure 18).

The mean value of hip angles was used to determine the kicking/stretching phase. The starting point and the ending points were defined as when the hip angle crossed the mean hip angle (horizontal) line. Then two vertical lines were drawn through the starting and the ending points to define the two phases for other variables. The in-between phase was defined as the period between two continuous kicking/stretching phases.

The same criteria was applied to define the two phases for the knee kicker and the air stretcher. In addition, there was an infrared light emitting diode marker on the moving part of the stretcher. The marker captured the carpet-stretching process and provided additional assistance to define the kicking/stretching phase, if EMG and postural data were not clear enough to distinguish the two phases.

For the air stretcher (Figure 19), while the carpet was stretching, subjects tended to bend their trunk to a low position, using their leg muscle to keep their body stable and pulling the trigger of the stretcher. The process was characterized by low trunk angle, and relatively active RF and RD muscle activities.

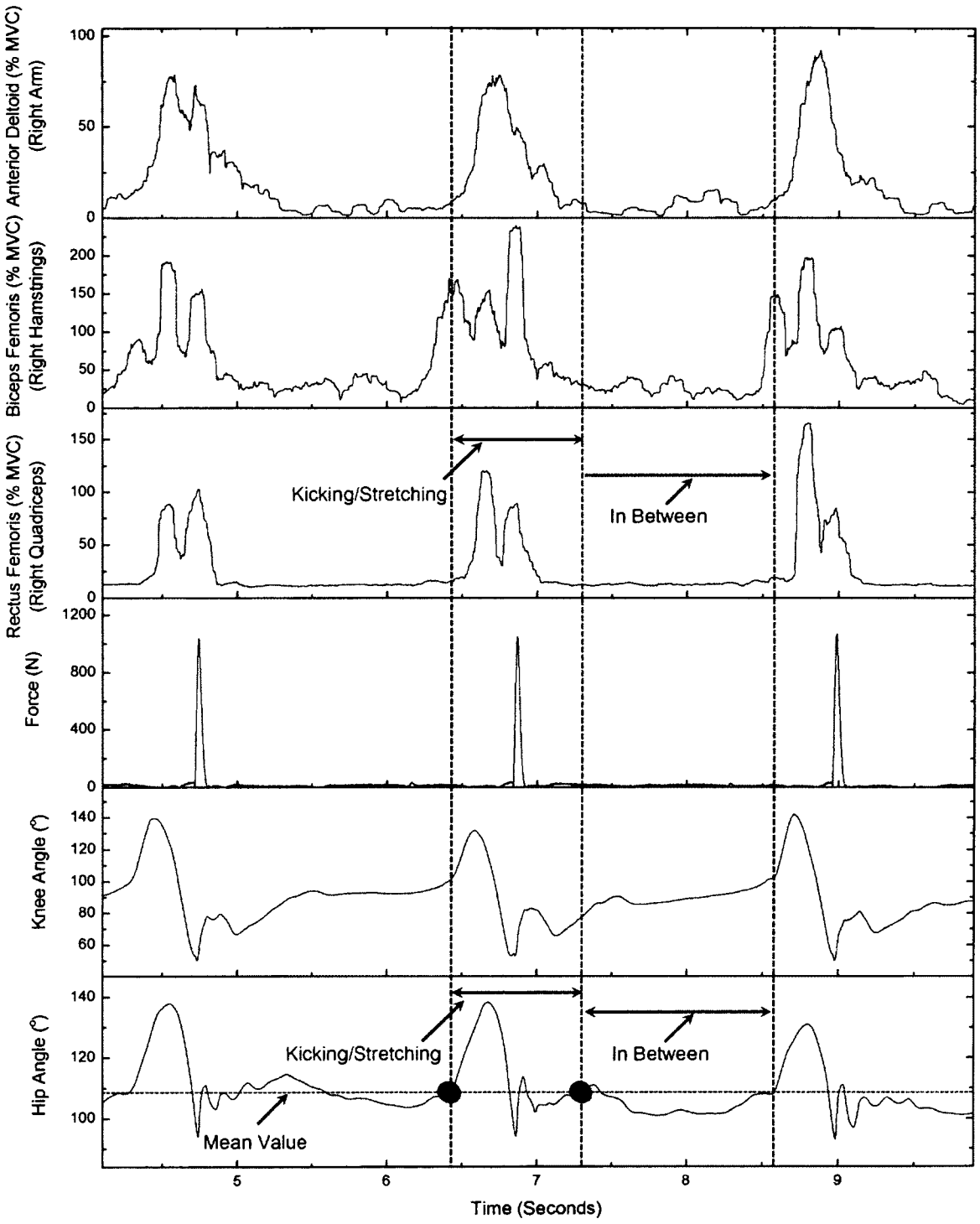


Figure 18. Concurrent muscle activity and position changes for one subject was using the knee kicker, illustrating the definition of the two phases of the task.

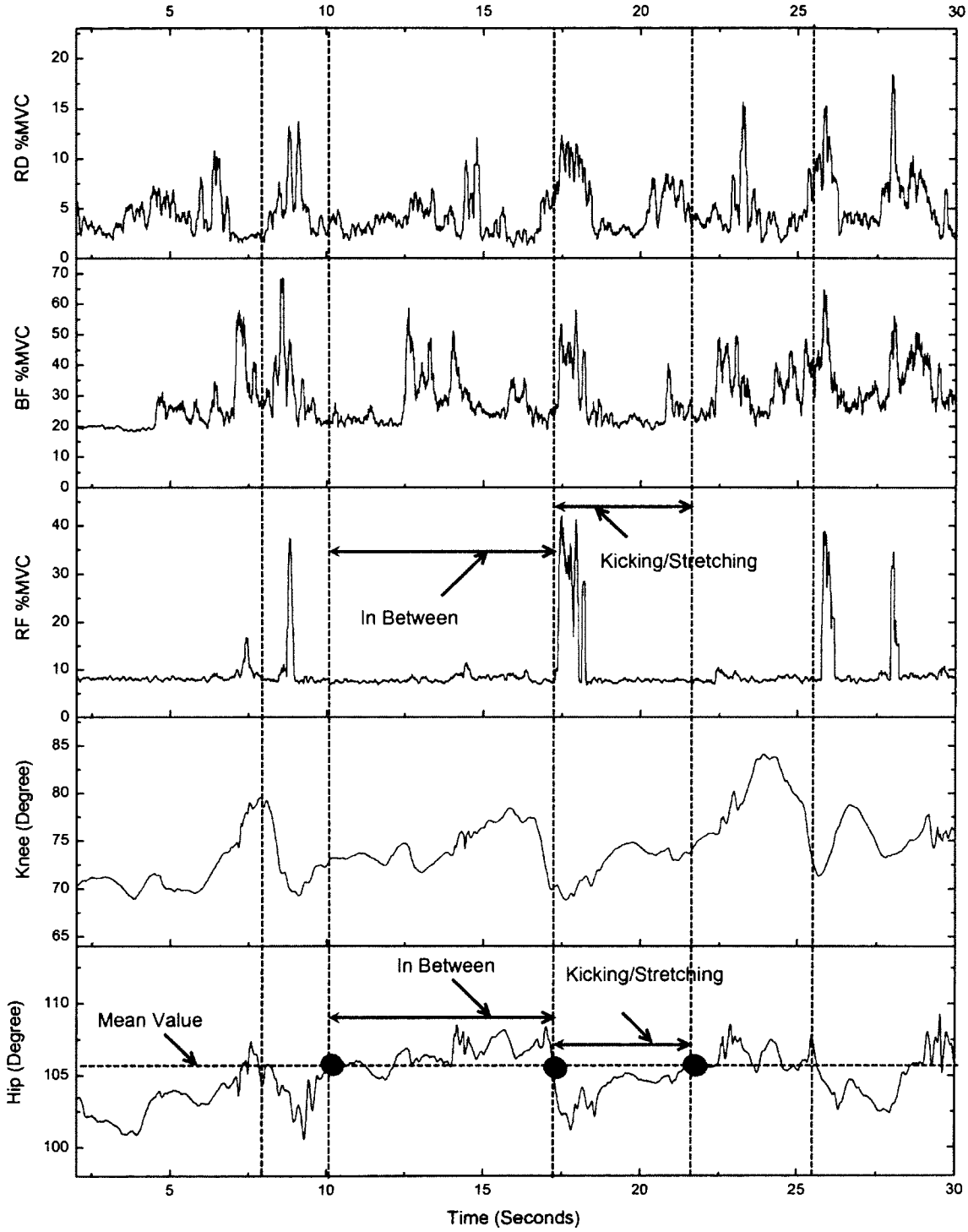


Figure 19 Concurrent muscle activity and position changes for one subject was using the air stretcher, illustrating the definition of the two phases of the task.

4.2.3 Data management and analysis

For EMG data, the baseline value for each subject was subtracted from both the MVC and trial data, prior to analysis. An RMS algorithm with a 0.1 second time constant was implemented in software to normalize and smooth the EMG data. For each trial, only the middle work cycle was chosen to calculate an average EMG for each muscle.

Original data from the motion capture system only included the positions of the markers. A MatLab (MatLab Version 2009, MathWorks, Natick, MA) script was adapted from other scripts available from the Harvard Occupational Biomechanics and Ergonomics Laboratory in order to calculate knee and hip angles (Dennerlein and Johnson, 2006).

Because of the uncertainty of the distribution of both EMG and postural signals, the 10^{th}, 50^{th}, 90^{th} and (90^{th} – 10^{th}) percentile difference of signal amplitude for each body segment were calculated and compared between the knee kicker and the air stretcher. The 50^{th} percentile is the median, by definition; the difference between 90th and 10^{th} percentiles provided a measure of the range of motion (Dennerlein and Johnson, 2006). Standard error of these percentiles among subjects was calculated. Standard errors from the mean were calculated.

The independent variable was tool type. The dependent variables were the EMG values for four different muscles, and the knee and hip angles. Paired t-tests were applied to test the within-subject differences between the kicker and the stretcher.

4.3 RESULTS

Nine professional carpet installers (8 male and 1 female) were recruited for this study. They had a mean body weight of 797.5 N (SD: 148.6 N) and a mean height of 173.1 cm (SD: 10.5 cm). Subject three did not finish the whole experiment and his data were omitted from the results.

4.3.1 EMG data

For the kicking/stretching phase, there were significant differences for leg muscle activity (BF and RF), with a higher %MVC exerted when using the kicker (50^{th} and 90^{th} percentile values) (Figure 20 and Table 6). The kicker also created a higher %MVC for the right anterior deltoid.

For the in-between phase, there were no significant differences between tools for the leg muscles (BF and RF), except BF at 90^{th} level (Figure 21 and Table 7). There was still a higher %MVC for the right anterior deltoid with the kicker compared to the air stretcher.

For LD, there were no significant differences for both phases except the 90^{th} percentile in the kicking/stretching phase.

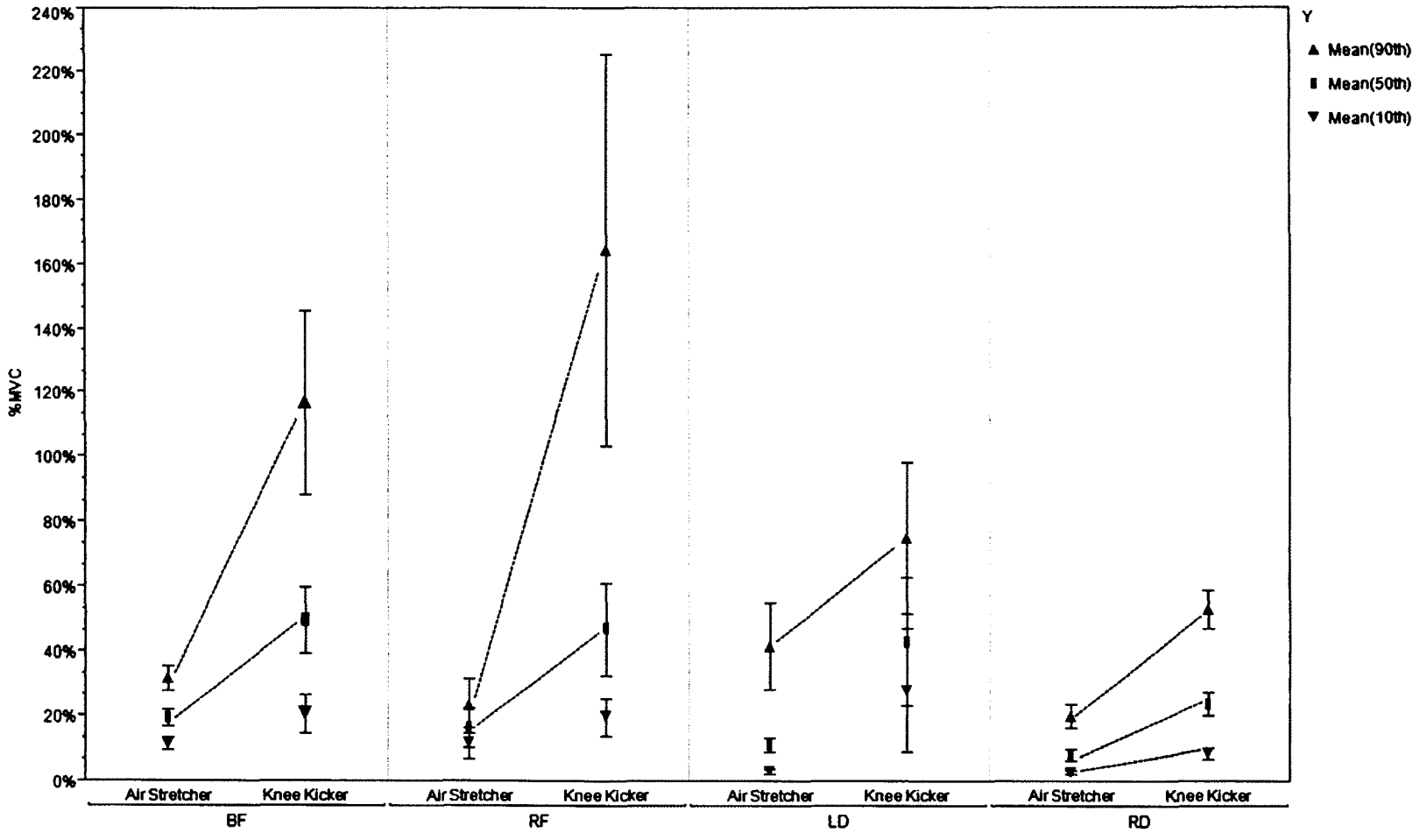


Figure 20. For the kicking/stretching phase, EMG amplitude distribution (10^{th}, 50^{th} and 90^{th} percentile) values varied between tools for Biceps Femoris (BF), Rectus Femoris (RF), Left and Right Deltoid (LD and RD). Each error bar is constructed using 1 standard error from the mean. MVC=Maximum voluntary isometric contraction. Dotted lines indicate significant differences.

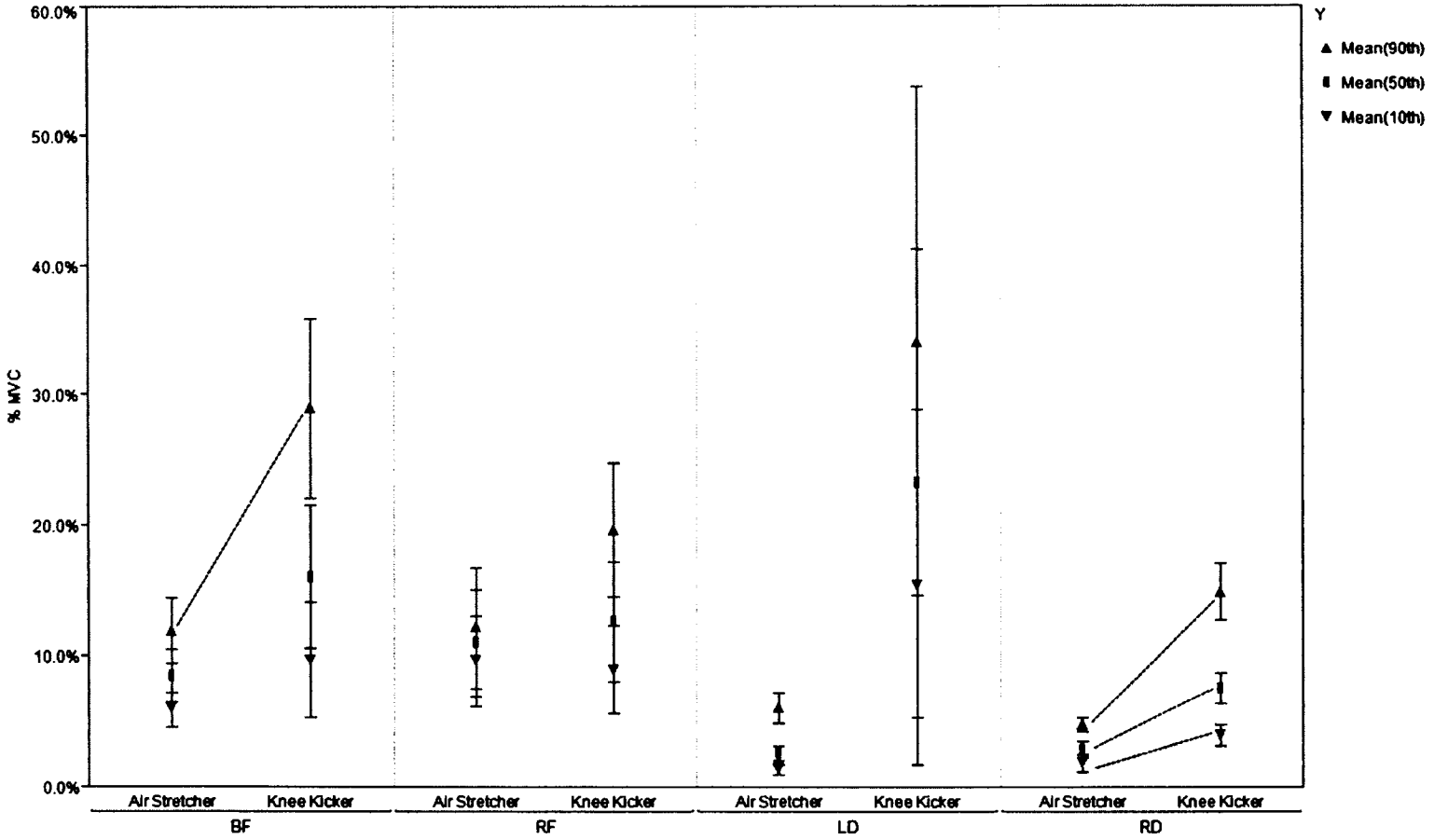


Figure 21. For the in-between phase, EMG amplitude distribution (10th, 50th and 90th percentile) values varied between tools for Biceps Femoris (BF), Rectus Femoris (RF), Left and Right Deltoid (LD and RD). Each error bar is constructed using 1 standard error from the mean. MVC=Maximum voluntary isometric contraction. Dotted lines indicate significant differences

Table 6 Distribution of muscle activity values from electromyography, in eight professional floor-coverers, by tool (paired t-test on differences between the stretcher and the kicker) for the kicking/stretching phase.

	Muscle	Percentile	%MVC for stretcher	%MVC for kicker	p*
Kicking/stretching	BF	10th	11.71%	20.94%	0.0609
		50th*	19.66%	49.87%	0.0064
		90th*	31.98%	117.22%	0.0069
	RF	10th	11.93%	19.87%	0.1241
		50th*	16.61%	47.15%	0.0259
		90th*	23.42%	164.56%	0.0253
	LD	10th	3.43%	28.29%	0.1091
		50th	11.60%	43.13%	0.0724
		90th*	41.95%	75.09%	0.0122
	RD	10th*	3.15%	8.93%	0.0162
		50th*	8.59%	23.99%	0.0028
		90th*	20.19%	53.41%	0.002

1 * p-value < 0.05

2 BF: biceps femoris; RF: rectus femoris; LD: left anterior deltoid; RD: right anterior deltoid

Table 7 Distribution of muscle activity values from electromyography, in eight professional floor-coverers, by tool (paired t-test on differences between the stretcher and the kicker) for the in-between phase.

	Muscle	Percentile	%MVC for stretcher	%MVC for kicker	p*
In-between	BF	10th	5.95%	9.73%	0.2098
		50th	8.54%	16.14%	0.0859
		90th*	11.99%	29.11%	0.022
	RF	10th	9.67%	8.99%	0.3883
		50th	11.03%	12.72%	0.3485
		90th	12.22%	19.74%	0.0959
	LD	10th	1.47%	15.41%	0.1623
		50th	2.68%	23.35%	0.1381
		90th	6.09%	34.26%	0.0863
	RD	10th*	1.90%	3.99%	0.0231
		50th*	2.92%	7.55%	0.0067
		90th*	4.82%	14.97%	0.0014

1 * p-value < 0.05

2 BF: biceps femoris; RF: rectus femoris; LD: left anterior deltoid; RD: right anterior deltoid

4.3.2 Motion analysis

Six subjects were included in the motion analysis. Data from subjects 5 and 7 were not used because the motion markers were often lost to the cameras during the experiment.

Figure 22 shows an example presenting the joint angle comparison between the kicker and the stretcher for two subjects who were randomly selected. For these two subjects, different tools led to remarkably different body motion patterns. Three were little motion with the stretcher compared with the kicker.

For the kicking/stretching phase, the stretcher had a significantly smaller range of motion (90^{th} -10^{th}) than did the kicker (Figure 23 and Table 8). The stretcher involved higher knee extension than the kicker (10^{th} and 50^{th}). However, higher thigh extension (50^{th} and 90^{th}) occurred during use of the kicker.

For the in-between phase (Figure 24 and Table 8), the range of motion (90^{th} -10^{th}) for the stretcher was significantly smaller than that for the kicker. Similar to the kicking/stretching phase, the stretcher led to higher knee extensions (all levels), but the kicker created higher thigh extension (50^{th} and 90^{th}).

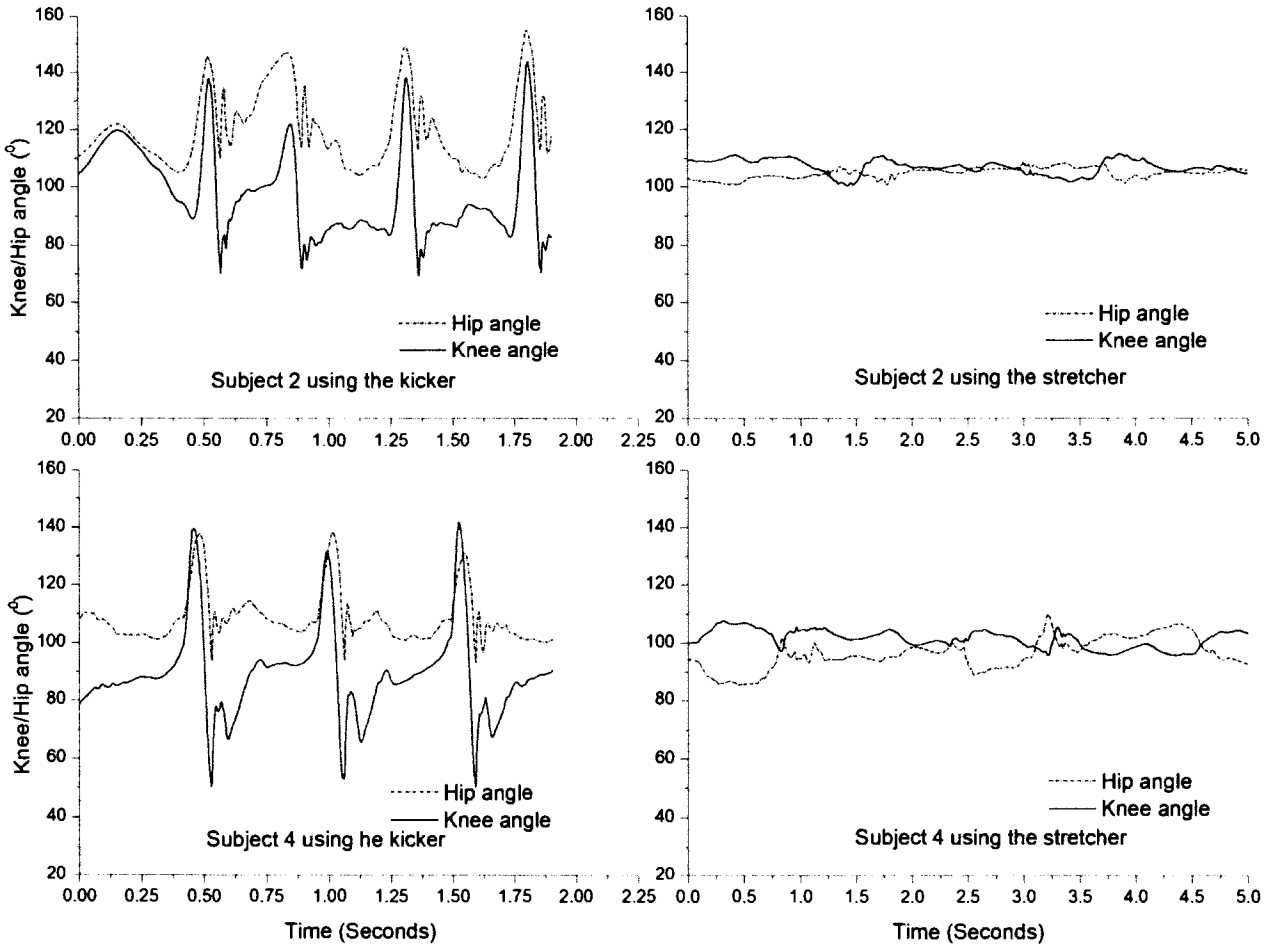


Figure 22 Knee and thigh angle comparison between using the kicker and the stretcher (subject 2 and subject 4). The selected duration for the stretcher was longer than that for the kicker in order to present more than two work cycles.

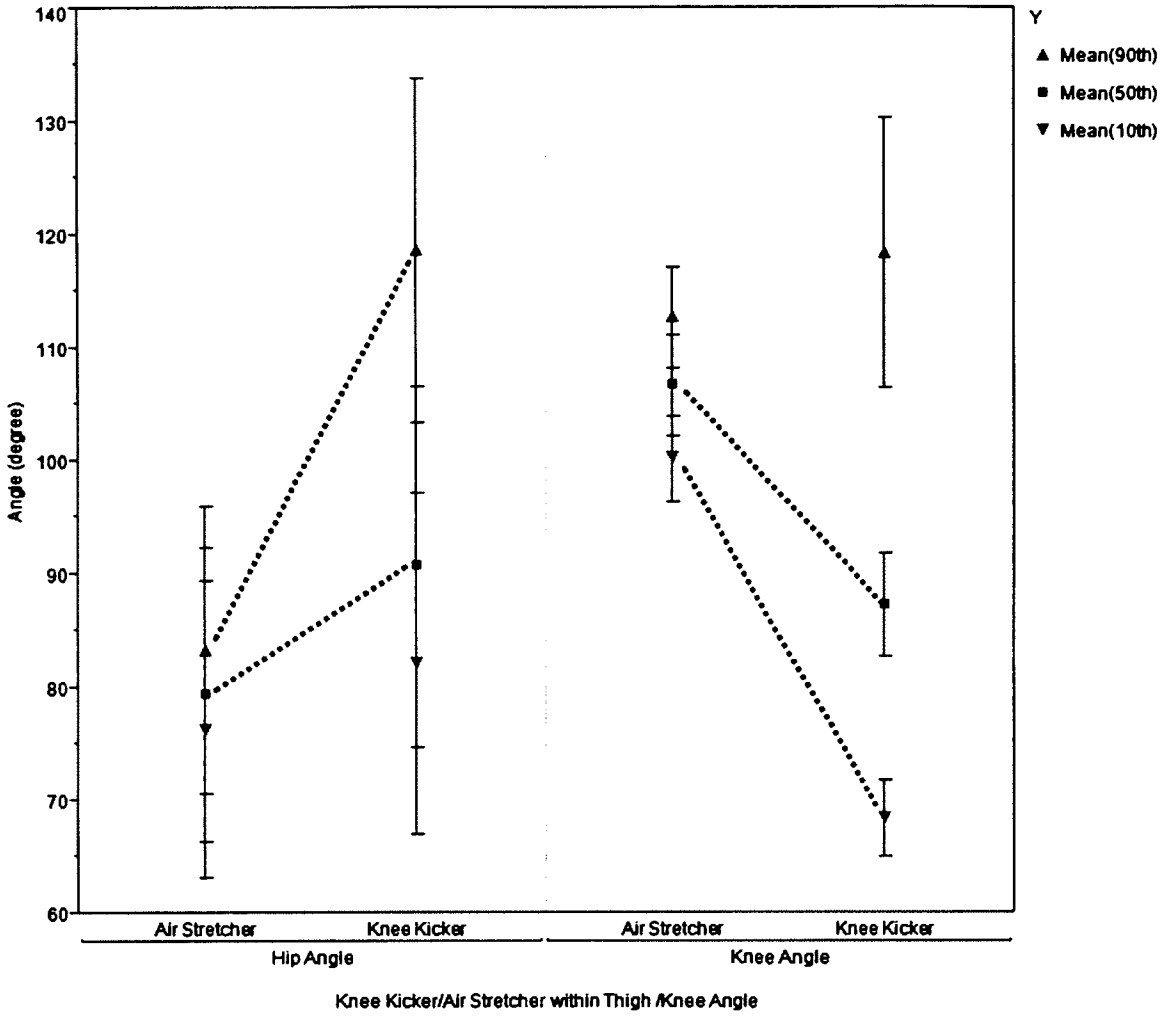


Figure 23 Comparison of the knee and hip angles (10^{th}, 50^{th} and 90^{th}) between using the kicker and the stretcher for the kicking/stretching phase. Dot lines indicated significant differences.

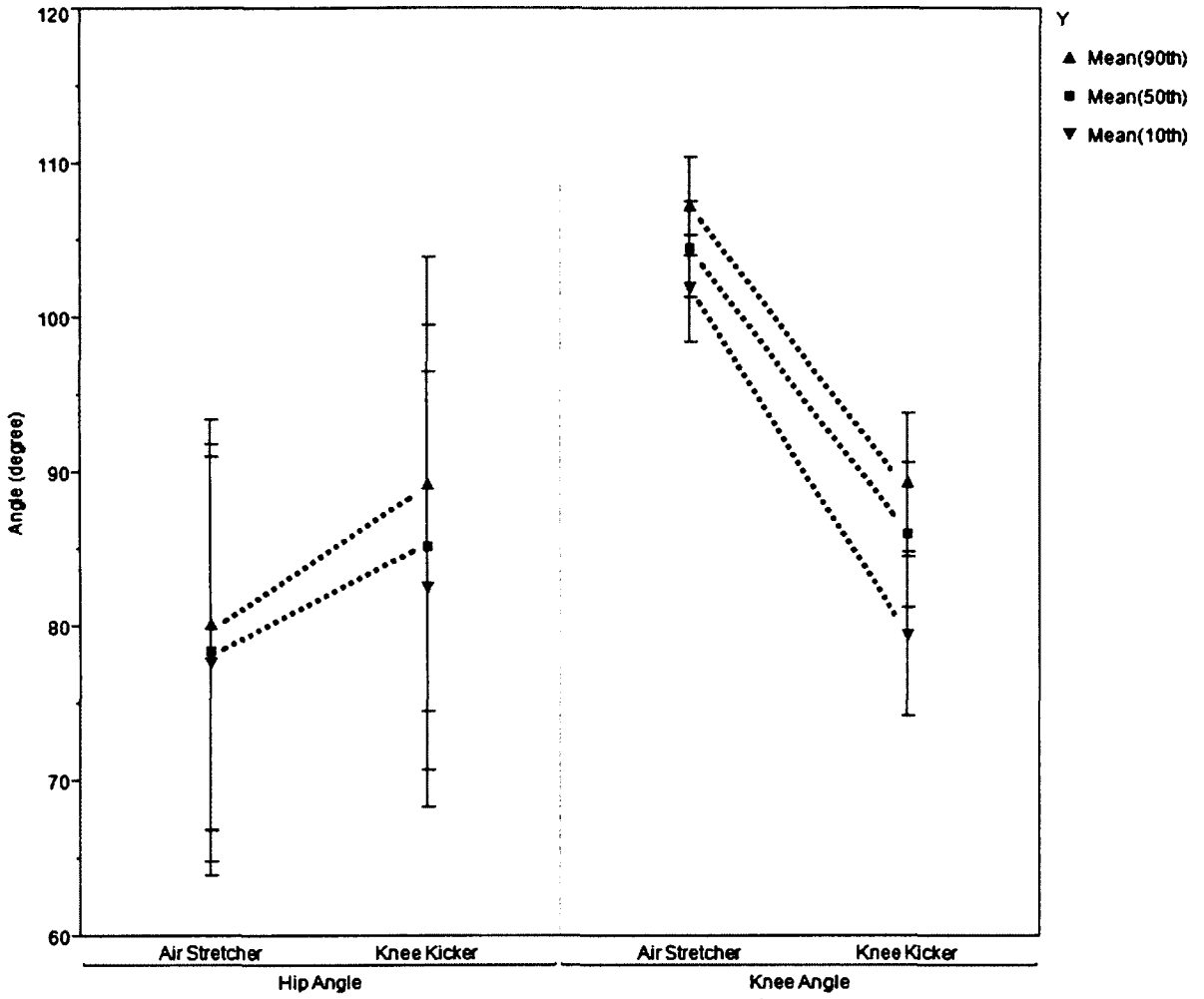


Figure 24 Comparison of the knee and hip angles (10^{th}, 50^{th} and 90^{th}) between using the kicker and the stretcher for the in-between phase. Dot lines indicated significant differences.

Table 8 Distribution of postural parameters from the motion tracking system, in six professional floor-coverers, by phase of carpet-laying and tool (paired t-test on differences between the stretcher and the kicker).

Phases	Angle	Percentile	Average angle for the stretcher	Average angle for the kicker	p
Kicking/stretching	Knee angle	10th*	100.2	68.5	0.0042
		50th*	106.8	87.3	0.0366
		90th	112.8	118.4	0.3698
		90th-10th*	12.6	50.0	0.0098
	Hip angle	10th	76.3	82.1	0.0611
		50th*	79.4	90.7	0.0088
		90th*	83.3	118.7	0.0002
		90th-10th*	7.0	36.6	0.0024
In-between	Knee angle	10th*	101.9	79.4	0.017
		50th*	104.5	86.0	0.0288
		90th*	107.3	89.4	0.0315
		90th-10th*	5.4	10.0	0.0315
	Hip angle	10th*	77.6	82.5	0.0244
		50th*	78.4	85.2	0.0153
		90th*	80.2	89.3	0.0132
		90th-10th*	2.7	6.8	0.0132

1 * means p value was smaller than 0.05, and the difference was significant

2 for angle and SD for angel, the unit was degree

4.4 DISCUSSION

This experimental study using professional floor layers documented that the alternative carpet-laying tool could decrease activity required from the major leg muscles, as well as decrease leg range of motion and extreme extensions (140 degree for hip or knee angles).

The knee-kicker required frequent flexion and extension for the knee and the hip while kicking, but the air-stretcher eliminated the kicking action; therefore, it effectively decreased the requirements for two leg muscle activities (BF and RF) for the kicking/stretching phase. For the in-between phase, since most of the activity consisted of adjusting the tool and body positions, leg muscle activities were not significant different except 90^{th} of BF. These findings indicated that the new tool did not create more leg muscle strain during the in-between phase while dramatically decreasing leg muscle activities for the kicking/stretching phase.

While using the kicker, workers needed to use their right arm (RD muscle) to secure the kicker against the impact force as high as four times of their body weight while kicking (Bhattacharya et al., 1986). However, for the stretcher, the RD was required only to support the body and to pull the pneumatic lever to trigger the stretching. This can explain why the differences for RD were significant for all levels between two tools during the kicking/stretching phase. For both tools, LD supported the body weight; this similar function resulted in similar muscle activities in both phases except 90^{th} at the kicking/stretching phase.

For postural data, the stretcher significantly decreased range of motion (90^{th} -10^{th}) for both knee and thigh extensions for both phases, and it eliminated several extreme extensions (10^{th} and 90^{th}). The new tool changed users' body postures: workers tended to keep higher knee extension and lower thigh extensions for both phases. This study did not control durations of each kicking and postures of kicking for subjects. Subjects were asked to do the kicking as they usually do. Subjects presented different styles of doing their jobs. For instance, some subjects tended to keep their knee in the air to be ready while they were still adjusting the kicker, but some subjects only lifted their knee when it was necessary.

4.4.1 Weaknesses and strengths of this study

There were several scenarios when the EMG RMS went beyond the measured MVC with the %MVC exceeded 100%. One explanation was that the MVC was measured during static tasks, but kicking was a dynamic activity; thus, the added force and velocity factor may produce EMG spikes. In addition, relative movements between the skin and the electrodes during the kicking could also cause the spikes. This issue was also found by other researchers (Bhattacharya et al., 1986).

There were only nine subjects who finished the experiment and their data were used to do the muscle activities analysis. Only six of them could be included in the postural data analysis due to the missing marker issue. In additionally, this study did not consider gender, anthropometry, seniority, etc. These between-subjects factors could explain

muscle activities and postural data visibilities, therefore the difference in this study may be overestimated.

4.5 CONCLUSION AND RECOMMENDATION

Based on the above results, the air stretcher significantly decreased major muscle activities during the kicking/stretching phase; it also decreased range of motion for the knee and hip.

Striking the pad of the knee kicker with the knee produces high shearing forces that can strain ligaments (Ariel, 1975). This new tool eliminates the kicking and can protect the workers' knees. The new tool does not remove the kneeling posture, and there are some tools in the market that allow carpenters to perform stretching while standing, such as the power stretcher which uses leverage cogs to stretcher the carpet. However, the power stretcher received complains due to its large size and inconvenience to carry. This air stretcher could be a compromise between the kicker and the power stretcher.

4.6 LITERATURE CITED:

Ariel, B.G., 1975. Biomechanical analysis of the knee joint during deep knee bends with heavy load. XXth World Congress in Sports Medicine , 53-60.

Bhattacharya, A., Ramakrishanan, H., Habes, D., 1986. Electromyographic patterns associated with a carpet installation task. Ergonomics 29, 1073-1084.

Bhattacharya, A., Mueller, M., Putz-Anderson, V., 1985. Traumatogenic factors affecting the knees of carpet installers. Appl. Ergon. 16, 243-50.

Bureau of Labor Statistics, 2010. Occupational Employment and Wages, May 2010,47-2041 Carpet Installers. 2011, 1.

Dennerlein, J.T., Johnson, P.W., 2006. Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. Ergonomics 49, 45-61.

Jensen, L.K., Kofoed, L.B., 2002. Musculoskeletal disorders among floor layers: is prevention possible? Appl. Occup. Environ. Hyg. 17, 797-806.

Kivimaki, J., Riihimaki, H., Hanninen, K., 1992. Knee disorders in carpet and floor layers and painters. Scand. J. Work Environ. Health 18, 310-316.

National Safety Council, 2008. Injury Facts 2008. National Safety Council.

Tanaka, S., Lee, S.T., Halperin, W.E., Thun, M., Smith, a.B., 1989. Reducing knee morbidity among carpetlayers. Am. J. Public Health 79, 334-5.

The New England Regional Council of Carpenters, 2009. Affiliated Trades of the Carpenters Union. 2010, 1.

Yuan, L., Buchholz, B., Dale, A.M., 2011. Knee Disorders Among Carpenters in the St. Louis Area. The Open Occupational Health & Safety Journal 3, 31-38.

Yuan, L., Buchholz, B., Fulmer, S., Jing, X.L., 2009. Knee Disorders among Union Carpenters.

5 A QUANTITATIVE ANALYSIS OF PRESSURE ON THE KNEE AMONG FLOOR COVERERS AND A QUESTIONNAIRE FOR CHOOSING KNEEPADS

5.1 INTRODUCTION

A carpet installer spends 75% of his time in the kneeling/crawling position (Bhattacharya et al., 1985). The floor-covering task involves a combination of posture, force, acceleration, and repetition that are biomechanically demanding and lead to increased occurrence of knee disorders and injuries. Epidemiologic studies have shown that prolonged kneeling has a moderate association with knee disorders and injuries such as knee osteoarthritis, bursitis and meniscal disorders (Jensen, 2008) (Kivimaki et al., 1992).

Professional floor coverers have traditionally used kneepads to protect their knees, so do homeowners who carry out their own home improvement projects. Between 1887 and 2009, the United State government has issued more than 400 patents related to kneepads. Despite this, limited research has been conducted to study the effectiveness of protection that the kneepad confers.

Moore et al. (Moore et al., 2009) conducted an experiment to study stress transmitted to anatomic landmarks of the knee while in static kneeling postures, with and without kneepads. They found that the majority of the pressure was transmitted to the combined

patellar tendon (PT) and the tibial tubercle (TT), rather than just the patella as might have previously been assumed. They also found that peak pressures of greater than 25 PSI were experienced even while wearing kneepads. Therefore it was suggested that a novel kneepad design was needed that could redistribute the stress at the knee across a greater surface area and to other regions of the leg, away from key structure of the knee (Porter et al., 2010).

Pro Knee (ProKnee Corp, Whitefield, Maine) (Figure 3) is an advanced kneepad which is much larger than a regular kneepad, in that it covers the whole shinbone. In the great Boston area, this kneepad dominates the professional pad market among floor coverers. A Pro Knee kneepad requires personal measurements, such as the circumference of the calf and the length of the leg, so that it can be built to fit its user.

The purpose of this experiment was to compare contact area, mean and peak pressures in kneeling while wearing an advanced (Pro Knee) kneepad, a regular kneepad, and no kneepad. The other purpose was to identify other reasons, apart from subjectively-experienced pressure distribution, that workers might prefer a specific type of kneepad.

Figure 25 Regular kneepad (left) and the Pro Knee (right)

5.2 METHODS

5.2.1 Instruments

For each study subject, one pressure sensor (model 5315) (Tekscan, Inc., Boston, MA) was secured on the surface of the dominated knee. Key spots, such as the patellar tendon and the tibial tubercle, were covered with the sensor. The pressure sensor was placed between the kneepad and the knee to ensure accurate data from direct contact. The sensor was originally 19.20" by 16.80" but was cut to 19.20" by 5.5" to cover the entire surface of the shinbone along its length.

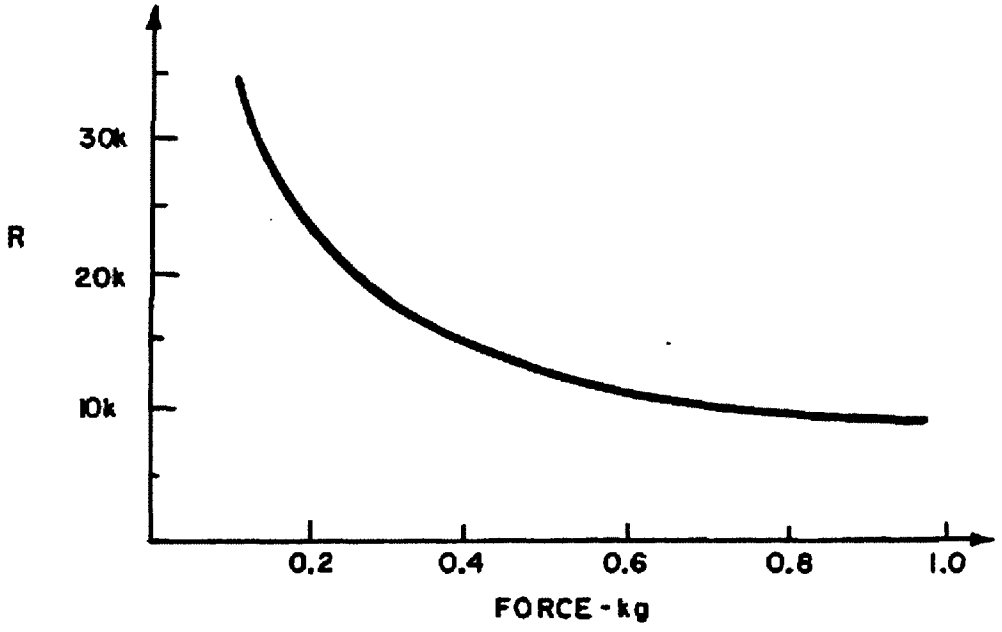


Figure 26 An example of the relationship between resistance and force. Unit for resistance is ohm. Unit for force is kg. Adapted from "Maness, William L., et al. "Pressure and contact sensor system for measuring dental occlusion." U.S. Patent No. 4,856,993. 15 Aug. 1989."

This sensor system consists of an ultra-thin (0.18mm) two-layer sheet and each layer is built on a flexible substrate made of Mylar, a polyester film. An electrically conductive ink is printed on the film coated with a pressure-sensitive, resistive ink, in such a fashion that parallel rows of electrodes on the top layer face parallel columns of electrodes on the bottom layer through the resistive ink. The intersections of the rows and columns construct the pressure-sensing cells called sensels. A sensel acts as a variable resistor in an electrical circuit. When the sensor is unloaded, its resistance is infinite; when load is applied to the sheet, the electrical signal output from this system will respond accordingly. After measuring the changes in current flow at each intersection point, the applied force distribution pattern can be measured by converting electrical signals to force through the resistance-to-force relationship showing in Figure 26 (Maness et al., 1989). With the Tekscan system, force measurements can be made either statically or dynamically, and the information can be seen as graphically informative 2-D or 3-D displays (Figure 27). With knowledge of the force on each sensel, the size of each sensel, and the number of sensels with forces applied, Tekscan, a matrix-based system, is able to measure the pressure distribution.

Contact area was calculated by the number of the loaded sensels times the known size of each sensel. The pressure for each sensel was calculated by dividing the force by the given sensel size. Mean pressure was calculated by dividing the total force by the contact area. Peak pressure was defined by the largest pressure among all sensels. The software provides contact area, mean and peak pressure for the entire sensor or for a defined area

of the sensor, in real time. For this study, pressures under 0.5 PSI were disregarded to correct overestimation due to low sensel density; the threshold of 0.5 PSI was based on preliminary experiments.

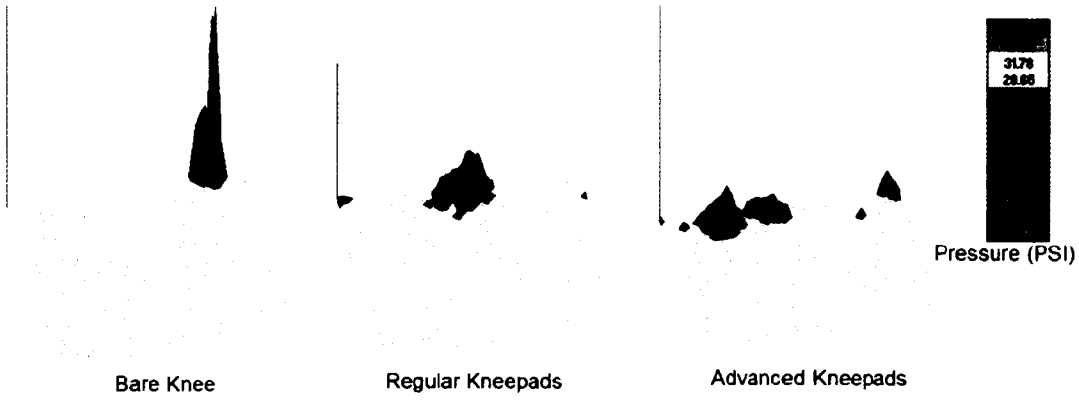


Figure 27 The pressure and contact area comparison among the bare knee, regular and advanced kneepads for the same subject while sitting on heels with trunk straight and arms down

5.2.2 Experimented Design

Ten professional floor coverers were recruited for this study through local Carpenter Union (2168), local ProKnee kneepad distributor, and local carpet companies. A recruitment flyer was provided with the purpose and procedure of the study. Before the experiment, each subject read, and signed the informed consent with UMass Lowell IRB approval (IRB No.:10-099-BUC-XPD). Typical carpet installing tasks were simulated in the biomechanics lab in the Work Environment Department at UMass Lowell, or at subject's home depends on subject's willing. Subjects brought their own ProKnee pads, and regular knee pads were provided by researchers.

First, the pressure mat was placed to cover key spots of the knee; calibrate was performed. Then data were collected while subjects maintained static postures including two different leg (sitting on heels and kneeling), three trunk (neutral posture, mild and severe trunk flexion) and two arm postures (two arms down and two arms up) (Table 9). There were 12 different posture combinations (Table 10). Each subject was asked to maintain these postures for the three knee protection conditions in a random order. Three knee protection conditions were: the bare knee; with the regular kneepad; and with the advanced pad. Each posture was performed for 15 seconds. Participants had a five-minute break when they finished experiment with one of the three knee protections. The entire experiment lasted about an hour.

Table 9 Body posture definitions for the experiment

Body segments	Posture definitions in the experiment
Trunk – Refers to the position of the upper body above the hips in relation to the lower body below the hips, where the axis of rotation is considered to be the hips.	**Neutral (0)** – Trunk flexion, twist or bending in any direction, is 0 degree. **Mild flexion (30)** – Forward trunk flexion is 30 degrees. **Severe flexion (50)** – Forward trunk flexion is 50 degrees
Legs – Stand and Squat refer to the degree of flexion of either one or both knees. Walk, kneel, sit and kick refer additionally to whole-body activity and support surface.	**Sitting on heels** –Workers sitting on both heels **Kneeling** – Workers have both knees on supporting surface.
Arms – Refer to the included angle (either flexion or abduction) of the humerus in reference to the trunk.	**Arms down (0)** – The humerus of both the left and right arms are elevated 0 degrees from the trunk. **Arms Up (120)** – The humerus of both the left and right arms are elevated 120 degrees from the trunk.

Table 10 Twelve posture combinations including leg, trunk and arm

Leg Posture	Trunk Posture	Arm Posture
Sitting on heels	Neutral	Down
Sitting on heels	Neutral	UP
Sitting on heels	Mild	Down
Sitting on heels	Mild	UP
Sitting on heels	Severe	Down
Sitting on heels	Severe	UP
Kneeling	Neutral	Down
Kneeling	Neutral	UP
Kneeling	Mild	Down
Kneeling	Mild	UP
Kneeling	Severe	Down
Kneeling	Severe	UP

A questionnaire was administered after the experiment. Questionnaire items included work-related factors (Good Pressure Distribution, Improving Work Performance), usability factors (Well Attached to the Knee, Durability, Easy to Get on and Take off, Not Getting Sweaty), aesthetic factors and others. Firstly, subjects were asked to evaluate the importance of each factor from 1 to 5 (with 5 meaning the most important factor). Items with higher importance scores play more important roles during selection of knee pads. Then subjects were asked to rate the advanced kneepad and the regular kneepads for the same group of items from 1 to 3 (1 = bad, 2 = Ok, and 3 = good). Participants received additional oral explanations for items in the questionnaire to ensure they perceived the correct information.

5.2.3 Data analysis and data interpretation

The four independent variables were pad type, leg, trunk and arm posture. The dependent variables were contact area, mean and peak pressures.

Three separate four-way analysis of variance (ANOVA) were conducted to examine the relationship between each dependent variable and the four independent variables. Subject was considered as a random factor. When significance was observed for an effect ($p < 0.05$), a post-hoc Tukey's HSD test was used to identify if differences existed between comparisons (Young et al., 2012).

For questionnaire data, the means of the importance scores were calculated. The difference of rating scores were the average rating of the advanced kneepad minus the average rating of the regular kneepad. The maximum of the difference was 2 and the minimum was -2.

5.3 RESULTS

Contact area varied significantly (ANOVA, $p < 0.05$) among the bare knee, the regular kneepad and the advanced pad. Both kneepads increased the contact area, and the advanced kneepad had a much larger contact area than the regular one (Table 11, Figure 28). Contact area also varied significantly between the two leg postures and among the three trunk postures. Sitting on heels led to less contact area than kneeling, and more trunk flexion resulted in more contact area (Table 11, Table 12).

Table 11 Mean for main effects of Pads and Leg for 10 subjects

	Pads				Leg		
	ANOVA [1,2]	Bare Knee	RegularPads	ProKneePads	ANOVA	SittingOnHeels	Kneeling
Contact Area (in^2)	**p<0.001**	**3.94^C**	**14.65^B**	**23.24^A**	**p<0.001**	**12.95^B**	**14.94^A**
Mean Pressure (PSI)	**p<0.001**	**22.45^A**	**5.07^B**	**3.35^C**	**p<0.001**	**11.14^A**	**9.44^B**
Peak Pressure (PSI)	**p<0.001**	**58.09^A**	**17.51^B**	**9.96^C**	p=0.191	29.23	27.81

[1]Randomized block design ANOVA with subject as a random variable, Pads, Leg, Trunk and Arm as independent effects. This model included interaction terms.
[2]For each dependent variables, values with different superscript letters indicate significant difference (A>B>C)

Table 12 Mean for main effects of Trunk and Arm for 10 subjects

	Trunk				Arm		
	ANOVA [1,2]	Neutral	MildFlexion	SevereFlexion	ANOVA	Down	Up
Contact Area (in^2)	**p<0.001**	**13.26^C**	**13.93^B**	**14.65^A**	p=0.119	13.77	14.12
Mean Pressure (PSI)	p=0.353	10.00	10.26	10.60	p=0.773	10.34	10.24
Peak Pressure (PSI)	p=0.262	27.69	28.13	29.75	p=0.831	28.64	28.41

[1]Randomized block design ANOVA with subject as a random variable, Pads, Leg, Trunk and Arm as independent effects. This model included interaction terms.
[2]For each dependent variables, values with different superscript letters indicate significant difference (A>B>C)

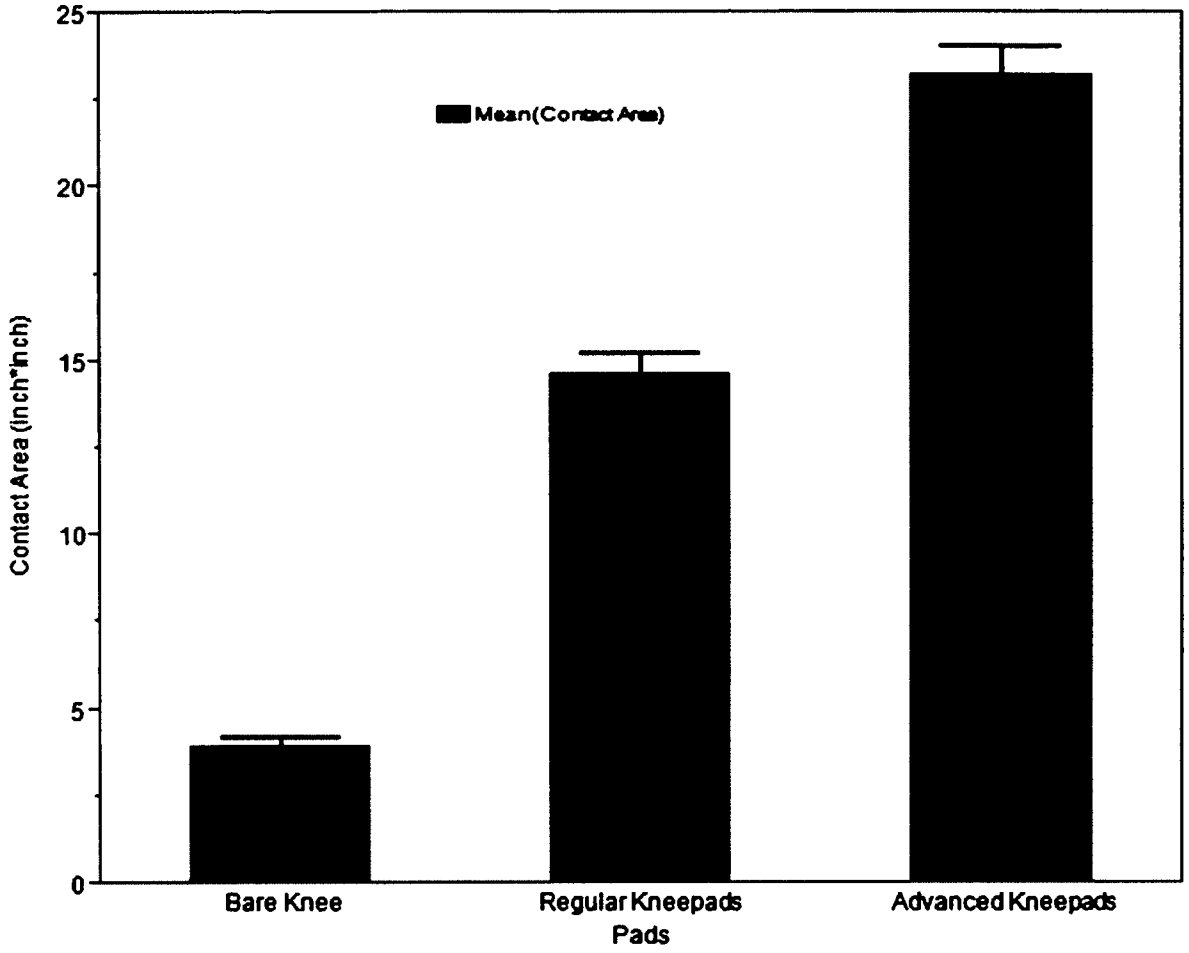


Figure 28 Contact area for bare knee and different pads with 95% confidence intervals

Mean pressure varied significantly among the bare knee, the regular kneepad and the advanced pad with the highest mean pressure from the bare knee (Table 11 and Figure 29). The mean pressure also varied significantly between leg postures with higher mean pressure from sitting on heels (Table 11).

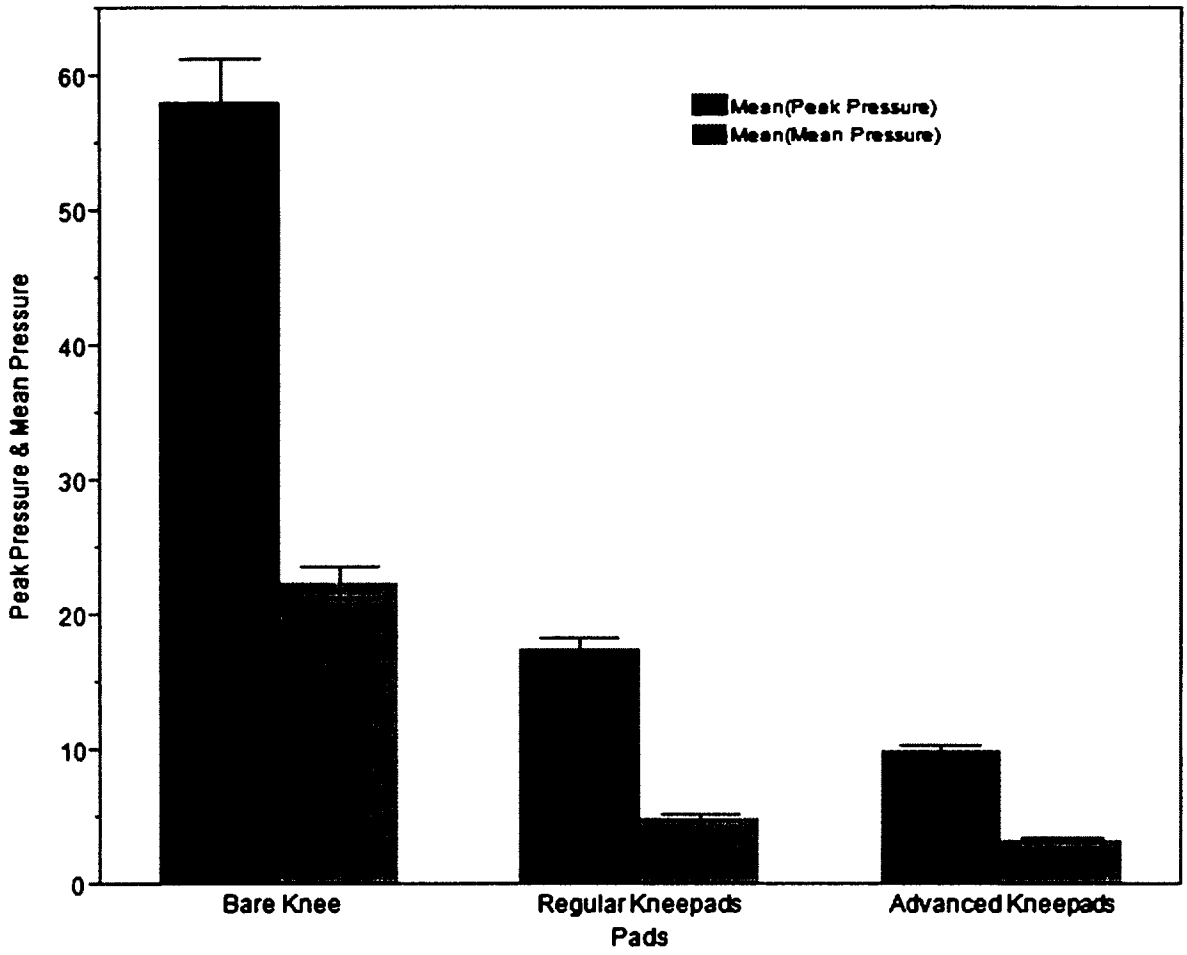


Figure 29 Peak and mean pressure for bare knee and different pads with 95% confidence intervals

Peak pressure varied significantly among the bare knee, the regular and the advanced pad. The bare knee was associated with much higher peak pressure than either kneepad (Table 11 and Figure 29). None of the postures had a significant effect on peak pressure.

The contact area was significantly different (ANOVA, $p < 0.05$) for the interaction between pads and leg posture (Figure 30). For both the bare knee and the regular kneepad, contact area for sitting on heels was smaller than for kneeling, but not for the

advanced pad. The interaction between pads and trunk postures was also significant (Figure 31). Compared with the regular kneepad, the advanced kneepad had a large increase in contact area with trunk flexion.

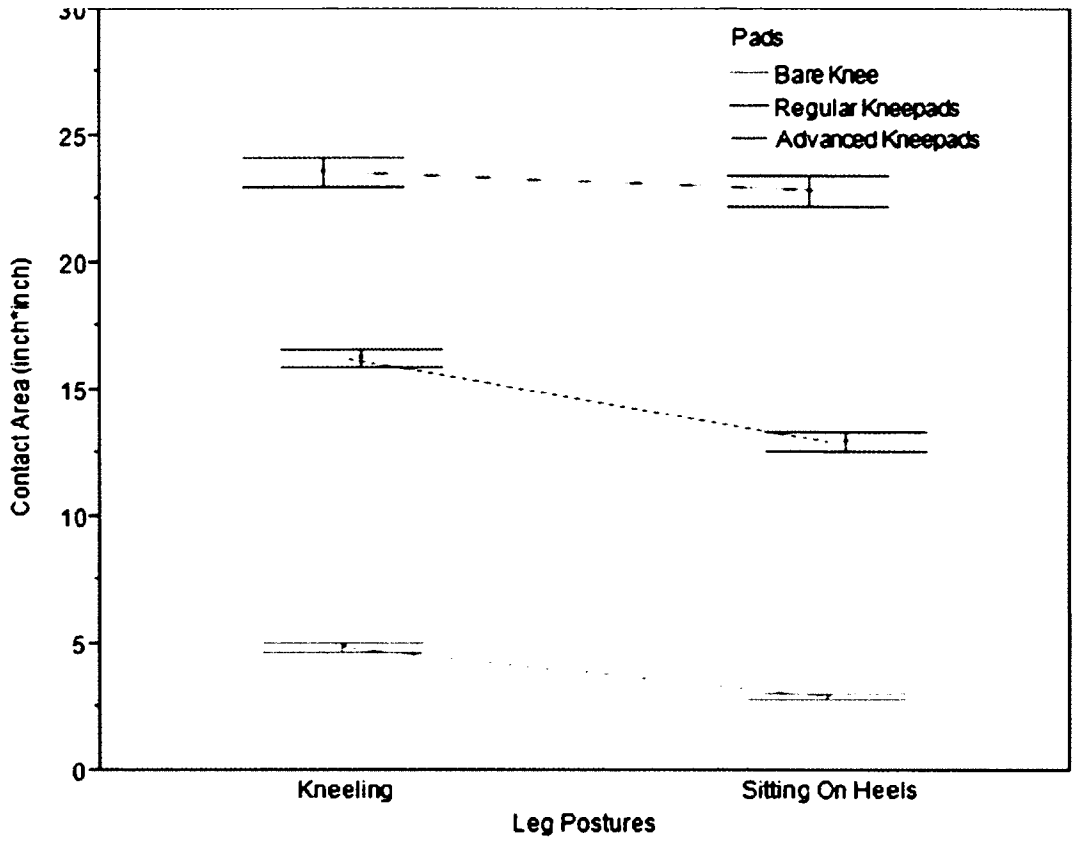


Figure 30 The interaction between pads and leg posture with 95% confidence intervals

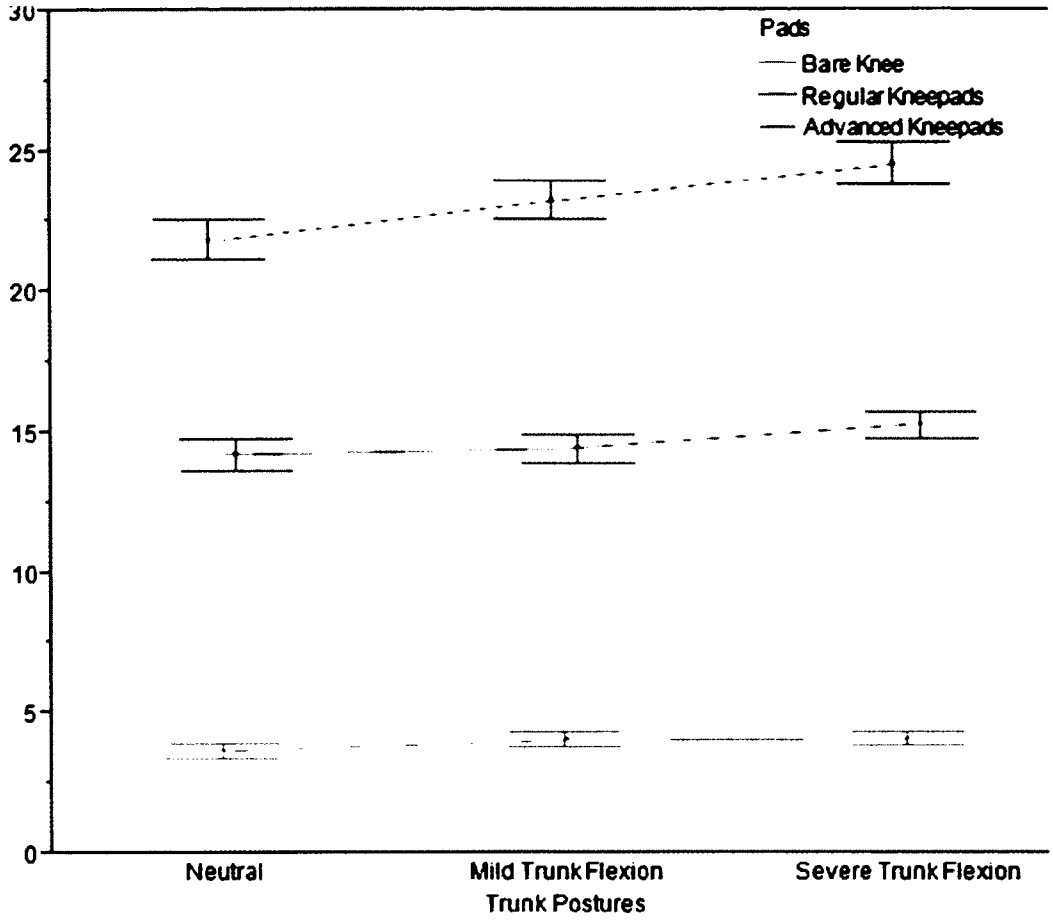


Figure 31 The interaction between pads and trunk posture were significant with 95% confidence intervals

For the bare knee condition, mean pressure increased dramatically from kneeling to sitting on heels, but for both kneepads, the mean pressure was similar for sitting on heels and kneeling (Figure 32).

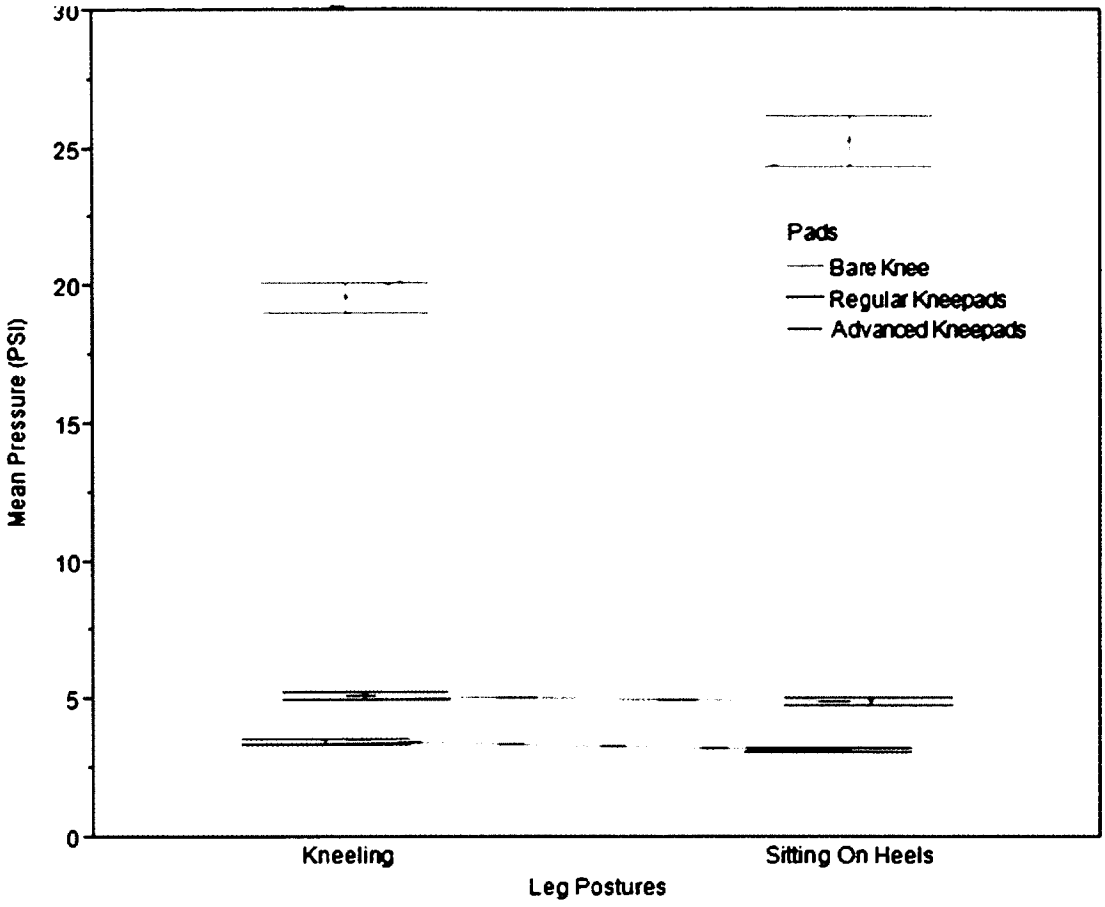


Figure 32 Mean pressure VS leg by pads with 95% confidence intervals

For the bare knee condition, peak pressure increased from kneeling to sitting on heels, but for both pads peak pressure for sitting on heels and kneeling posture were similar (Figure 33).

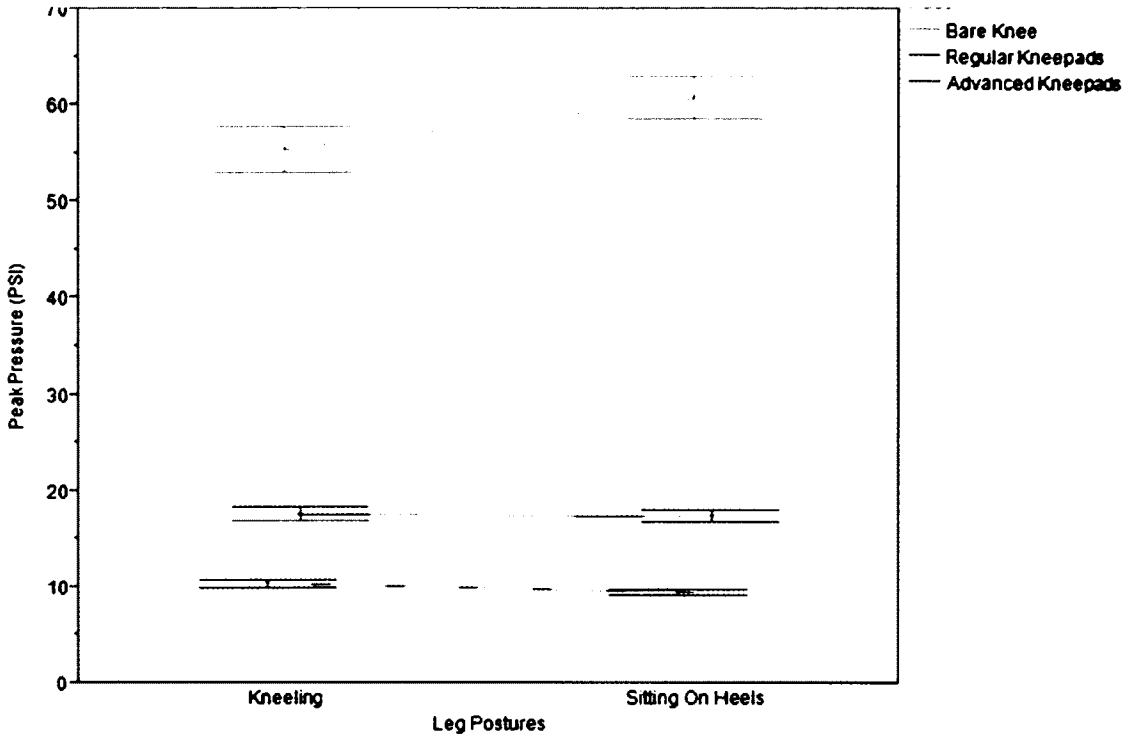


Figure 33 Interaction between Pads and Leg for peak pressure with 95% confidence intervals

Pressure distribution had the highest importance score (4.94). The advanced kneepad (rating 3.0) was rated as providing a better pressure distribution than the regular one (rating 1.41) (Figure 34 and Table). Work-related factors (Good Pressure Distribution, Improving Work Performance) had high importance scores. There were some usability factors, such as Well Attached to the Knee, Easy to Get on and Take off, Not Getting Sweaty, that also had importance scores greater than 3.

The advanced kneepad was rated higher on all factors with an importance score over 3 (Good Pressure Distribution, Well Attached to the Knee, Good Durability, Improving Work Performance, Easy to Get on and Take off, Not Getting Sweaty) over the regular

pad. The regular kneepads gained the advantage for Easy to Carry and Store, Low Cost, Light Weight, but all three had importance scores less than 3.

Table 13 Questionnaire results including importance scores for factors, and the comparison between two pads

	Importance[1]	Rating[2](Advanced)	Rating[2] (Regular)	Difference[3]
Good Aesthetic Factors	1.53	2.65	1.76	0.88
Light Weight	2.41	1.88	2.76	-0.88
Low Cost	2.82	1.59	2.76	-1.18
Easy to Carry and Store	2.88	2.00	2.82	-0.82
Good Customer Services from suppliers	2.94	2.53	1.76	0.76
Not Getting Sweaty	3.24	2.29	2.06	0.24
Easy to Get on and Take off	3.65	2.88	2.12	0.76
Improving Work Performance	4.12	2.76	1.76	1.00
Good Durability	4.35	2.82	1.59	1.24
Well Attached to the Knee	4.59	2.88	1.53	1.35
Good Pressure Distribution	4.94	3.00	1.41	1.59

[1] from 5 to 1, the importance decreased. 5 = highest importance; 1 = lowest importance

[2] from 3 to 1, the ratings decreased. 3, 2 and 1 indicated Good, OK and Bad, respectively

[3] The difference was rating from advanced kneepads minus rating from regular kneepads

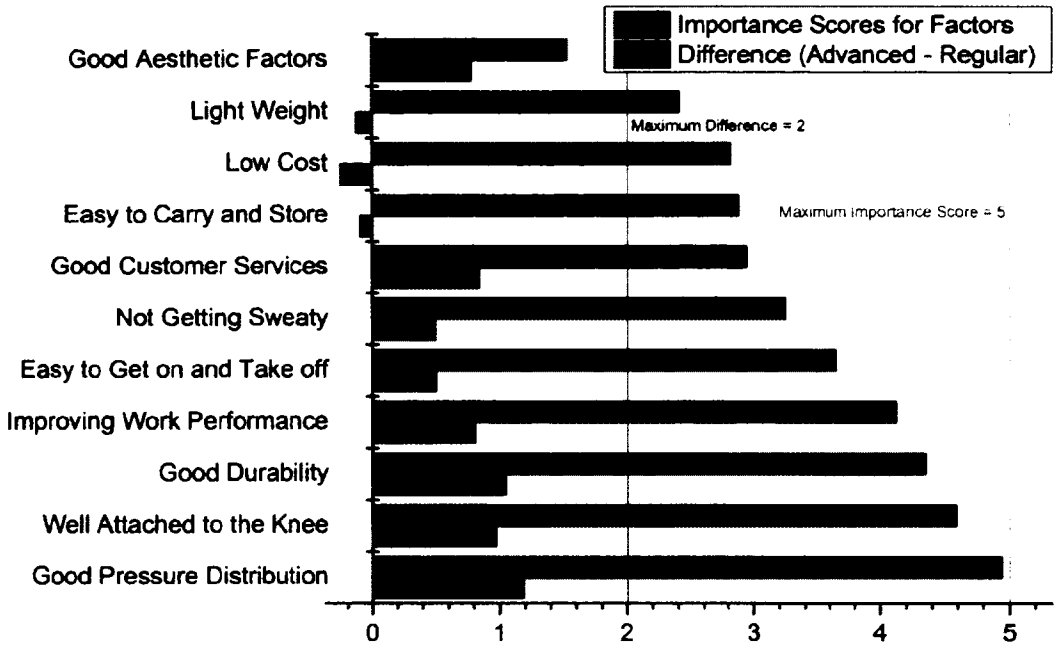


Figure 34 Questionnaire results for importance scores and the differences of rating between two pads (From 5 to 1, the importance decreased: 5 indicated an important reason; 1 indicated factors subjects do not care; From 3 to 1, the ratings decreased: 3, 2 and 1

5.4 DISCUSSION

This is the first study to compare two kneepads regarding to contact area, mean and peak pressure. Generally, the advanced pad provides better protection than the regular one.

Both kneepads increased the contact area dramatically compared with the bare knee, but the advanced ProKnee kneepad almost doubled the contact area compared with the regular one. This is because, unlike the regular pad that only covers the knee area, the advanced pad covers the knee area and the entire shinbone so force is redistributed to a larger area. When subjects bent their trunk with mild and severe flexion, the advanced pad also increased the contact area. The most likely explanation is that subjects shifted some body weight to the shinbone to keep balance while bending the trunk. Since the shinbone was covered by the advanced pad, therefore the contact area increased. For the regular pad, the subject could only shift his/her body weight between the knee area and the toe, so the shinbone was not occupied to increase the contact area. For the bare knee, contact area for sitting on heels was much smaller than that for kneeling. This is because while sitting on heels, contact area was limited to the small area of the tibial tubercle and part of the patellar tendon. By contrast, while kneeling, a large area of the patella joined with the patella tendon and the tibial tubercle to increase the contact area.

The relationship between the pads and contact area is opposite to the relationship with mean pressure. This can be explained by the principle of pressure: a large contact area lowers the mean pressure from the same amount of applied force. The bare knee

condition had the smallest contact area; therefore, the mean pressure was the highest. By contrast, the advanced kneepad had a larger contact area than the regular one, so the mean pressure for the advanced pad was lower. Sitting on heels led to a smaller contact area than in kneeling, so mean pressure while sitting on heels was higher.

The peak pressure measured (58 PSI for the bare knee on average) in this study is slightly higher than other studies (45 PSI for bare knee) (Porter et al., 2010). In this study, subjects were asked to kneel on hard concrete, which led to a smaller contact area than other surfaces such as carpet or hardwood floor. Therefore, peak pressures were higher.

One hypothesis of this study was that trunk, leg and arm postures would have a significant effect on the mean and peak pressure. The results showed that leg posture had a significant impact on contact area and mean pressure, but no impact on peak pressure. Trunk posture only had an impact on contact area. Arm posture had no significant impact on any of these three dependent variables. One explanation is that body postures changed not only the center of the body mass but also the size of contact area. Changing the center of the body mass leaded to redistribution of the force on the kneepad and the toe. Both the force on the kneepad, and the contact area influenced the mean and peak pressure on the knee. For several scenarios, the relationship between these two factors (the force and the contact area) and body postures were not on the same direction, so there were no-significant relationship between postures and two pressures. Additionally, arms may not heavy enough to cause significant changes of mean and peak pressure.

The laboratory experiment confirmed the advanced pad provided better pressure distribution than the regular one. The questionnaire results showed that workers were able to receive and rate this difference correctly.

Factors, such as Good Pressure Distribution and Improving Work Performance, had high importance scores. After all, a kneepad, as a protective device, is designed to protect users during working. Therefore, professional floor coverers, who use kneepads every day, have high requirements for work-related factors.

Workers were less interested in factors such as Good Customer Service, Low Cost, Light Weight and Good Aesthetic Factors (Figure 34). They likely wanted a good protection system regardless of the cost. In addition, kneepads are not high maintenance products, so customer service did not have a high importance score.

Three factors (Well Attached to the Knee, Easy to Get on and Take off, and Not Getting Sweaty) also received high-level attention from workers. These factors were more like usability concerns. These results suggest that usability for protection devices needs further attention.

5.4.1 Limitations

The sensel density represents the total number of sensels per unit of area. At the beginning of this study, both a big (model 5315) and a small sensor (Model 5076) had been considered. The small sensor had higher sensel density (177.8 sensel per in^2) than

the big sensor (6.3 sensel per in^2), therefore could provide more accurate measurement than the big sensor.

However, the small sensor was not as large as the big sensor to cover the shinbone. So, the big sensor was selected. The big sensor with low sensel density would overestimate the contact area. Because the sensor was sensitive and the single sensel size was big, if a small part of the sensel received a tiny pressure, the entire sensel was counted as active contact area.

The default threshold of pressure to qualify active cells is zero. If a threshold bigger than zero is chosen, measured contact area would decrease compared with that for zero threshold, so the measured area could close to the true value, and to correct the overestimation. The reason is that cells with pressure lower than the threshold will not be identified as active cells, so its contact area will not be counted. The appropriate threshold is determined by both loadings and different types of sensors. The threshold for sensors with low sensel density is bigger that for sensors with lower sensel density. In this case, a threshold of 0.5 PSI was used for the chosen sensor (model 5315). Sensels with pressure under 0.5 PSI were not counted as active sensels and were not included in the measured contact area. Using the threshold made the measurement of the contact area close to the true value.

5.5 CONCLUSIONS

Compared with the bare knee, both kneepads increased contact area and decreased mean and peak pressure. Generally, the advanced kneepads performed better than the regular kneepads. Given the amount of time that floor coverers spend kneeling or crawling, it is recommended that they use the advanced kneepads in order to have the best knee protection possible.

5.6 LITERATURE CITED:

Bhattacharya, A., Mueller, M., Putz-Anderson, V., 1985. Traumatogenic factors affecting the knees of carpet installers. Appl. Ergon. 16, 243-50.

Jensen, L.K., 2008. Hip osteoarthritis: influence of work with heavy lifting, climbing stairs or ladders, or combining kneeling/squatting with heavy lifting. Occup. Environ. Med. 65, 6-19.

Kivimaki, J., Riihimaki, H., Hanninen, K., 1992. Knee disorders in carpet and floor layers and painters. Scand. J. Work Environ. Health 18, 310-316.

Maness, W.L., Golden, R.F., Benjamin, M.H., Podoloff, R.M., 1989. Pressure and contact sensor system for measuring dental occlusion. Pressure and contact sensor system for measuring dental occlusion U.S. Patent No. 4,856,993.

Moore, S.M., Porter, W.L., Mayton, A.G., 2009. Pressures applied to anatomical landmarks of the knee while in kneeling postures. 2009 ASB Annual Meeting Program.

Porter, W.L., Mayton, A.G., Moore, S.M., 2010. Pressure distribution on the anatomic landmarks of the knee and the effect of kneepads. Appl. Ergon. 42, 106-13.

Young, J.G., Trudeau, M., Odell, D., Marinelli, K., Dennerlein, J.T., 2012. Touch-screen tablet user configurations and case-supported tilt affect head and neck flexion angles. Work 41, 81-91.

6 CONCLUSION

This dissertation focused exclusively on biomechanical exposure to the knee joint in floor covering work, and how that could be reduced. Compared with the low back or other joints that have been intensively studied with regard to musculoskeletal disorders, the knee remains severely understudied. Floor coverers, who have suffered a high prevalence of knee-related disorders and injuries, have received inadequate attention from scientific studies.

This dissertation includes four papers each examining different aspects of knee stressing exposures. The first paper described the observation and analysis of ergonomic exposures at the task level, with specific consideration of the knee as well as other major body segment postures, MMH, tool usage and other work-related factors. The second paper discussed the kinematic and kinetic patterns of the kicking movement for the knee kicker, a tool for stretching carpet. The third paper compared exposures when using the knee kicker to an alternative tool, to determine if the new device improved body movements and muscle activities. The last paper compared regular kneepads with advanced kneepads in order to examine the efficiency of pressure distribution, and the relationship between body postures and pressure. It also applied a usability survey to probe other factors that might influence use and adoption in the field, which could not be measured directly in the laboratory.

This dissertation combined multiple measurement approaches, including observational ergonomic exposure assessment, direct measurements from EMG, motion

tracking system, load cell, and pressure sensors and questionnaire. Variables included categorical postural data, muscle EMG data, direct measured body posture, impact force, and qualitative survey data. Results provided profound information for a comprehensive understanding of the exposure for floor covering job from many different perspectives.

The measurements were both real-time and cumulative exposure. Real-time measurement included muscle activities, body segments movements, impact force during kicking, mean and peak pressure, and contact area. Cumulative measurements were data obtained from the observational study such as body postures, tool and equipment usage, manual material handling and other data for a typical 8-hour workday from a historical large database. Therefore, it is possible to create an exposure index with both durations of exposures and magnitudes of exposures. The index could combine with other factors, such as personality, social support, and others in order to create a model that can explain the pathology of injuries or disorders. Because of the quantitative nature of data in this study, it is even possible to create a dose-response relationship between exposures and injuries or disorders.

This dissertation includes not only measurement of exposures but also measurements to evaluate two interventions, the air stretcher and the advanced kneepad. For exposure measurement, this dissertation makes the magnitude of exposure clear at the detailed level of tasks. By doing this, practitioners could target specific tasks and redesign them to decrease exposure. For engineering interventions, the differences between the alternative and the original device were discussed with accurate measurement. Therefore, the extent

of the advantages of these interventions could be investigated. All these findings are ready to be presented to floor coverers, union officers, insurance providers, policy makers, and other researchers. More than this, even the complete systematic study was designed for the knee joint, but the conceptual framework is suitable for other segments after appropriate adjustments.

6.1 LIMITATIONS AND STRENGTHS OF THIS DISSERTATION

For both observational and laboratory studies, convenience sampling was applied. It would be ideal to randomly select workers, and then obtain their permission to participate in the study, but it was not practical due to the difficulties of gaining access to construction sites and workers. Although convenience sampling was the only available way to recruit subjects, researchers tried best to include workers from different seniority levels, different age, and others. Similar sampling issues have occurred for other researchers (Kurowski, Gore, Buchholz, & Punnett, 2012). Additionally, researchers applied a sampling strategy of observing multiple days with fewer hours rather than observing more hours in fewer days, in order to decrease day-to-day variability in the exposure assessment of kneeling and squatting (Tak, Paquet, Woskie, Buchholz, & Punnett, 2009).

There were ten subjects for each of the two laboratory experiments. These subjects may not be representative of the entire population of floor coverers. Additionally, both laboratory studies were not performed in the real work field where other uncontrolled variables could change the experiment results. In both studies, the environment was controlled (the same surface, carpet conditions, tools, kneepads, and others), this may overestimate or underestimate the exposures and other ergonomic characteristics. However, since two laboratory studies emphasize the comparison between devices, so these underestimation or overestimation could be canceled out.

Compared with administrative approaches that require cooperation from different parties (owners, contractors, subcontractors, and safety staff), engineering approaches require less effort. Users could enjoy the benefits from tools or equipment at the moment when they receive them. Construction unions have been trying to persuade employers to pay for essential tools and protection devices. Research results from this dissertation can be used by them to negotiate with their employers.

6.2 FUTURE RECOMMENDATION

Through the kneepad study, many comments and suggestions have been received with the potentials to improve the design of kneepads. Therefore, the next project could be re-designing a kneepad to suit the particular needs for floor coverers. The new kneepad should provide the necessary protection to the kneecap where floor coverers create the large impact force, and provide better ventilation to deal with the high volume of moisture due to long time of usage. New kneepads could be significantly lighter than current products because the pressure distribution map provides evidence to get rid of parts of the kneepad, where contact pressure does not occur.

A cost-effective study for the alternative of the kicker or the advanced kneepad is also interesting. Both the stretcher and the advanced kneepad require a small amount of investment at the beginning, but the avoided medical bills or sick days and potential surgery cost will benefit users in a long run. Theoretically, it could be predicted how many years after introducing alternatives, the initial investment will be paid off with appropriate estimations of prevalence and cost of knee-related disorders and injuries. This kind of results, in monetary units, would be extremely useful for workers or union representatives to persuade employers to purchase alternatives for workers in order to improve the workers' work environment.

6.3 LITERATURE CITED

Kurowski, A., Gore, R., Buchholz, B., & Punnett, L. (2012). Differences among nursing homes in outcomes of a safe resident handling program. Journal of healthcare risk management : the journal of the American Society for Healthcare Risk Management, 32(1), 35–51. doi:10.1002/jhrm.21083

Tak, S., Paquet, V., Woskie, S., Buchholz, B., & Punnett, L. (2009). Variability in risk factors for knee injury in construction. Journal of occupational and environmental hygiene, 6(2), 113–20. doi:10.1080/15459620802615822

APPENDICES

APPENDIX I: THE QUESTIONNAIRE

Background information

How many years have you been a floor coverer? ( )

How many years have you been using the Pro Knee kneepads ( )

Which local union do you belong to? ( )

Where did you first hear about Pro Knee (you can choose more than one answers):

Co-workers

Local Union

Employer

Catalog

Doctor

Insurance company

Other (please list)

Check your knee pad preference for the following factors:

	Regular	Pro Knee
Looks good		
Weight		
Easy to carry and store		
Durability		
Pressure distribution		
Stability		
Ventilation (sweaty)		
Position of the strap		
Easy to get on and take off		
Improve work performance		
Price		
Service		

For the same factors, which one (s) are most important when you make decisions about knee pads:

	Not a reason for me	Reason	Important reason
Looks good			
Weight			
Easy to carry and store			
Durability			
Pressure distribution			
Stability			
Ventilation			
Position of the strap			
Easy to get on and take off			
Improve work performance			
Price			
Service			

Other reasons or comments:

How do you rate the Pro Knee kneepads?

Great	Good	OK	I do not like it	I hate it

How do you rate regular kneepads?

Great	Good	OK	I do not like it	I hate it

APPENDIX II: INFORMED CONSENT FORM

IRB INFORMED CONSENT FORM
For Seeking Consent for Human Subjects to Participate in Research
For IRB Use Only: IRB No.: **07-110-BUC-XPD**
(A copy of this form must be provided to the study participant after signing it. The original is retained by the PI.)

Project Title: Biomechanical Evaluation of Air Stretcher as Alternative for Carpet Knee-kicker

Principal Investigator: Bryan Buchholz, Ph.D.
Co-PI(s):
Student Investigator(s): Brad Schugardt, Xiaolu Jing
Date Submitted: November 9, 2007

This form has been approved for use by the UMass Lowell IRB and is valid for a period not to exceed one year from the approval date.
Authorized IRB Approval Signature: [signature] **Approval Date:** November 16, 2007

Essential Sections of the Informed Consent Form (see IRB Policy and Procedures):

Study Purpose: The purpose of this research project is to evaluate physical exposures that may lead to knee disorders in carpenters.

Procedure and Duration: You will be performing specific tasks common to your trade in a laboratory. The motions of your legs and activity of your muscles will be recorded as you perform these tasks. Muscle activity will be measured using sensors attached over the muscles in a manner similar to how an electrocardiogram measures heart activity.

Potential Risks and Discomfort: There are no risks associated with the use of this measurement equipment.

Incentives/Compensation (if any): You will receive a cash incentive of $50 for your participation whether or not the measurements are completed.

Anticipated Benefits to the Subject or to Non-subjects: You may receive no direct benefit from your participation in this study, but the information gained may result in the improved health of carpenters.

Right to Refusal or Withdrawal of Participation: Your participation in this study is completely voluntary, and your participation, or non-participation, will not affect other relationships (e.g., employer). You may discontinue your participation in this research program at any time without penalty or costs of any nature, character and kind.

Assurances of Privacy and Confidentiality: Every precaution shall be taken to protect your privacy and the confidentiality of the records and data pertaining to you in particular, and the research program in general, to prevent specific identification of you as an individual to persons not related to this research program.

Additional Information: If you do not understand any portion of what you are being asked to do, or the contents of this form, the researchers are available to provide a complete

explanation. If you have any questions relating to this research project, please contact Bryan Buchholz, Ph.D., at the following address and phone number:

Bryan Buchholz, Ph.D.
Department of Work Environment
University of Massachusetts Lowell
One University Ave.
Lowell, MA 01854
(978) 934-3241

PRINCIPAL INVESTIGATOR SIGNATURE(S) -See definition of PI for who is authorized to sign here.
1. Printed Name: Bryan Buchholz, Ph.D. Signature: Date: 11/9/07

2. Printed Name: Signature: Date:

PERSON OBTAINING CONSENT
Printed Name: Date:

Signature:

PARTICIPANT SIGNATURE
I understand the foreseeable risks and/or discomfort that have been described in this document. I have read the statements contained herein, have had the opportunity to fully discuss my concerns and questions, and fully understand the nature and character of my involvement in this research program as a participant and the attendant risks and consequences.

Research Participant:
Printed Name: Date:

Signature:

Parent, Guardian, or Legal Representative (if applicable):
Printed Name: Date:

Signature:

Agency or Administrative Official (if applicable):
Printed Name: Date:

Signature:

IRB INFORMED CONSENT or AGREEMENT TO PARTICIPATE FORM

IRB No.: 10-099-BUC-XPD Rev. No./Date:2/9-20-11

Project Title: Quantitative Analysis of the Pressure on the Knee among Floor Coverers
Principal Investigator: Bryan Buchholz, Ph.D.
Contact Information: 978-934-3241; bryan_buchholz@uml.edu
Co-PI(s):
Student Investigator(s): XiaoLu Jing
Date Submitted: 09/20/2011

This form has been approved for use by the UML IRB and is valid for up to one year from the approval date.
(PIs -Give a copy of this form to the study participant after they sign it. Originals are to be retained by the PI.)

Authorized IRB Approval Signature: Stephen Dow **Approval Date**: September 28, 2011

---

1. Study Purpose: The objective of this study is to measure and compare how different kinds of kneepads can protect Floor Layers' knees using pressure measurement sensors.

2. Procedure and Duration: Three thin pressure mats will be taped on your legs (one on each knee and the other on the lower thigh of your kicking leg) using latex–free tape. You will wear kneepads over the pressure mats. You will be asked to perform the movements you usually perform during floor laying with two conditions: 1) installing hardwood floor; and 2) installing carpet. This will include kneeling, crawling and kicking the knee kicker. Each condition (installing hardwood floor and installing carpet) will last 20 minutes. Each condition will be performed three times using different types of knee pads. The entire experiment will last less than three hours including preparation and two short questionnaires before and after the experiment.

3. Potential Risks and Discomfort: There are no risks associated with the use of this measurement equipment. There may be some discomfort to have the pressure mats inside of the kneepads but this is not expected to be great.

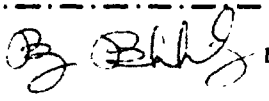
4. Incentives/Compensation: You will receive a cash incentive of $100 for your participation after the experiment. If you cannot finish the entire experiment, you will still receive the incentive. If you choose not to participate before the experiment starts, you will not receive the incentive.

5. Anticipated Benefits to the Subject or to Non-subjects: You may receive no direct benefit from your participation in this study, but the information gained may result in the improved health of carpenters.

6. Right to Refusal or Withdrawal of Participation: Your participation in this study is completely voluntary, and your participation, or non-participation, will not affect other relationships (e.g., employer). You may discontinue your participation in this research program at any time without penalty or costs of any nature, character and kind.

7. Assurances of Privacy and Confidentiality: Every precaution shall be taken to protect your privacy and the confidentiality of the records and data pertaining to you in particular, and the research program in general, to prevent specific identification of you as an individual to persons not related to this research program.

8. Additional Information (Include contact information for researchers): If you do not understand any portion of what you are being asked to do, or the contents of this form, the researchers are available to provide a complete. There are some screening criteria: male only; native English speaker; not obese; without knee injuries.

PRINCIPAL INVESTIGATOR SIGNATURE(S)
1. Printed Name: Bryan Buchholz, Ph.D. Signature:  Date: 9/20/11

PERSON OBTAINING CONSENT
Printed Name: Date:

Signature:

PARTICIPANT SIGNATURE

I understand the potential risks and/or discomforts that have been described in this document and by the researcher. By signing below, I am indicating that I have read this document, had the opportunity to discuss any concerns and ask questions about the research, and understand the risks and consequences from participating in this study.

Research Participant:
Printed Name: Date:

Signature:

7 BIOGRAPHIC SKETCH OF AUTHOR

The author, XiaoLu Jing, is originally from HuBei, China and attended China Geoscience University where he received a bachelor degree in Safety Engineering in 2003 and a master degree in 2006. His research interest include biomechanics, motion tracking, knee-related ergonomic exposure measurement, construction safety and ergonomics.