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The effects of mats on back and leg fatigue

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Prolonged standing is common in many industrial workplaces. It is also quite common for workers to complain of discomfort in the back and legs as a result of prolonged standing. Mats are often provided for the worker to relieve this fatigue. However, there is no quantitative evidence that these mats relieve leg and back fatigue. Five subjects were asked to stand on a concrete surface and two mat surfaces for prolonged periods of time. Spectral electromyographic analyses indicated that mats reduced localized muscle fatigue in the erector spinae muscle only. Furthermore, this fatigue reduction occurred only with the more compressible of the two mats tested. These results imply that localized muscular fatigue in the leg may not be relieved with 'anti-fatigue' mats, and some of these mats only benefit the back.

Keywords: Muscle fatigue, low back, lower extremity, electromyography, standing, floors

Introduction

Prolonged standing to perform work tasks is common in industry. Ryan (1989) studied musculoskeletal symptoms in supermarket workers and found that the highest prevalence of discomfort was reported for the low back, which occurred mostly in the checkout department where workers stood 90% of the time. Discomfort complaints for the legs and feet were also high, which endorses reports from other industries (Avers, 1991). For at least a couple of decades there has been documentation of the high incidence of low back pain in people who stand every day for four or more hours (Magora, 1972). Low back pain is common, afflicting about 85% of people during their lives (Spengler *et al*, 1986), and it is very expensive to industry, incurring an estimated compensatable cost of $11.1 billion for one year (Webster and Snook, 1990). However, in industry prolonged standing tasks persist, sit/stand work areas are unusual and cardboard is still frequently seen under workers' feet.

The variety of 'anti-fatigue' mats on the market has grown in recent years, which suggests that industry is attempting to address some of the reported physical problems of standing. Companies frequently ask about the effectiveness of mats, but results of investigations give conflicting information.

Psychophysical, physiological and biomechanical measures have been used to investigate the effects of flooring on lower-extremity symptoms during prolonged standing. Most of the studies included subjective discomfort ratings. Discomfort has consistently been reported to increase over time with standing, and generally appears to be greatest at the feet, becoming progressively less from the feet up (Redfern and Chaffin, 1988; Konz *et al*, 1990; Zhang *et al*, 1991). Konz *et al* (1990) found a significant difference between some mats and the concrete floor but only for discomfort ratings of the legs, not the low back and above. Some compressibility of a mat was subjectively preferable, as found by Redfern and Chaffin (1988), but they can also be too soft. However, Konz *et al* (1990) found that the best-rated mats were the least compressible. All the mats in the studies differed and cannot be accurately compared since compressibility data were not adequately reported.

There are contentions that much of the discomfort in the lower extremities during standing is from venous pooling rather than fatigue of the muscles (Brantingham *et al*, 1970; Winkel and Jorgensen, 1986; Konz *et al*, 1990). Significantly higher leg and foot skin temperatures and lower heart rates have been found for different floor surfaces (Rys and Konz, 1990), which supports the physiological basis of hampered circulation.

Body movement has been assessed by video recordings and force platform measures and has been found to be a sensitive measure of the effects of standing duration but a poor indicator of the type of floor. However, the test conditions should involve at least an hour of standing to see the effect (Zhang *et al*, 1991).

Electromyographic (EMG) studies by Basmajian (1979) indicated that postural alignment is primarily attained by activity in the soleus, iliopsoas, sacrospinalis and neck extensor muscles, but additional compensatory muscular activity was suggested by Zhang *et al* (1991) to

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overcome the natural postural swaying during standing, which was noted by Brantingham *et al* (1970). Zhang (1991) studied the anterior tibialis and gastrocnemius muscles but showed no fatigue effect, contrary to Kuorinka *et al* (1978). However, all the previous studies investigating fatigue through EMG evaluated the increased muscle contraction levels via processed EMG activity, which is a weak indicator of muscle fatigue. Marras (1992) points out that increased contraction levels, as measured by processed EMG activity, cause second-order effects in the signal spectrum that are not well documented by processed EMG. Evaluation of the EMG power spectrum, however, relates to first-order effects in the signal spectrum and is a much more reliable means of detecting localized fatigue.

Despite subjective reports of low-back discomfort with standing, and some relief from mats (Rys and Konz, 1989), Zhang *et al* (1991) did not record EMGs for the low back muscles. Since circulation effects contribute to lower extremity discomfort, EMG measurement of the lower back muscles may give differential information on the influence of floor surfaces on standing fatigue.

The choice of mats for a poultry processing environment is very limited because of United States Department of Agriculture (USDA) regulations and the extremely slippery nature of poultry fat. A thick black mat is commercially available whereas a thinner blue mat is not sold as matting but is often used as one. These mats have been used on a trial basis in a poultry processing plant and informal subjective feedback has found the blue mat to be less slippery and more comfortable. Often the black mat was reported as being ineffective in reducing body discomfort.

The purpose of this study was to assess objectively the physical effects of these two types of mat and a concrete floor while standing, and to determine which mats would be effective in reducing localized muscle fatigue in such environments.

Method

The approach used in this study was to use EMG power spectrum analysis of leg and lower back muscles to assess localized fatigue. Compensatory leg muscles of the anterior tibialis and gatrocnemius were studied, as well as the major trunk supporting muscle of the back, while subjects performed light work in a standing position.

Subjects

Two male and three female volunteers participated in this experiment. All of them were students, whose age ranged from 21 to 25 years. Their mean height was 169.3 cm (SD = 8.01) and their mean weight was 58.6 kg (SD = 11.3). They were all in good health and had no history of injuries or significant back or leg pain.

Experimental design

The experiment was designed to test fatigue-reduction effects when a subject was standing on a mat, compared with a concrete surface. Three different floor conditions were selected as independent variables: concrete; a thin blue mat (mat 1); and a thick black mat (mat 2). The sequence of testing different floor conditions was randomized.

Mat compression was measured with a MTS Bionix 858 servo hydraulic materials testing system. The foot pressure applied on the mat was estimated from the formula used by Konz and Subramanian (1989) and shown in Equation (1). Body weight was assumed to be 170 lb (77.3 kg).

$$\begin{aligned}\text{Pressure} &= 0.15 + 0.0026 \times \text{weight} \\ &= 0.35\ \text{kg/cm}^2\end{aligned} \qquad (1)$$

This pressure per unit surface area will generate 17.15 kg (37.75 lb) for the 7 × 7 cm mat samples. An 18 kg force was therefore used to test the compression of the mats (Konz and Subramanian, 1989). The resultant mat compression values are shown in Table 1.

Local muscle fatigue as defined by EMG spectral analysis was used as the dependent variable in this experiment. Chaffin (1969, 1973) and Petrofsky (1979) have shown that by observing the reduction in the spectral shift of EMG median frequency one can identify localized muscular fatigue. In this experiment median frequency shift (towards the lower frequencies) was calculated from a power density spectrum of the EMG signal. The EMG signals were collected from three muscle groups. These included the gastrocnemius, tibialis anterior and erector spinae muscle groups. For the purposes of this study the muscles on the dominant side of the body were tested. EMG data were collected when the subject exerted 75% of maximum voluntary contraction (MVC) for 5 s under isometric conditions (standard test contraction).

In order to observe the fatigue reduction as precisely as possible, the same subject repeated the standing task three times under different floor conditions. To control for carry-over effects, each experimental condition was tested on a different day. A randomized within-subject design was chosen to measure the fatigue reduction effect of the mats.

Apparatus

A Kin/Com dynamometer was used to control 75% of maximum voluntary contraction (MVC) from each muscle group. This 75% MVC served as a standard test contraction, during which the EMG signal was recorded. With this dynamometer, a subject can monitor the amount of force displayed digitally on a VDT screen when he or she exerts isometric force. The Kin/Com was adjusted to accommodate testing of the various muscle groups.

Table 1 Mat compressibility characteristics

Mat	Thickness (mm)	Compression (mm)	Compression (%)
1 (Blue, thin)	8	0.55	6.9
2 (Black, thick)	22	0.49	2.2

An EMG system was used to collect raw EMG signals. Silver–silver chloride surface electrodes were used to measure raw EMG signals from the subject's skin area. The electrodes were placed over the belly on the muscles of interest at the mid-point of the muscle length. The EMG signals were notch-filtered at 60 Hz and low-pass filtered at 1000 Hz.

A spectrum analyser (Rapid Systems 4 × 4) was used to transform the raw EMG into spectral EMG. The analyser consisted of a four-channel circuit which collected the raw EMG signals. This circuit was connected to a microcomputer, in which software was used to transform the raw data into spectral data. The sampling frequency of the analyser was 1 kHz, because the raw EMG signal has a bandwidth ranging between 1 and 1000 Hz. The sampling time of the spectral analyser depended on the sampling frequency, and was set at 0.5 s.

A 103 cm high table was placed in front of the standing subject during the test. The subject was permitted to do light work, such as data entry or word processing, during the standing task. The subjects wore cotton socks without shoes during the test session.

Procedure

Initially, the subject was positioned relative to the Kin/Com dynamometer to measure MVC of the dominant erector spinae muscle. The subject extended the trunk against a dynamometer lever arm while in an upright position. A digital torque signal was also displayed, which permitted the subject to control torque output in the subsequent submaximal exertions. The dominant leg was also tested by exerting a force against a pulley system connected to the dynamometer. After the leg was stabilized, the foot was dorsiflexed to generate a maximum force. The MVC of the tibialis anterior was then recorded. The leg was then straightened to maintain a full length of the gastrocnemius since the origin of the muscle was above the knee level (on the posterior side of the femur). The foot was secured and plantarflexed to measure the MVC of gastrocnemius.

Electrodes and a ground electrode were then placed on the muscle groups of interest. Since the gastrocnemius and soleus share most of the same skin surface region, the medial head of the gastrocnemius was located to isolate the EMG signal from the soleus. Raw EMG signals were examined visually on an oscilloscope to ensure signal quality. The quality of the signal was determined in terms of low noise when the muscle was inactive, absence of electromagnetic interference, and electrical response to muscle contraction. After that, the subject was again positioned relative to the Kin/Com and exerted the 75% of isometric MVC. The raw EMG data were collected while the subject was maintaining the exertion for 5 s. The experimenter monitored the isometric exertion digitally and recorded a stable 75% MVC exertion for a 2 s period. This data collection process was repeated for each muscle. Next, the subject was asked to stand on either a concrete surface or one of the mat conditions for a 2 h period. The subject was not allowed to use a footrest or any other fatigue-relieving mechanism during the test period. The subject was only allowed to do light work, such as data entry or word processing, during the 2 h period.

Immediately after completing the 2 h of standing, the subject was asked to perform the 75% MVC standard contractions again while the EMG signals were recorded. Spectral EMG data were collected and stored for further analysis.

Data analysis

The median frequencies of spectral EMG data were computed by the software developed in the Biodynamics Laboratory. Since the shift of median frequency (towards the lower frequency) during comparable muscle exertions is an indicator of muscle fatigue, it can be assumed that the greater the drop of the median frequency, the greater the muscle fatigue. Median frequency differences were computed for the three floor conditions for the overall muscles as well as for each of the three individual muscles. Statistical analysis software was used to test the significance of difference of the median frequencies between independent variables: concrete, mat 1 and mat 2.

Results

A summary of the analysis of variance (ANOVA) results is shown in Table 2. These results indicated that different floor conditions could change the fatigue of overall muscles significantly, and the degree of muscle fatigue was also significantly different from one muscle to another. It was also shown that the difference between subjects was not a significant factor in muscle fatigue.

In order to determine which mats significantly affected collective muscle fatigue only, a Duncan multiple range *post hoc* test was performed. The results of these analyses are summarized in Figure 1. This grouping comparison shows that mat 1 (blue thin mat) reduced muscle fatigue more than mat 2 (black thick mat) when compared with the concrete condition, even though there was no significant difference between mat 1 and mat 2. The least median frequency drop was regarded as zero in this experiment, and the mean values in this figure were normalized accordingly.

Table 2 ANOVA summary of fatigue differences

Source	DF	MS	F	$Pr > F$
Subject	4	16.65	0.27	0.8958
Mat	2	304.53	4.91	0.0140*
Muscle	2	489.11	7.89	0.0017**
Subject × Mat	8	163.12	2.63	0.0251*
Subject × Muscle	8	218.19	3.52	0.0052**
Mat × Muscle	4	79.02	1.28	0.3008
Error	31	61.96		

*significant at $p < 0.05$
**significant at $p < 0.01$

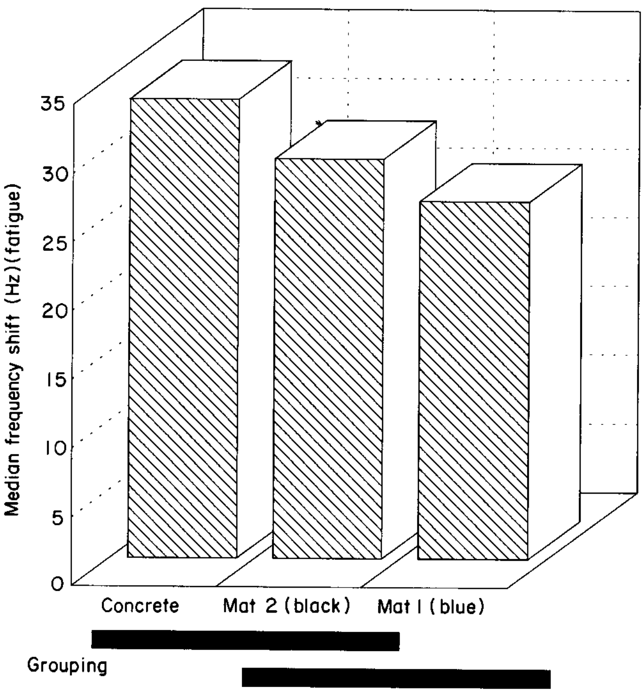

Figure 1 Muscle fatigue and significance grouping as a function of experimental floor conditions

This evaluation indicates that mat 1 was the best floor condition for reduction of muscle fatigue in this test. Mat 2 had a limited fatigue-reducing tendency but it was not statistically significant. The statistically significant differences among the different muscle groups are summarized in Table 3.

Table 3 indicates that there was only a significant difference between the gastrocnemius muscle and the erector spinae muscle. In order to determine which muscle experienced the most fatigue, these mean values were compared by Duncan multiple range test. The muscle fatigue and grouping differences are summarized in Figure 2.

Evaluation of these results indicates that the gastrocnemius experienced the most fatigue among muscle groups, regardless of floor conditions. Further tests were therefore performed to examine how individual muscle fatigue changed as a function of floor conditions. These results are displayed in Table 4.

Table 3 Significant fatigue differences between muscle groups

Contrast	DF	MS	*F*	*Pr* > *F*
ES versus GAS	1	955.83	15.43	0.0004**
ES versus TA	1	218.03	3.52	0.0701
GAS versus TA	1	195.64	3.16	0.0854

ES, erector spinae; GAS, gastrocnemius; TA, tibialis anterior
**significant at $p < 0.01$

Table 4 Significant fatigue reactions among muscles as affected by experimental floor conditions

Muscle	Source	DF	MS	*F*	*Pr* > *F*
Gastrocnemius	Mat	2	25.66	0.11	0.8964
Tibialis anterior	Mat	2	160.40	1.61	0.2584
Erector spinae	Mat	2	366.89	14.60	0.0001**

**significant at $p < 0.01$

Table 4 indicates that only the erector spinae muscle group experienced a significant fatigue effect as a function of floor conditions. The fatigue characteristics of the erector spinae muscle are shown in Figure 3 along with the *post hoc* significance groupings. The *post hoc* summary of the mean value of median frequency drop is summarized in Table 5. Mat 1 exhibited the most fatigue-reducing effect on the erector spinae muscle while mat 2 did not have an effect. This table indicates that mat 2 is not statistically different from the concrete mat condition. This table also indicates that mat 1 is solely responsible for ANOVA mat fatigue reduction significance.

Discussion

The focus of this study was limited to an investigation of localized muscular fatigue of selected muscles. These muscles were identified by previous studies as those that were associated with standing discomfort. Previous EMG studies (Kuorinka *et al*, 1978; Zhang *et al*, 1991) showed varied responses to prolonged standing when

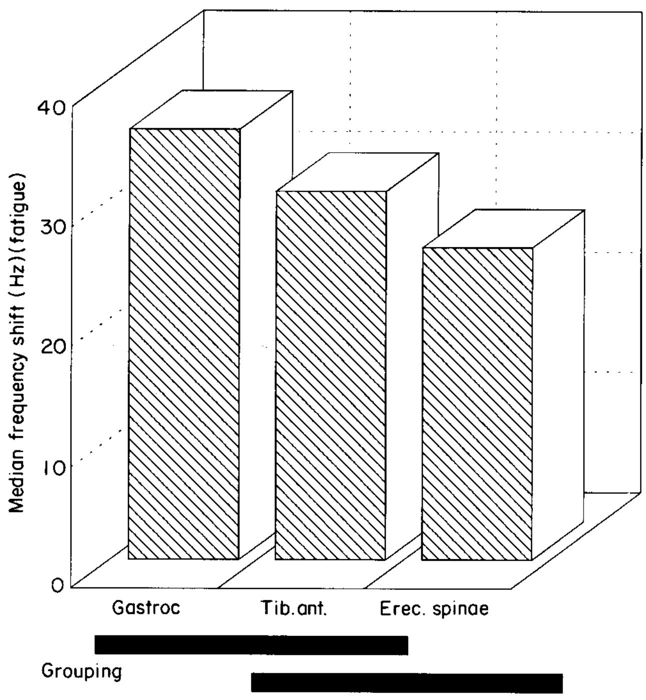

Figure 2 Muscle fatigue and significance grouping as a function of muscle group

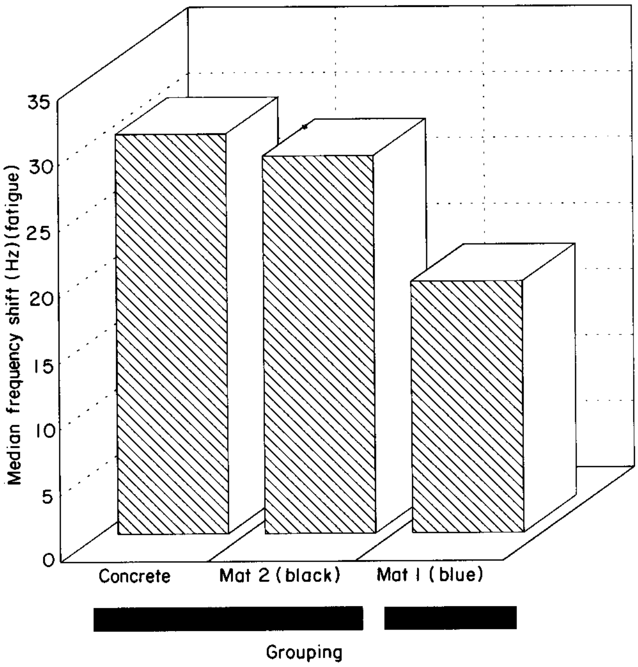

Figure 3 Muscle fatigue and significance grouping as a function of experimental floor conditions for the erector spinae muscle

EMG activity or amplitude were evaluated in the leg muscles. However, we were unable to find any previous studies that examined the fatiguability of the muscles under these conditions using EMG spectral analysis techniques.

This study has found that there is significant localized muscle fatigue in the leg muscles due to prolonged standing. This agrees with the findings of Kuorinka *et al* (1978), who found increased activity in the leg musculature. The gastrocnemius appears to be particularly affected by prolonged standing. Basmajian (1979) argues that lower extremity fatigue during standing is more a result of circulatory insufficiencies and pressures on body structures than of continuous muscular contractions. This study has shown that even these low-level prolonged muscular contractions can result in significant localized muscular fatigue.

This study has shown that, at least for the anti-fatigue mats examined in this study, there is not a significant fatigue reduction in the leg musculature. Thus these mats do little to reduce leg muscular fatigue due to prolonged muscular contractions of the gastrocnemius and tibialis anterior muscles. Konz *et al* (1990) did find differences in discomfort ratings of the legs among different mats. However, this finding may be more a function of venous pooling, as hypothesized by Brantingham *et al* (1970) and Basmajian (1979).

This study has also shown that the back musculature (erector spinae muscle) is the only muscle group to benefit from anti-fatigue mats. Thus anti-fatigue mats only appear to affect muscular fatigue in the back. It is also notable that only certain mats (mat 1) effectively reduce muscle fatigue in this muscle group. It is unclear why only one of the mats resulted in fatigue reduction in the back musculature. However, a possible explanation may be the degree of trunk stability that is imposed because of the mat surface. The compressibility characteristics associated with mat 1 were much greater than those of mat 2. It is hypothesized that the more compressible mat (mat 1) resulted in more postural sway in the subjects, since it created an unstable base of support for the subject. This postural sway would require the subject to alternately contract the agonist–antagonist trunk muscles, thereby increasing blood flow via a 'pumping' action of the muscles. Since the body is essentially an inverted pendulum during sway, the trunk muscles would experience more of this pumping than would the leg muscles. The less compressible mat might cause more co-contraction of the trunk muscles to maintain a more static posture, thereby reducing the opportunity to pump blood into the muscle. This difference may provide a potential explanation of how fatigue is reduced in the trunk muscles only. However, this hypothesis could only be confirmed by further studies that measure postural sway via kinematic assessment, foot pressure measurements, and monitoring of the EMG activity of multiple trunk muscles.

Several limitations of this study should also be noted. It was limited in scope, in that we operationally defined fatigue as only localized muscular fatigue that would be objectively identifiable via EMG spectral analysis techniques. We did not examine any of the traditional indicators of fatigue or discomfort, such as body discomfort ratings, body motions, pressure distributions, or blood flow. Future studies may also wish to examine these other measures simultaneously with EMG spectral analysis techniques. Another factor that may limit the applicability of these data to general industry is the fact that in this study subjects were tested under the various experimental conditions without shoes. While this allowed us to control for differences in shoe characteristics between subjects, future studies may want to standardize shoe wear or make this an experimental variable.

Future studies may also be expanded to include many more types of mats as well as 'anti-fatigue' shoe insoles, which have become commonplace in many industries.

Acknowledgement

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Table 5 Significant fatigue differences between experimental conditions for the erector spinae muscle

Contrast	DF	MS	*F*	*Pr* > *F*
Mats versus concrete	1	278.73	11.09	0.0029**
Mat 1 versus concrete	1	631.24	25.12	0.0001**
Mat 2 versus concrete	1	14.38	0.57	0.4570

**significant at $p < 0.01$

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