

Traumatogenic factors affecting the knees of carpet installers

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An ergonomics analysis of carpet installation tasks was performed. The purpose was to identify and quantify potential sources of biomechanical trauma that may be responsible for the high rates of knee morbidity found by previous researchers among carpet layers. Nine carpet layers were studied either at an apartment building worksite or at a training school. Results from a job analysis indicated that workers spent approximately 75% of their time in the kneeling position using a tool called a knee-kicker to stretch and install carpet. Awkward body postures were identified from films of workers installing carpets. At the moment of impact the knee is severely flexed, subtended angles were less than 60 degrees. To obtain measures of impact force on the knee, the kicker-tool was instrumented with a load cell. Workers who executed the hardest kicks with the tool produced impact peak forces that averaged 3019 newtons (N), which is equivalent to about four times body weight. Measures from an accelerometer attached to the worker's knee showed values in excess of 120 m/s², which are comparable to those found during vigorous running and jumping exercises. The results imply that repetitive impact of the knee joint from the use of the knee-kicker combined with knee flexion, kneeling and squatting may be responsible for the high level of occupational knee-morbidity found among carpet layers.

Keywords: Occupational safety, knees, carpet laying

Introduction

The study of the occurrence of musculoskeletal disorders in the workplace has been mainly limited to the low back, and upper extremities of the body (NIOSH, 1981; Armstrong, 1983). Only recently have investigators at the National Institute for Occupational Safety and Health (NIOSH) provided the relevant information regarding occupationally related musculoskeletal dysfunction of the lower extremities (Tanaka *et al*, 1982; Putz-Anderson and Frederick, 1983). A variety of occupations require extensive use of hip, knee, ankle and foot in the performance of their jobs. Tanaka *et al* (1982) reported that the occupations requiring kneeling have much higher knee-morbidity ratios (percent claims/percent work force) than those occupations requiring either no kneeling, or less kneeling. Some of these occupations include carpet layers, tile setters and floor layers. Of these, carpet layers have the most knee injuries. Their morbidity ratio (107.8) exceeded twice that of tile setters and general floor layers.

Ekstrom *et al* (1981) also examined the prevalence of knee symptoms among different trades in the Swedish building industry. Their initial result supports the hypothesis that the prevalence of knee symptoms closely parallels the degree to which different jobs require workers to kneel. For example, 24.1% of carpet layers studied had knee symptoms compared with 14.4% of electricians or 10.0% of truck drivers.

In addition to kneeling, carpet installers, at least in the United States, use their knee as a power source to impact a tool called the knee-kicker. The knee-kicker has been used with little variation for over 80 years as the main tool for installing wall-to-wall carpet. Since the job is physically very demanding, only the most fit workers remain in the profession beyond a few years. Unfortunately, little is known about the nature of the biomechanical forces on the knees and their role, if any, in contributing to morbidity data for carpet layers.

The purpose of the present study was both to identify the different types of working postures used in installing

wall-to-wall carpet, and to quantify the biomechanical forces exerted on the knee associated with the different working postures and the use of a tool called the knee-kicker.

Methods

1. Study population

A total of nine male workers from the Resilient Floor Layers and Decorators Local Union participated in the study. These workers were the only ones available at the time of the study. Out of nine workers, only two (Numbers 1 and 2) consistently performed the knee-kicking activity, and worker No 3 performed this task on one occasion only. The remaining workers performed related tasks. Table 1 provides the details of workers' height/weight, job experience and job activities evaluated for the present study. Participation in the study was voluntary and availability depended upon workload on the days of the study. Therefore, for certain aspects of the study only a few workers were available.

2. Study site

All of the measurements were taken at a worksite in a ten-storey apartment building, except for the impact force-measurements which were obtained at the carpet installers' training school under work conditions that approximated the apartment worksite.

3. Carpet installation – task steps

Installing carpet at the worksite studied required six distinct steps, as illustrated in Fig. 1. Each step posed

Table 1: Anthropometric data and job related information*

Worker No	Activities related to the job	No of years of job experience	Body weight (kg)	Height (cm)
1	a, b, c, d	7	91	191
2	a, b, c	20	107	178
3	a, b, c	35	101	180
4	a, b, c	34	105	188
5	c	not avail	80	175
6	c, d	not avail	93	183
7	c, b	not avail	82	180
8	d	4	75	173
9	d	2	76	188
Mean ± SEM			90 ± 4.1	182 ± 2.1

a: Cumulative loading of knee

b: Body postures associated with knee-kicking

c: Impact acceleration of lower extremity

d: Impact knee force

*Based upon estimates made by the workers

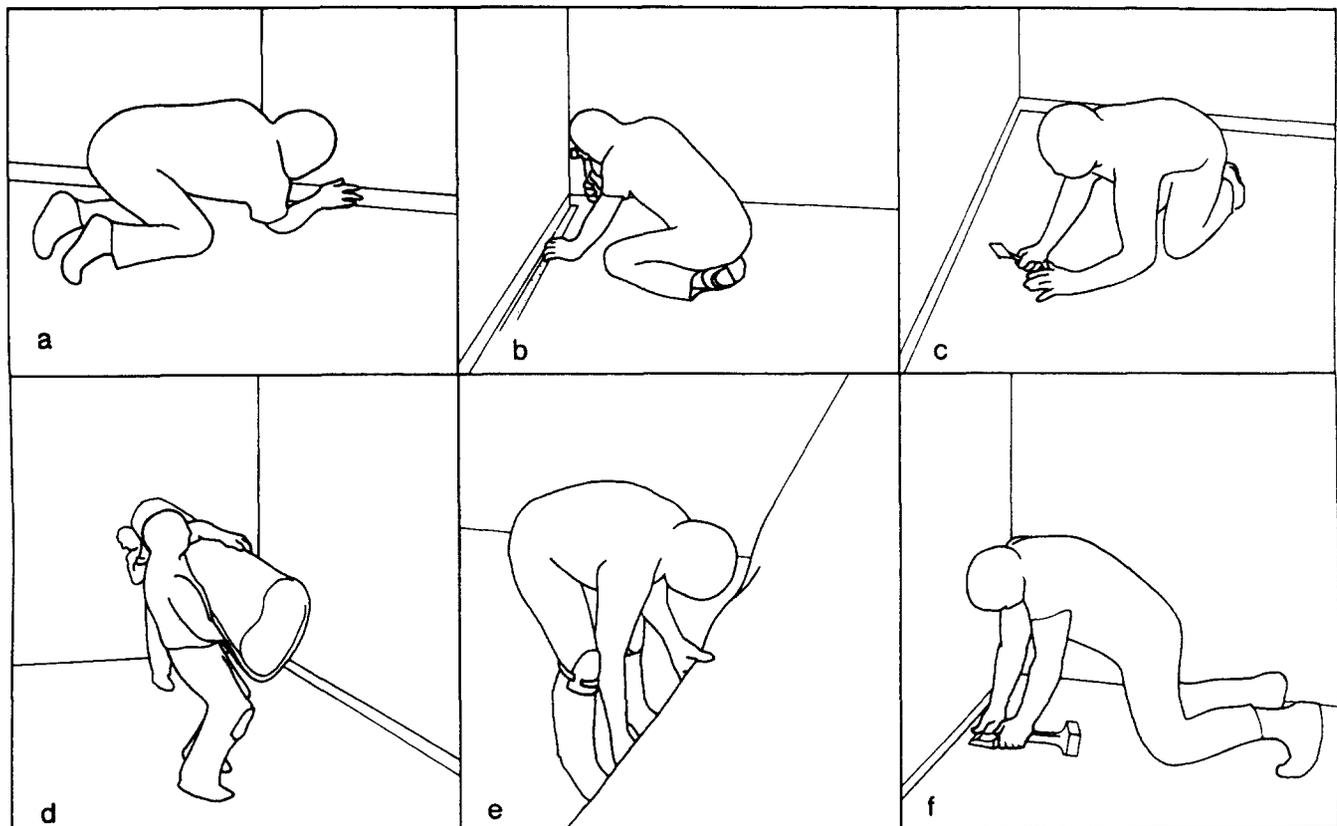


Fig. 1 Body postures associated with carpet installation process

unusual biomechanical demands on the musculoskeletal system. A brief description of each step follows:

(a) Narrow plastic bases in the form of long strips were glued to the bottom of the wall to form a boundary between the wall and floor. To apply the base strip, a worker normally had to kneel on the cement floor with the torso flexed and twisted towards the wall. This is shown in Frame (a) of Fig. 1.

(b) Wooden tack strips or tacklers, which were used to secure the carpet against the wall, were then nailed down around the perimeter of the floor. This task usually required that the workers either sit on the concrete floor or kneel. See Frame (b) of Fig. 1.

(c) The third step involved laying and glueing the carpet pad to the floor. The job required extensive kneeling, and trunk flexion, creating awkward postures, as illustrated in Frame (c) of Fig. 1.

(d & e) The carpet rolls, which weighed about 68 kg, were carried to the room by one or two men, unrolled and pulled into place. Workers assumed a variety of positions in performing this strenuous task including stooping, flexion-extension of trunk and a combination of sagittal and asymmetrical lifting. Frames (d) and (e) of Fig. 1 show two of the postures used to perform this work.

(f) The carpet was trimmed and finally secured to the tack strips by stretching. The stretching was accomplished with a combination of a hand-power stretcher and extensive use of the knee-kicker tool. The hand-power stretcher consists of a long metal tube about 5 cm in diameter, which can be extended from a minimum of about 1 m to 10 m or more by adding extension tubes. A plate with a set of teeth for gripping the carpet is attached to one end of the tube: a bumper plate or heel is attached to the other end which is braced against a wall. The tool operates like an automobile lift or jack when the handle is pumped. As the tool extends, carpet is pushed against the wall and is easily caught by the nails in the tack strips. Although the tool is effective in stretching large sections of carpet, the installer must exercise caution because the generated force is sufficient to tear a carpet or push out a weak wall. The tool appears to pose little or no risk to the user; however, many installers avoid using it because it is somewhat cumbersome to assemble and requires more time to use than the knee-kicker.

In contrast the knee-kicker is small and easy to manipulate, but requires the worker to supply the source of power in the form of vigorous 'knee kicks' to the padded end of the tool. To perform this action efficiently, the worker aligns his body with the long axis of the tool and places the suprapatellar region of his knee at the back of the tool in the direction of the intended stretch. Frame (f) of Fig. 1 illustrates a typical knee-kicking posture. The worker is kneeling and facing the wall. When the gripping end is embedded in the pile of the carpet, the applied force is sufficient to stretch the carpet over the tack strip.

We were interested in studying the carpet stretching activity. The most distinguishing aspect of this job is the potential traumatogenic effect of using the knee-kicker. To characterise the biomechanical elements of this activity, information was obtained bearing on the following:

- (1) work variables – i.e., task time, number of kicks, etc,
- (2) body and knee postures, (3) impact acceleration, and

- (4) impact force on the knee. From this information a cumulative load index was computed for each worker involved in the use of the kicker.

4. Instrumentation/procedures for data collection

(a) *Task variables:* A written record of job activity was obtained each day for each of the three workers available during the carpet stretching phase of the study. Data were collected on the number of kicks applied by each worker, amount of time spent kneeling, and the amount of time using the knee-kicker and power stretcher.

(b) *Body postures:* An 8 mm Super 8 (Model 514x L-S, 24 frames/s, Cansound, Cannon Inc) was used to film the knee-kicking activity. The film was analysed using a special stop-action projector (Lafayette Instrument Co, Lafayette, IN), a sonic digitiser (Model GP-8, Science Accessories Corp, Southport, CT) and a pre-programmed computer system. This system provided calculation of angular changes of body segments associated with the use of kicker. In order to facilitate film analysis, a scaled x-y co-ordinate system was placed in the field of view. The x direction was parallel to the direction of motion of the moving leg and to the floor. Each worker performed his normal knee kicking activity for about 30 s. The film was then analysed to obtain body posture data associated with the knee-kicking activity.

(c) *Impact acceleration:* For the measurement of leg acceleration, a miniature piezoresistive accelerometer (Model EGC-500 DS-20; ± 20 G; Entran Devices, Little Falls) was used. The frequency response of the accelerometer was flat from 0–800 Hz. The non-linearity was less than $\pm 1\%$ of full scale. The accelerometer was factory tested and calibrated for the dynamic range. Static calibration was performed according to the manufacturer's instructions. This procedure essentially involved static calibration technique published previously (Bhattacharya *et al*, 1980). For this purpose, the sensitive axis of the accelerometer was first placed along the positive direction of the earth's gravity (or perpendicular to the floor) for $+1G$ ($+9.81$ m/s²) calibration signal, then the accelerometer axis was reversed for $-1G$ value. The signal from the accelerometer was conditioned by the Gould Transducer Amplifier (Model 13-4615-50, Gould Instrument, Inc, Cleveland, OH) which had a flat frequency response from 0 to 1 kHz. The output from the amplifier was then recorded on a high pen response type Gould strip chart recorder (2600 Series Gould, Gould Instrument, Inc, Cleveland, OH). The rise time for this recorder was less than 5 ms for full scale deflection.

The accelerometer was attached to the kicking leg with micropore tape. The sensitive axis of the accelerometer was placed above the patella, and lateral to the head of the femur. Such a placement enabled the sensitive axis of the accelerometer to be in the direction of the long axis of the knee-kicker. This position provided a measurement of the largest contributing component of the impact acceleration when the suprapatellar region contacted the kicker (Fig. 2B). The workers were requested to perform two types of kicks: a light kick, approximately one-half of their normal force, and a hard kick, which approximated the normal to heavy kick required to stretch a large piece of carpet. In the course of installing carpets, workers use a combination of light and

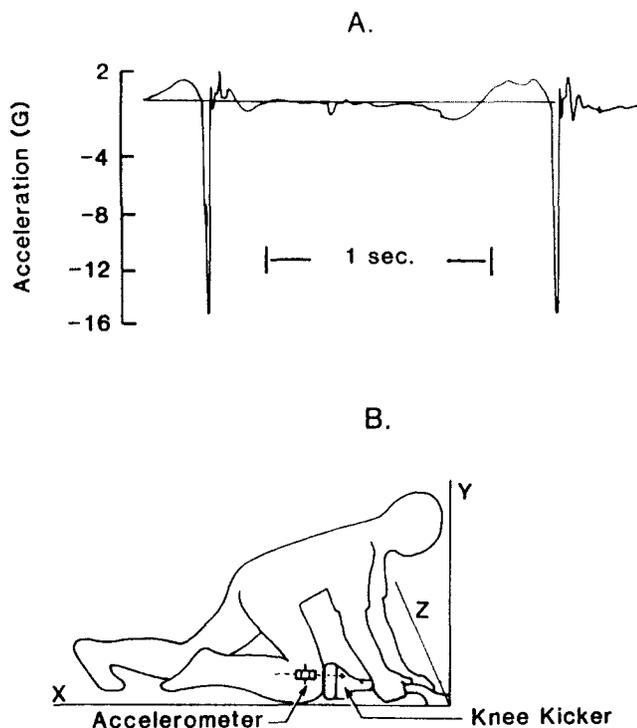


Fig. 2 A. Impact acceleration waveform during impact kick cycle from one worker. $1G = 9.81 \text{ m/s}^2$
 B. Location of accelerometer placement

hard kick depending upon the size and amount of carpet that needs stretching.

(d) *Impact knee force*: In order to measure the impact force during knee-kicking, a load cell (Model 31/2328; 1368 kg; Sensotec, Columbus, OH) was mounted in the middle of the shaft of the knee-kicker, as shown in Fig. 3. Each side of the load cell was attached to a steel reinforced-square flange that provided stability and strength. The peak values of the actual impact were obtained from a portable display unit (Model: 450-D; Sensotec, Columbus, OH). The rise time of the display unit was 0.5 ms, and it was fitted with appropriate circuitry to capture and display the peak impact force. The load cell was calibrated in the laboratory and compared with the built-in calibration system provided by the manufacturer.

(e) *Computation of cumulative impact loading index*: To quantify the amount of impact loading that the installer's

knees were being subjected to, a cumulative impact loading index (CIL) was developed and defined as follows:

$$\text{CIL Index/hr} = \frac{[\text{AIF/K}] \times [\text{SumK}] \times 60}{\text{SumTK}} \quad \text{newtons/h}$$

Where:

$$\text{AIF/K} = \text{Average Impact-Force/Kick} \quad \text{newtons/kick}$$

$$= \frac{(\text{light kick force} + \text{hard kick force})}{2}$$

2

SumK = Sum total number of kicks during study period

SumTK = Sum total of time in study period using knee-kicker (min)

The impact-force values were obtained from a load cell that was installed in the knee-kicker.

Results

1. General task analysis

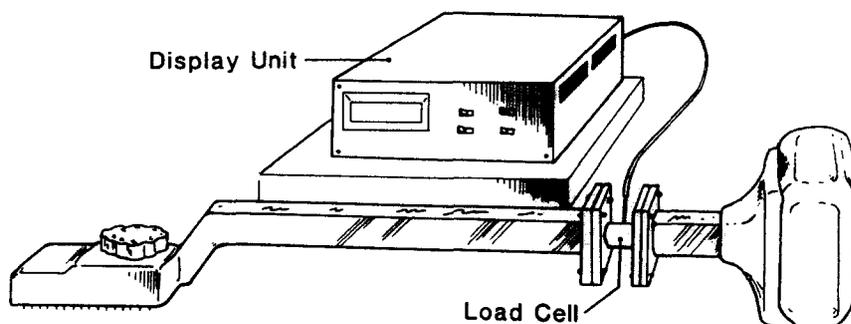
For approximately 3 h each day the activities of each of three workers who were assigned to carpet stretching were categorised by task, and the duration of each task was measured. The results of the task analysis are shown in Fig. 4A. On the average, the three workers spent about 75% of their time using the knee-kicker, 15% of the time they used the power stretcher, and the remaining time was spent doing jobs not requiring kneeling, such as walking to pick up job-related tools, etc.

Only one of the nine workers observed was using knee pads and this was in conjunction with laying the narrow plastic bases (Fig. 1A). The available knee pads cover the subpatellar region, but provide little protection for the upper part of the knee which is used in impacting the kicker. Workers report that the pads get in the way, and the straps frequently pinch their legs. The pads also reduced the range of knee motion needed to impact the kicker. As a consequence, none of the installers wore knee pads when they used the knee-kicker.

2. Cumulative loading of the knee

Fig. 4B shows the number of kicks applied per hour for each worker. They averaged 141 kicks per hour. Based on two workers per job, about 90 min were required to complete the final trimming and stretching for each apartment with a perimeter of 39 m. About 44 kicks were needed to install 10 sq m of carpet.

Fig. 3 Schematic of instrumented knee-kicker and the display unit



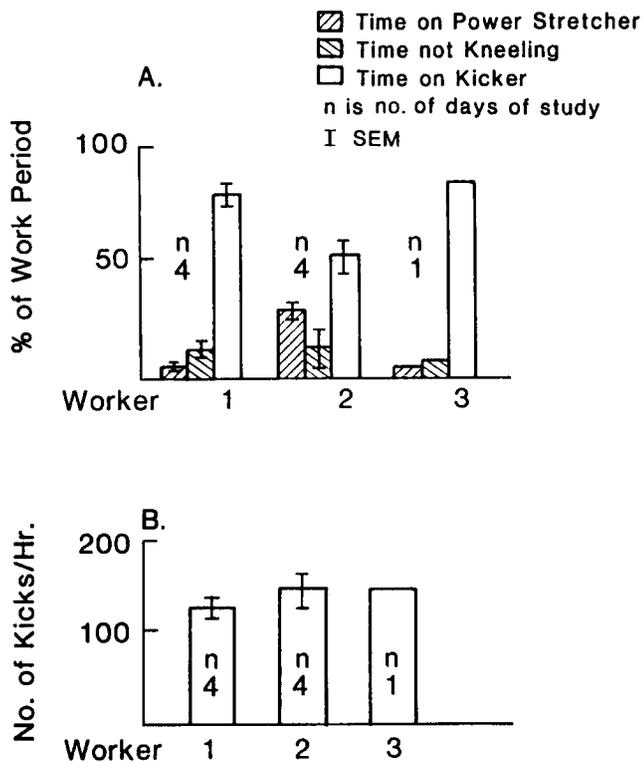


Fig. 4 A: Task analysis data from three workers performing the carpet stretching job; the data show mean \pm SEM
 B: Data for number of kicks/hour applied by three workers

A CIL index/hr was computed for one of the workers using the knee-kicker. His average kicks per hour value was 129 and the average of light and hard kick impact force value was 2034N. After normalising (dividing by 100,000), the CIL value for the worker was 2.6. Similar analysis on workers 2 and 3 was not possible since they were not available for impact force measurement. More workers need to be tested to ascertain what constitutes a critical or hazardous CIL level. The assumption in these calculations is that the average impact force-value for a worker is representative of his impact force values over the entire working period. A more rigorous procedure would include a time weighted average of light and hard kick forces for the calculations of CIL index to provide a general indicator of cumulative loading.

3. Body postures associated with knee-kicking activity

Fig. 5A-B illustrates typical postural changes associated with the knee-kicking cycle. The sketches shown in Fig. 5A were extracted from the sequential frames obtained from the films. During the preparatory phase of the knee-kick motion, the entire weight was essentially sustained by the left knee, left leg and left arm. The right leg (the kicking leg) stayed airborne most of the time except when it impacted the knee-kicker. Fig. 5B shows the angular displacement data, recorded from a worker (No 1), associated with the knee and hip angles illustrated in Fig. 5A. During the first part of the kicking cycle, the knee was partially flexed, about 145° (subtended angle), while the hip angle was the highest, nearly 155° . As the knee approached the kicker, the knee and hip angles decreased rapidly and the upper

torso began moving up, away from the floor. At the instant of impact, the knee and hip angles were at their lowest values, about 60° and 100° , respectively. The upper torso was slightly flexed on impact, but remained relatively parallel to the floor throughout the kicking motion. The duration of knee contact with the kicker at impact averaged 0.045 s (SEM = 0.0023) and the total kick cycle averaged 1.6 s (SEM = 0.19). Most of the body displacement was in the horizontal direction, about 70% more than in the vertical direction. Table 2 presents average data of knee flexion and extension angles from five workers.

4. Impact acceleration of lower extremity

Table 2 shows the average impact acceleration data. Workers were asked to kick several times lightly or about at one-half maximum. This was followed by a request to kick hard or near the maximum. For six of the seven workers, the hard kick produced acceleration values near or above the maximum limit of the accelerometer (± 20 G or $\pm 196.2\text{m/s}^2$), whereas, for the light kick, the average impact acceleration was 12.3 G (121m/s^2). Since the acceleration values for the hard kick were above the maximum limit of the transducer for the majority of workers, it was difficult to determine the true acceleration values and these data therefore were not used for subsequent analysis.

A representative waveform of impact acceleration for one worker (No 6) is shown in Fig. 2A. The acceleration of the kicking leg approaches +2G (19.6m/s^2) before it hits the pad of the kicker. On impact the knee decelerates, which is represented by the sharp drop in the absolute value, which is followed by a negative acceleration impulse.

5. Impact knee forces

Impact forces from our workers who were instructed to kick light (half-maximum) and kick hard (full-kick), are shown in Table 2. For the hard kick, values averaged 3019 N, or about four times body weight, whereas for the light kick they averaged 2469 N, three times body weight. The large variability, which exceeded 10% of the mean, was due to differences in the kicking style and the inertia of the worker's kicking leg. The force measuring instrument was not used to record the duration of impact force.

Discussion

The job of installing carpet requires that some workers spend as much as 75% of their time in the kneeling position with postures requiring near-maximum knee flexion. Knee-flexion angles (subtended) of workers at impact averaged about 58° , which implies that their knees were considerably more flexed than is required during activities of daily living. For example, sitting, tying shoe laces and walking upstairs require knee flexion angles (subtended) of only 87° , 74° , and 97° , respectively (Lubenthal *et al.*, 1972). Moreover, even lifting objects with bent knees, as required in many manual materials handling jobs, requires a knee flexion angle (subtended) of only between 65 and 60° (Lubenthal *et al.*, 1972).

Ariel (1974) showed that knee-flexion beyond 60° (subtended) produced shearing forces that strained ligaments. Trent *et al.* (1976) found that the cruciate ligaments increased in length by up to 6 mm between full-extension and 75 degrees of flexion, which approaches the ligament's

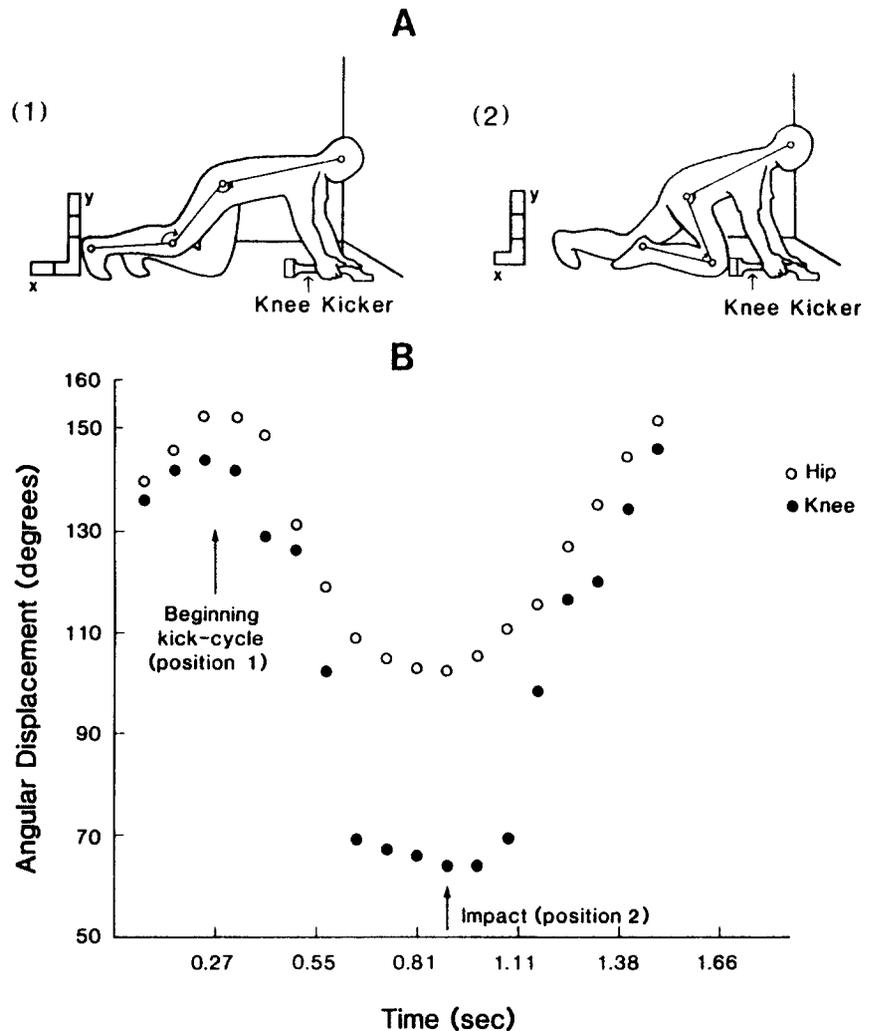


Fig. 5 A: Typical postural changes associated with the knee-kicking cycle
 (1) Beginning kick cycle, and
 (2) Impact kick cycle
 B: Angular displacement data recorded from one worker associated with the knee and hip angles during one kicking cycle. These are subtended angles

rupture value of 10 mm. These values may underestimate the potential ligamentous trauma among carpet layers since data do not include the inertial effects of dynamic aspects of knee-kicking.

The average maximum value of the impact knee-force found in this study is about 41% of the compressive strength of the knee joint along the long axis. According to Bargren *et al* (1978) the maximum compressive strength of the knee joint is about 7300 N. Previous investigators including Maquet (1976) and Radin and Paul (1971a) have suggested that articular stresses frequently exceeding the resistance capacity of bone and cartilage tissues may induce osteoarthritic lesions.

During the impact phase, abnormal load bearing conditions could develop in some workers, depending upon the position of the femur and the tibia. For example, if the impact force from kicking acts eccentrically at the articulating surface, the pressure distribution on the cartilage may be uneven, which provides a condition conducive for developing osteoarthritis (Maquet, 1976). Alternatively, the impact force may act laterally causing eccentric squeezing of the patella against the femur. The latter condition of localised stress is associated with the development of bone osteophytes, destruction of cartilage and narrowing of joint spaces.

Previous researchers (Radin and Paul, 1971a) have shown that periodic impact-loading causes more rapid damage to

the cartilage than that produced by static loading. An explanation offered by Sokaloff (1963) and Radin and Paul (1970) and Radin (1976) is that the visco-elastic properties of the cartilage are not effective for attenuating impulsive loads. The major difference between the impact load and the static load lies in the time constants of force applied. For the impact loading, the time constant of the force produced is of such length that the damping properties of the subchondral bone, which have been implied to protect the cartilage, is potentially ineffective (Radin and Paul, 1971b). Hence, high compressive load-induced squeezing of cartilaginous interstitial fluid cause significant cartilage surface contact and accelerate wear.

A main recommendation for reducing knee trauma from carpet installing is to educate workers to the potential for knee injury and encourage them to use the hand-power stretcher. Newer models of knee-kickers are available that are less cumbersome to use. Improved work practices are also needed that include rotating the job of stretching carpet among more members of the work crew and encouraging the use of knee-cushions or protectors (Bhattacharya *et al*, 1985).

An improved knee-pad has been suggested by Ekstrom *et al* (1981). The knee-pad has a large pocket sewn on the trouser legs in front of the knee. One or two sheets of elastic material must be placed in the pocket. The material should be flexible, light in weight, have good insulation

Table 2: Kinematic and kinetic data (mean \pm SEM) associated with carpet stretching activity

Knee flexion Δ extension angle (degrees)		Impact force* (newtons)		Impact acceleration (G)	Time required per kicking cycle or kick (sec/kick)
Beginning kick	Impact	Light kick	Hard kick	Light kick \dagger	
128.4 \pm 23	57.4 \pm 5	2469 \pm 271	3019 \pm 240	12.3 \pm 1.3	1.6 \pm .19
(N = 5)	(N = 5)	(N = 4)	(N = 4)	(N = 5)	(N = 5)

Δ See Fig. 5 and text for the definition of beginning and impact kick cycle. The angles are the subtended angles.

* Values are the averages of three kicks/worker.

\dagger Values are the average of three to seven kicks/worker. Seven workers participated in this study but only five workers' data were considered light. The remaining two consistently produced only hard kicks. The hard kick produced acceleration values above the maximum measuring limit of the accelerometer.

properties and not absorb moisture. Ekstrom recommends the use of flexible cellular plastic with closed cells of approximately 2 cm thickness to distribute the pressure.

In summary, the results indicate that the job of installing carpet requires combinations of posture, force, acceleration and repetition that are biomechanically-demanding, and thereby pose a high risk of knee dysfunction. Clearly, there is a need for further research in the biomechanics of occupational knee injury. Such studies, however, should endeavour to include roentgenographic data to determine the location of the trauma at the tibio-femoral joint and medical/clinical diagnostic data to identify the nature and degree, if any, of pathological knee conditions among carpet layers. By comparing the actual medical and diagnostic information data with a measure of hazard exposure for each worker, such as computed from a measure of cumulative index loading, the etiological basis of carpet layer's knee can be further clarified.

References

Ariel, B.G.

1974 Biomechanical analysis of the knee joint during deep knee bends with heavy load. In R.C. Nelson and C.A. Moorehouse, *Biomechanics IV*, University Park Press, pp 44–52.

Armstrong, T.J.

1983 An ergonomic guide to carpal tunnel syndrome. Amer Indust Hyg Assn Monogram.

Bargren, J.H., Day, W.H., Freeman, M.A.R., and Swanson, S.A.V.

1978 *J Bone Joint Surg (Br)*, **60B**, 256–261. Mechanical tests on the tibial components of non-hinged knee prosthesis

Bhattacharya, A., McCutcheon, E.P., Shvartz, E., and Greenleaf, J.E.

1980 *J Appl Physiol: Respirat Environ. Exercise Physiol*,

49.5: 881–887. Body acceleration distribution and O_2 uptake in humans during running and jumping.

Bhattacharya, A., Putz-Anderson, V., and Habes, D.

1985 American Industrial Hygiene Conference, Las Vegas, NV. Preliminary guidelines for the development of work practices procedures for carpet layer's job.

Ekstrom, et al

1981 *Bygghalsan Bulletin*. The kneeling working posture – aspects on occurrence of symptoms, pressure patterns and knee protection materials, Oreboro, Sweden.

Laubenthal, K.N., Smidt, G.L., and Kettelkamp, D.B.

1972 *Physical Therapy*, **52.1**, 34–43. A quantitative analysis of knee motion during activities of daily living.

Maquet, P.G.J.

1976 *Biomechanics of the knee: with application to the pathogenesis and the surgical treatment of osteoarthritis*. Springer-Verlag, New York.

NIOSH

1981 Work practices guide for manual lifting, DHHS (NIOSH) Publication No 81–122.

Putz-Anderson, V., and Frederick, L.J.

1983 Amer Indust Hyg Conference, Philadelphia. Repetitive trauma to the knee: An overview.

Radin, E.L.

1976 *Bulletin on the Rheumatic Diseases*, **26.7**, 862–865. Mechanical aspects of osteoarthritis.

Radin, E.L., and Paul, I.L.

1970 *Arthritis and Rheumatism*, **13.2**, 139–144. Does cartilage compliance reduce skeletal impact loads?

Radin, E.L., and Paul, I.L.

1971a *Arthritis and Rheumatism*, **14.3**, 356–362. Response of joints to impact loading, I. In vitro wear.

Radin, E.L., and Paul, I.L.

1971b *Clin Orthop*, 78, 342-344. Importance of bone in sparing articular cartilage from impact.

Sokoloff, L.

1963 *Science*, 141, 1055. Elasticity of articular cartilage.

Tanaka, S., Smith, A.B., Halperin, W., and Jensen, R.

1982 *The New England Journal of Medicine*, 307.20, 1277. Carpet-layer's knee.

Trent, P.S., Walker, P.S., and Wolf, B.

1976 *Clin Orthop*, 117, 263. Ligament length patterns, strength and rotational axes of the knee joint.

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