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Electromyographic patterns associated with a carpet installation task

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Previous studies have indicated that the knee joint is subject to impact forces greater than 3000 newtons when workers use a knee-kicker to install carpet. Such forces may be modified, however, by the action of large muscle groups in the legs and upper body. To evaluate the role of these key muscle groups, electromyographic (EMG) data were collected from the rectus femoris, long head of the biceps femoris, anterior deltoid, and extensor carpi radialis muscles of eight male subjects. Each subject simulated the four static body postures most commonly used during carpet installation. These were (*a*) on hands and knees, (*b*) beginning kick cycle, (*c*) mid-kick cycle and (*d*) impact kick cycle. To assess the dynamic component of the task, each subject performed the act of carpet stretching using a knee-kicker. For both static and dynamic activities, the anterior deltoid showed the highest normalized EMG values. It was also found that immediately before the impact phase the knee flexor muscles contracted, and it appears that such muscle activity in conjunction with activities (not measured in this study) of other hamstring muscles, facilitates development of an optimal blow to the kicking tool. Finally, the results seemed to support the recommendation that forward body movement post-impact phase be minimized in order to reduce excessive activity of the shoulder flexors.

1. Introduction

A variety of occupations require the use of the leg in the performance of jobs. Historically, two major types of occupationally-related lower extremity injuries have been identified, i.e. 'beat knee' and 'housemaid's knee' (Atkins and Marks 1952). The beat knee is prevalent among miners who work in low seam mines, and is characterized as a mixture of cellulitis and bursitis over the kneecap. Housemaid's knee is described as prepatellar bursitis. While miner's beat knee and the housemaid's knee were reported in the early literature, recent studies have focused attention more on knee disorders among carpet layers, tile setters and floor layers (Bhattacharya *et al.* 1985 b, Ekstrom *et al.* 1981). Of these, carpet layers have a morbidity ratio (percentage of claims/percentage of total work force) of 107·8, which is twice that of tile setters and general floor layers (Tanaka *et al.* 1982).

Studies reported from our laboratory (Mueller and Bhattacharya 1984, Bhattacharya *et al.* 1985 a) have found that the job of installing carpet requires that some workers spend as much as 75% of their time in the kneeling position with postures

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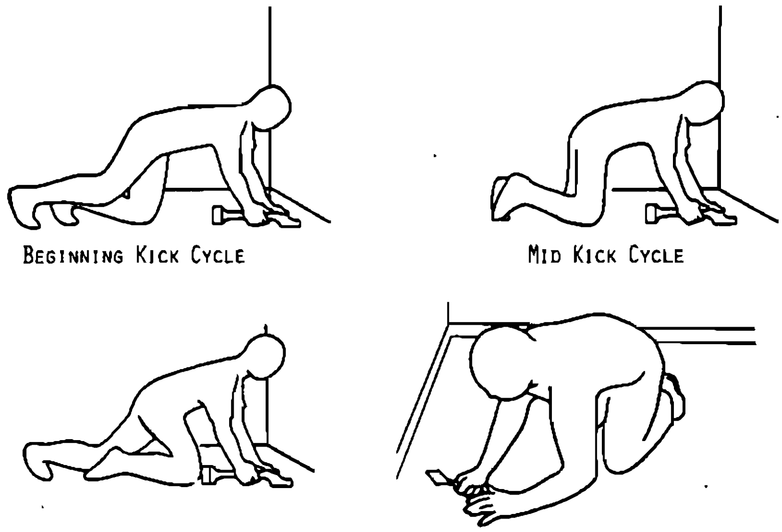

Figure 1. Body postures commonly used in the carpet installation task.

requiring near maximum knee flexion. In addition to kneeling, these workers use their knee as a power source to impact a tool called the knee-kicker to stretch and install carpet. On average, these workers were found to produce an impact force of 3000 newtons (N) at a repetition rate of 140 kicks per hour (Bhattacharya *et al.* 1985 b).

The results from our previous studies (Bhattacharya *et al.* 1985 a, b, Mueller and Bhattacharya *et al.* 1984) have implied that the carpet installation task can produce substantial biomechanical loading on the musculoskeletal system, particularly the knee joint. Furthermore, the carpet stretching task requires vigorous movement of the body in the sagittal plane producing undue demand on most of the major muscle groups (figure 1). During the various phases of the carpet installation task, certain muscle groups are more active than others. Furthermore, these muscular activity patterns modify the biomechanical loading of the joints.

The purpose of the present study was to determine the electromyographic activity patterns associated with typical static postures and dynamic activities of the carpet installation task.

2. Methods

Eight male subjects (mean body weight: 64·4 kg $\pm$ 9·3 standard deviation (s.d.) and mean height: 173·4 cm $\pm$ 9·3 s.d.) were chosen from the University community. Each subject was given a thorough physical examination and health history check up. Anyone with the presence or history of musculoskeletal disorders was excluded from the study.

2.1. *Task*

Subjects' maximum muscle strengths were measured for the following muscle groups: right-arm wrist extensors (extensor carpi radialis), shoulder flexors (anterior deltoid), right-leg knee extensors (rectus femoris), and knee flexors (biceps femoris). The muscle of interest involved in each of these exertions is in parenthesis. The subjects were asked to simulate the four static body postures most commonly associated with the carpet installation task (Bhattacharya *et al.* 1985 a). These postures were: (*a*) on hands and knees, (*b*) beginning kick cycle, (*c*) mid-kick cycle and (*d*) impact kick cycle (figure 1). Finally, subjects were required to perform the act of carpet stretching using the carpet layer's main tool, a knee-kicker. All simulations took place at our specially developed carpet installation facility.

2.2. *EMG recording procedure*

We were interested in investigating the activity patterns of some of the relevant muscle groups of the right-side upper and lower limbs. Electromyography (EMG) was used to measure the muscular activity patterns. The EMG signals were detected by standard size Beckman surface electrodes which were applied to the skin using a monopolar arrangement. The electrodes were placed in a straight line over the belly of the muscle, the ground electrode in the middle, and the active and reference electrodes on either side. The approximate placement of the electrodes for each muscle group is as follows: over the belly of the rectus femoris for the knee extensor muscle group; on the long head of the biceps femoris for the knee flexor muscle group; over the belly of the extensor carpi radialis longus for the wrist extensors; and on the belly of the anterior deltoid for shoulder flexor group. The inter-electrode distances were 3 cm for the extensor carpi radialis and the anterior deltoid and 4 cm for the rectus femoris and the long head of the biceps femoris muscle groups. The electrodes were carefully taped down to the skin with micropore tape which minimized relative movement between the electrode and the skin. Before applying the electrodes, the skin was shaved and then cleaned with isopropyl alcohol swabs (Becton-Dickinson, Rutherford, NJ) to redness in order to lower the skin resistance. Generally, 15–30 minutes elapsed between the application of electrodes and the beginning of the experiment. This delay aided in stabilizing the skin resistance and obtaining noise-free EMG signals. The EMG signals were amplified by Beckman EMG couplers (Model 9852A; Sensormedics, Inc., Anaheim, CA) connected to Beckman R511A and R611 Dynographs (Beckman Instruments, Inc., Schiller Park, IL) and were recorded on a Hewlett Packard (Model 3960, Hewlett Packard, San Diego, CA) FM instrumentation tape recorder. These EMG couplers, which in the direct mode provided the raw EMG signal, have a flat frequency response between 5·3 and 1000 Hz. Each channel of the dynograph was calibrated with a 1 mV signal. The corresponding deflection was recorded on the chart paper. The four channels of direct EMG signals were simultaneously fed into another set of Beckman EMG couplers set in the average mode. In the average mode these couplers provide a linear envelope of full-wave rectified EMG signal. The cut-off frequency of the linear envelope detectors is 6·25 Hz. The linear envelope of full-wave rectified EMG signal for each muscle was used for data analysis.

2.3. *Strength measurements*

Dynamometry was used to measure the maximum isometric muscle strength values. For testing the maximum isometric strength of the knee extensor, the subject sat upright on a specially designed table which allowed positioning of the thigh at an angle of 90° with respect to the shank segment while the hip was at an angle of 90° flexion. The subject was instructed to extend the knee maximally and hold for about 3 seconds while maintaining his torso in the upright posture. This voluntary maximum extension force was measured using a load cell (SM-1000 Interface, Inc., Scottsdale, AZ) with one end attached to an immovable object and the other to the ankle via a cuff.

For testing the knee flexors, the subject lay down in the prone position on the platform with an angle of 90° between the thigh and the shank. In this case the subject was instructed to attempt to flex the knee maximally for 3 seconds. A load cell at the ankle level measured the maximum strength value.

The strength of the shoulder flexors was tested with the subject sitting upright on the same platform with a 90° elbow angle. The shoulder position was neutral for this test. A cuff attached to the upper elbow region was connected to a load cell which in turn was attached to an immovable object. The subject was instructed to attempt to flex the shoulder joint by moving the upper arm forward in the sagittal plane maximally without moving his upper torso forward. As with the other strength tests, the exertion was maintained for about 3 seconds.

The wrist extensor strength was determined with the subject sitting on a chair with his right forearm in the prone position resting (without hand) on a table so that the hand could extend freely against an immovable object placed vertically on the floor. A load cell was attached in between a chain connecting the immovable object to a handle held by the hand. For this test the subject was instructed to attempt to extend his wrist maximally for about 3 seconds.

All the strength tests were repeated three times and the strength data (from the load cell) were recorded on a Gould 2600 series (Gould Instrument, Inc., Cleveland, OH) chart paper recorder via transducer amplifier (Gould Model 13-4615-50). The frequency response of the amplifier was flat between d.c. and 1 KHz, and 60Hz for the recorder. The pen rise time for a full-scale deflection on the recorder was less than 5 ms. During these tests, EMG data were also recorded. At the end of the above-mentioned strength tests the subject was required to perform the static and dynamic activity as explained in the section 2.1. During these tests, EMG signals were continuously recorded. The baselines for EMG signals were obtained by having the subject sit quietly on a chair.

3. Data analysis

The schematic presented in figure 2 illustrates the EMG data analysis procedure used in this study. This procedure was based upon methods presented in the literature (Winter 1979). The maximum average EMG value (figure 2) during the static strength testing was taken as the 3-second average of the steady-state region of the linear envelope of full-wave rectified EMG signal. The force waveforms (force versus time) associated with static strength testing were also analysed using the above-mentioned

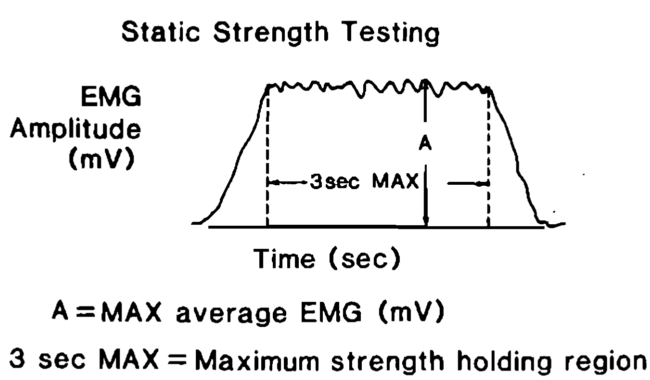

Figure 2. Drawing showing electromyographic data analysis procedure for static testing.

procedure. The results presented are the average of three consecutive strength tests. For a comparison of levels of muscle activity between different muscles and different postures, the EMG data are presented as percentages of the EMG activity obtained during an isometric maximum voluntary contraction test. Similar methods for reporting EMG data can be found in the literature (Ekholm *et al.* 1985).

4. Results

Figure 3 shows examples of waveforms for muscle strength, direct EMG, and the linear envelope of rectified EMG associated with the maximum isometric strength testing of the knee extensor muscle group from one subject. Similar waveforms were also obtained from the strength testing of the remaining muscle groups. The table shows mean ± s.d. data for the maximum isometric strength testing. The isometric muscle torque values for the knee flexors were comparable to that (35·4 Nm) reported by Schmidt (1973). However, the values for knee extensors were lower than those reported (102 Nm) by Schmidt (1973). These lower strength values can be explained in part by the fact that the subjects weighed (mean BW: 64·4 kg) less than the subjects (mean BW: 82 kg) tested by Schmidt (1973). Some of these discrepancies could also be related to differences in subject positioning during strength testing.

All subjects showed negligible EMG activity when they assumed the static posture of being on hands and knees. For the remaining three static postures of knee-kicking the results were different for different muscles (figures 4 and 5). For the beginning kick

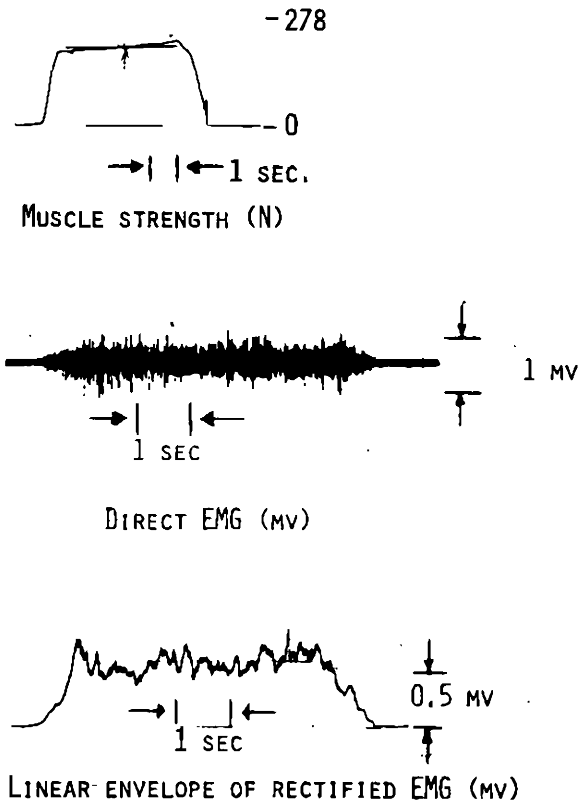

Figure 3. Example of raw data from maximal isometric strength testing (quadriceps muscle group).

Electromyographic and dynamometry data from maximum isometric strength testing.

Parameters Mean ± s.d.	Knee extensors	Wrist extensors	Shoulder flexors	Knee flexors
Muscle torque (Nm)	78·3 ± 35·6	7·8 ± 1·9	24·5 ± 5·8	35·5 ± 9·2
Maximum EMG (mV)	0·49 ± 0·2	1·5 ± 0·7	0·82 ± 0·3	1·13 ± 0·4

cycle, the EMG activity was present in the knee extensors, the knee flexors and the shoulder flexors. For the mid-kick cycle posture, the knee extensors showed very little EMG activity while the knee flexors and the shoulder flexors were dominant for all subjects. This pattern was more or less maintained for the shoulder flexors and the knee extensors for the final impact phase, while the knee flexors' activity reduced significantly at the point of impact. The wrist extensor muscles showed negligible activity for all the postures.

Most of the above-mentioned EMG activity patterns of static postures were also evident in dynamic knee-kicking activities. These are shown in figure 6. During dynamic activity at the beginning kick cycle, generally the knee extensors were most active in all subjects. In this phase, minor shoulder flexor activities were also present in some subjects. During the mid-kick cycle phase, the knee flexors showed some activity and the shoulder flexors also showed activity as the body moved forward.

Finally, just before the impact phase, the knee flexors and the shoulder flexors were most active. The only muscles which continued to be activated during the post-impact phase were the shoulder flexors. For the dynamic task the EMG activity of the three muscle groups was present for only a portion of the kicking cycle. On the average, for the eight subjects, these fractions of total cycle time (i.e. time interval between successive impacts) were: knee extensors, 35%; shoulder flexors (before impact), 23%; shoulder flexors (after impact), 30%; and knee flexors (before impact), 31%. In figure 6 the spikes appearing in the knee flexor and extensor EMG waveforms are due to impact artifact. Due to the presence of this impact artifact the dynamic EMG data is presented as raw EMG waveform for describing the muscular activity patterns.

5. Discussion

The carpet installation task requires the use of awkward body postures which are not commonly used in other occupations and/or in daily activities. The most common static posture utilized by the carpet layers is the hands and knees posture. In this position the entire body-weight is supported by the four limbs. In the laboratory simulation study, the body-weight was symmetrically distributed over the limbs which accounts for most of the muscles investigated being practically quiescent (figure 4).

The beginning kick cycle posture produced uneven loading on the body's musculoskeletal system. This posture required the subject to extend his kicking leg, although the amount of extension was not controlled. For professional carpet layers, the knee joint angle (subtended) at beginning kick cycle is about 128° (Bhattacharya *et al.* 1985 b). Since the subjects were maintaining the leg in the semi-extended posture without any support, both flexor and extensor activities were observed. As the subject assumed the mid-kick cycle posture, the body moved forward which increased shoulder flexor activity, and since the kicking leg was in the flexed position the knee flexors were

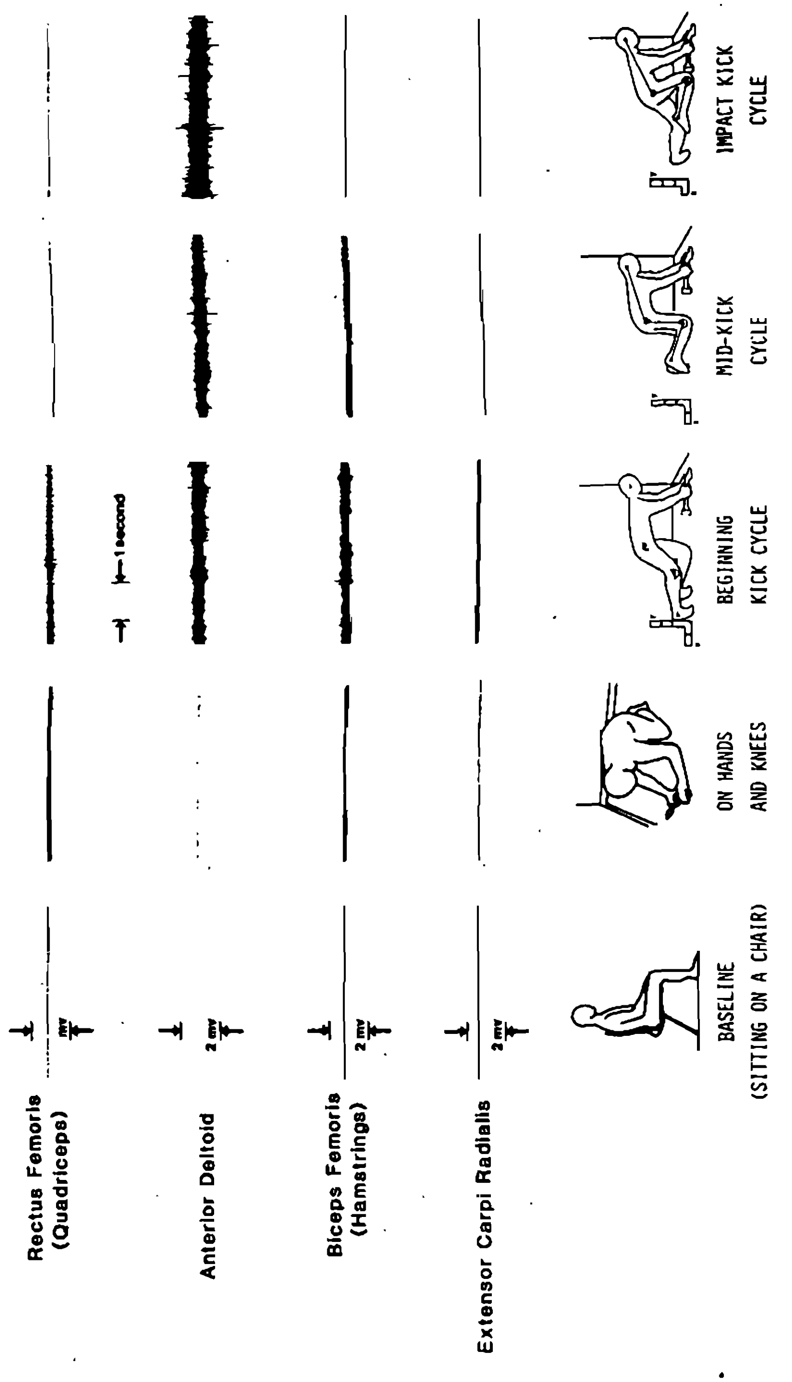

Figure 4. Raw electromyographic data associated with static postures of carpet installation task.

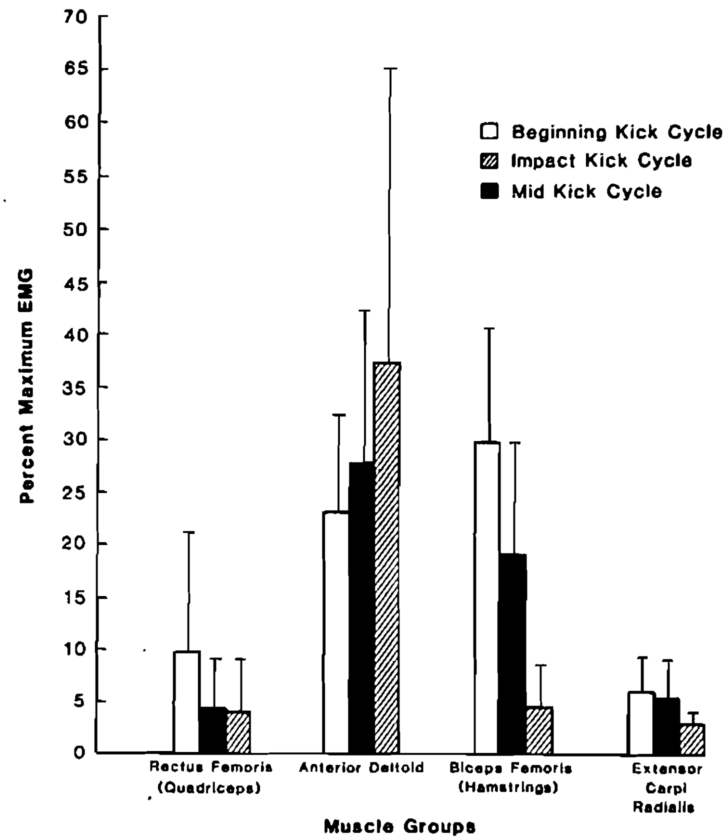

Figure 5. Percentage maximum EMG from static body postures commonly used in the carpet installation task. Bars show standard deviations.

more active than the extensors. In the impact static posture the whole body was in the extreme forward position which produced the most shoulder flexor activity. Since the impacting knee was essentially resting on the ground (or the kicker pad) while the leg was in this posture, the extensor and flexor activities were minimal.

The above static postures comprising the knee kicking task provided a step by step simulation of a very vigorous dynamic act. Generally, the muscular contraction patterns observed during static postures were similar to those occurring during actual dynamic kicking activity. However, in the dynamic kicking activity testing, we obtained a clearer illustration of the transfer of muscular activity patterns from some groups of muscles to others as the body moved from beginning kick cycle to impact phase (figure 6). Specifically, it was observed that in the beginning kick cycle phase, the subject moved so far backward that the entire body-weight was essentially resting on the left knee, resulting in practically no shoulder flexor activity. Immediately prior to the impact phase, the kicking leg was flexed, which was due to knee flexor and hip extensor (not measured) actions of the hamstrings. Just prior to actual impact, knee flexor muscular activities were observed (figure 6). In appears that such knee flexor activities in conjunction with activities of other (not measured in this study) hamstring muscles, facilitate development of an optimal blow to the kicking tool. The observed flexor activity at the point of impact may very well increase the joint stresses in addition

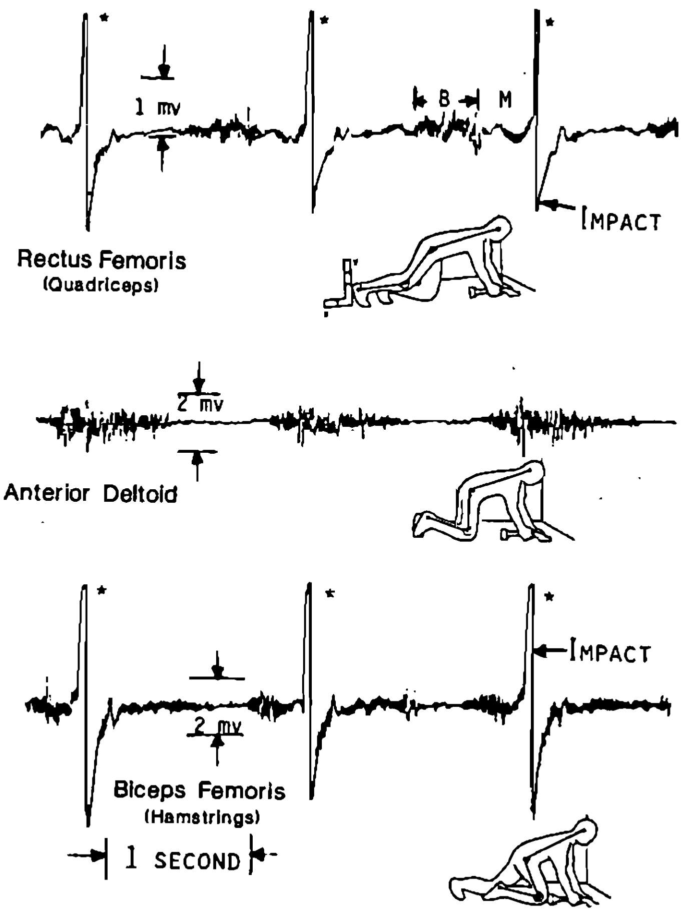

Figure 6. Raw EMG pattern associated with carpet stretching task. B, Beginning kicking cycle; M, mid-kicking cycle. *These spikes refer to impact artifact.

to what is already created by the excessive impact force of the kicker tool (Bhattacharya *et al.* 1985 b).

During the impact phase, due to a vigorous blow by the suprapatellar region of knee, there was an impact artifact in the EMG waveform from the knee flexors and the extensors. However, since the leg was in the flexed position during this phase, it is reasonable to assume that at least the knee flexors were activated. The shoulder flexor activities were present at all times during the impact phase (figure 6). Following the impact, the whole body moved further forward (with knee in the flexed position) for a while as indicated by continued shoulder flexor activity (figure 6). After this event, the body moved backward and the knee extended to the beginning kick cycle posture. Of the four muscle groups studied during dynamic activity, the shoulder flexors were active for the greatest portion of the kicking cycle. The static postures produced peak muscular activity values in the range of 3 to 37% of the maximum isometric value (figure 5). For the static postures, the shoulder flexors showed the highest overall activity values. This level of muscle activity for static postures may be endured for 10 minutes without muscle pain (Okada 1973). However, repeated exposure may bring about shoulder discomforts. These shoulder flexor activity levels are consistent with the finding in preliminary medical screening data from carpet layers that shoulder pain complaints are numerous. It is important to note, however, that carpet layers perform activities other than carpet stretching, such as carrying rolls of carpet, that could account for shoulder pain.

The data also appear to support the recommendation that while knee-kicking, the forward body movement post-impact phase should be minimized (Bhattacharya *et al.* 1985 c). In our field studies (Bhattacharya *et al.* 1985 b) we have observed that the experienced carpet layers rarely move their body forward after the impact phase. Furthermore, during the carpet stretching task they also avoid unnecessary extension and flexion of their knee joints, which might minimize undue strain to the musculature. On the other hand, less experienced workers (seven years of experience) were found to utilize excessive whole-body motion, thereby producing inordinate demand on the relevant muscle groups. Based on their observed movement patterns, the subjects in our laboratory simulation group appear to fall into a naive or new worker group.

The EMG activity patterns presented here could be valuable in determining the modifying influence of muscle contractions on the joint loading. This modifying effect is influenced by such factors as the muscle moment arm changes with respect to joint flexion-extension angles, line of action of the muscle, and the muscle moment values of the joint.

In summary, the availability of muscle activity patterns data aids in identifying muscle groups which are most affected in the performance of the carpet installation task. These data contribute toward developing recommendations regarding work practices for carpet installers (Bhattacharya *et al.* 1985 c). Finally, the results may help identify the role of appropriate muscle groups in the development of knee-joint and/or shoulder-joint muscle models for the carpet stretching task.

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Des études antérieures ont montré que l'articulation du genou peut subir des forces d'impact supérieures à 3000 newtons lorsque des ouvriers utilisent un tendeur pour genoux pour installer une moquette. Ces forces peuvent cependant être modifiées par la mise en oeuvre de groupes de grands muscles de la jambe et du corps. Afin d'évaluer le rôle de ces muscles-clés, on a recueilli des données électromyographiques (EMG) sur le muscle droit antérieur de la cuisse, sur la portion longue du biceps crural, sur le deltoïde antérieur et sur le muscle deuxième radial externe. Huit sujets hommes ont participé à l'expérience. Chacun d'entre eux a simulé les quatre postures statiques du corps les plus utilisées lors de l'installation d'une moquette. Celles-ci étaient (*a*) sur mains et genoux, (*b*) début d'un cycle de tension, (*c*) milieu du cycle et (*d*) phase d'impact du cycle. Afin d'analyser la composante dynamique de la tâche, chaque sujet a réalisé l'opération de tension de la moquette à l'aide du tendeur. Les valeurs normalisées de l'EMG les plus élevées sont apparues dans le deltoïde antérieur à la fois pour les opérations statiques et pour les opérations dynamiques. On a également observé qu'immédiatement avant la phase d'impact les muscles fléchisseurs du genou se contractaient et il est apparu qu'une telle activité musculaire conjugée

avec les activités d'autres muscles du jarret (non mesurées dans cette étude) facilite le développement du coup optimal sur le tendeur. Finalement, ces résultats semblent confirmer la recommandation qu'on peut minimiser le mouvement vers l'avant du corps lors de la phase post-impact, afin de réduire l'activité excessive dans les fléchisseurs de l'épaule.

Bereits vorliegende Studien weisen darauf hin, daß das Kniegelenk Kräfte aufbringen muß, die über 3000 N liegen können, wenn bei der Teppichverlegung von den Arbeitern Kniestößel benutzt werden. Diese Kräfte dürften auch durch Aktivierung großer Muskelgruppen der Beine und des Oberkörpers entstehen. Um die Funktion dieser Schlüsselmuskeln abschätzen zu können, wurden elektromyographische Daten (EMG) des m. rectus femoris, des langen Kopfes des m. carpiradialis bei 8 männlichen Versuchspersonen gesammelt. Alle Versuchspersonen simulierten die bei der Teppichverlegung am häufigsten vorkommenden statischen Körperhaltungen. Im einzelnen waren das (*a*) Stützen auf Hand und Knie, (*b*) beginnende Kick-Phase, (*c*) mittlere Kick-Phase und (*d*) Stößel Aufschlag Phase. Um die dynamische Komponente der Arbeitsaufgabe bewältigen zu können, führten alle Versuchspersonen das Teppichstrecken mit Hilfe eines Kniestößels durch. Sowohl bei statischer als auch bei dynamischer Arbeit zeigte der m. anterior deltoideus die höchstem EMG-Standard-Werte. Es wurde weiterhin gezeigt, daß unmittelbar vor der Aktivationsphase der Kniebeugemuskel kontrahiert. Dies scheint zusammen mit weiteren interaktiven Muskeln, die hier nicht gemessen wurden, die Entwicklung eines optimalen Bewegungsablaufs zu erleichtern. Letztlich scheinen die Ergebnisse den Vorschlag zu festigen, daß eine Körperfrontalbewegung direkt nach der Kraftaufbringungsphase zu minimieren ist, um übermäßige Aktivität der Schulterbeugemuskeln abzubauen.

今までの研究においてじゅうたんを敷くために作業者がニーキッカーを用いた時には膝関節に3000ニュートン以上の力が加わることが示されている。しかし，この様な力は下肢と上半身の大筋群の働きによって緩和される。これらの筋群の役割を評価するために，8名の男性被験者の大腿直筋，大腿二頭筋頭部，前三角筋，及び橈側手根伸筋からの筋電図を測定した。各被験者にじゅうたん敷き作業で良く用いられる4種類の模擬的な静的姿勢をとらせた。各姿勢は，(a)四つんばいの姿勢，(b)蹴り出しの姿勢，(c)蹴る中間姿勢，そして(d)蹴り込んだ瞬間の姿勢の4つである。作業の動的成分を評価するために各被験者にニーキッカーを用いたじゅうたんの引き延ばし作業を行わせた。静的活動及び動的活動の両方において，前三角筋が最も高い筋電活動を示した。また，衝撃を加える直前において膝の屈筋が収縮していることがわかった。この様な筋活動は他の膝屈曲筋等（本研究では測定しなかった）の活動と関連して蹴る道具に最適な衝撃を与える助けをしている様である。最後に，肩の屈筋の過度の活動を減じるためには衝撃を加えた後の体の前方への動きを最小限に止めるべきであるという考えが実験結果より支持されよう。

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