The Effects of Chair Design

On Back Muscle Fatigue

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ABSTRACT

The electromyographic activity of the paraspinal muscles at four levels were examined to investigate the effects of chair sitting on muscle activation patterns and muscle fatigue. The Balans, Nada-Chair Back Up, and Standard Office Chair were studied. Twenty four subjects were asked to engage in a seated writing task for 10 minutes for each of three chairs. Prior to the first writing period and between each writing period, the subjects were asked to perform a standardized muscle fatigue assessment while standing. The results of the study indicate that the seated writing task differentially effects only the paraspinal muscles at L3 site. During the writing task, the Balans chair required the largest amount of muscular effort. The standard Office chair showed evidence of fatigue. The Back Up chair yielded the best performance. In 87.5% of the comparisons the Nada-Chair Back Up has lower readings of muscular effort compared to the Balans and Office Chair. During the muscle fatigue testing during standing, evidence of increased muscle fatigue was observed as a function of each sit period. The greatest amount of fatigue was noted in those subjects who sat in the Back Up chair last. When the Back Up chair was first or second, the least amount of fatigue was observed. The IEMG results reflect a biomechanical model. The distribution of the Balans chair is unnatural and gives the least amount of support to the pelvis and lower spine, while the Back Up provides the greatest amount of support. The Balans chair overworks the low and mid back muscles, only to spare the cervical sets, while the Nada-Chair Back Up provides the greatest amount of lumbar support. The energy expenditure of the Office chair and Balans chair is significantly higher in the low and mid back area. This higher energy expenditure leads to fatigue while sitting. In conclusion, the level of muscular effort and accompanying fatigue associated with sitting are directly related to poor or inadequate biomechanical support of the chair.

INTRODUCTION

Back problems are very prevalent in our society. Dolce and Raczynski (1985) in reviewing the area stated that painful back disorders alone are a major medical problem. They claim that back pain alone has been reported to have a yearly incidence of 50 out of 1,000 workers. Further, an estimated 7 million Americans have been incapacitated by low back pain. In a representative study of the Dutch working population it was shown that 26.5% had suffered from a serious back problem (Hildebrandth & Van der Valk, 1990). The survey also showed that for sedentary occupation, the numbers of back problem complaints are even higher. These static working conditions, coupled with poor or inappropriate body mechanics, may cause prolonged tension in specific muscle groups. This in turn leads to fatigue and eventual muscle strain, and a myogenic etiology of pain.

The model of muscle fatigue has been gaining acceptance for explaining the deterioration of human performance over time. The term "fatigue" was categorized by Bills (1943) into three different groups. The first was subjective fatigue, characterized by psychological factors such as a decline in motivation and alertness. The second is objective fatigue which is manifested by a decline in productivity. The third is physiological fatigue which is characterized by changes in physiological processes. One example of physiological fatigue has been termed "Localized Muscular Fatigue" by Chaffin (1973). This refers to the inability of a given muscle to maintain a desired force and is associated with localized pain. This localized pain may be induced by the sustainedmuscle contractions associatedwith sedentary occupations (De Luca, 1984).

Muscle contractions produce as by products lactic and pyruvic acid. With sustained muscle contraction hydrogen ion concentration increases and a general PH decreases (Tesch et al, 1977). Stulen(1980) has shown that accumulation of acidic by products in the membrane environment may be expected to cause a decrease in the membrane conduction velocity. De Luca (1984) in a review article argues that during sustained, fatiguing contractions, the dominant factor is the amount of acidic by products which remain in the environment of a muscle fiber membrane.

A method which has gained acceptance recently for monitoring muscle fatigue is median frequency shift of the IEMG signal. This technique is based on the observation that the median frequency of the IEMG power spectrum decreases over time with sustained isometric contraction (Roy et al, 1988). This falling of the median frequency has been observed often and in a variety of muscles and throughout the human body (De Luca, 1984).

CHAIR FATIGUE STUDY

In order to prevent the injuries associated the prolonged sitting posture, correct biomechanical and muscular support are necessary. Interestingly enough, both depend on the type of chair used. In particular, the chair height and type of back support are of critical importance. Thus, a chair which provides the proper support, may also reduce back injuries associated with sedentary working conditions.

In recent years different products have been developed to provide the proper back support. The Balans chair (a kneeling chair) is one example. This chair has no back support and consists of a forward-tilting seat with a padded rest for the knees. The person bears the weight of the sitting on- the knees, while the pelvis is biomechanically tilted downward thus creating an increase in the lordotic curve. It is thought that placement of the spine in such a fashion would encourage the disk material anteriorly, and allow the weight of the body to hang on the anterior longitudinal ligament for support. Another new chair example is the Nada Back Up chair. It is actually a chair accessory. It uses a padded sling which stabilizes and supports the pelvis in an anterior position using straps around the knees.

The present study was undertaken to examine the effect of three different chairs on the fatiguability of the Cervical, Thoracic and Lumber muscle sites during a 10 minute seated writing task. The chairs chosen were the Balans chair and the Back Up chair because of their unique design. These were compared to a standard office chair. In addition, we utilized a standardized muscle fatigue monitoring technique associated with the standing posture. In it, the IEMG power spectrum during a period of sustained isometric muscle contraction is examined for the downward shift in the median frequency.

METHOD

SUBJECTS

Twelve subjects (nine females and three males) ranging in age from 25 to 45 years (X=37.4 years, sd 11.7) with a history of back pain were compared with twelve healthy subjects (6 females and six males) ranging in age between 34 to 51 years (X=39.4, sd 11.3). Twenty three subjects were right handed while one subject was left handed. The group of subjects with a history of back pain was determined based on self report of recurring back pain of at least one year.

CHAIR FATIGUE STUDY

PROCEDURES

Eight pairs of Silver-Silver Chloride electrodes were placed bilaterally over the subject's left and right Cl, T6, TlO and L3 muscle groups. These muscles were chosen as a representative selection of the Paraspinal muscles. The paired electrodes were placed 2 cm apart from each other and 2-3 cm out from the spine, oriented such they run parallel to the paraspinal muscles. A single electrode was placed for the ground lead. Each muscle site was prepared using a vigorous alcohol abrade. The electrodes were then slightly coated with electrolytic paste and placed over the muscle site.

The electromyographic portion of the study was conducted using a PHYSIOTECH 4000 EMG with an input impedance of 20 MOhms, and a fixed band pass filter of 40-450 Hz. The instrument has a Common Mode Rejection Ratio of >llO db with sensitivity of O-512 Microvolts. The PHYSIOTECH 4000 recorded both processed IEMG and median frequency from spectral analysis.

The flow of the study is represented in Table 1. Following placement of the electrodes and verification of the IEMG signal, each subject was asked to hold a 2.2 Kg. box at full arms length at a 90 degrees angle in front of the body for one minute. The subjects were encouraged to keep as motionless as possible. At the conclusion of the one minute period, the weight was removed and the subjects were asked to stand with both feet flat on the floor with the arms relaxed at their sides for two minutes.

Table 1. Study flow diagram for both the sit and stand periods.

STAND 1	SIT 1	STAND 2	SIT 2	STAND 3	SIT 3	STAND 4
	CHAIR 1		CHAIR 2		CHAIR 3	

The subjects were then directed to the first chair. The order of the chairs was assigned randomly. They were instructed to adjust each chair to their most comfortable position in front of the table. For the next ten minutes, the subjects were asked to engage in a writing task. All subjects were given the same book and were asked to copy continuously to the end of the ten minute period.

CHAIR FATIGUE STUDY

At the conclusion of the first sit period, the subjects were asked to stand for their second stand period. The muscle fatigue procedure used in the first stand period was performed again. This procedure was repeated for the third and fourth stand period. The subjects were also instructed to repeat the writing activity for their second and third sit periods.

RESULTS

The procedure for recording the IEMG activity during the stand period is shown in Table 2. The IEMG activity was measured in 15 second epochs beginning with the first 15 second of the stand period, and the last 15 seconds of the one minute time frame. At the end of the two minute period during the relaxed stand period a 15 second epoch was recorded. During the stand period only the T6 and L3 muscle sites were monitored and analyzed for median frequency shift. Epochs of 1.7 seconds were utilized for the spectral analysis. See Table 2. For the sit period the mean RMS levels of each 15 second IEMG epochs were utilized: One at the beginning of the 10 minute period, one after 5 minutes and one at the end of the period. See Table 3. All eight muscle sites were recorded during the sit period.

Table 2. Study flow of median frequency recordings for each Stand period.

Stand- holding 2.2 Kg. weight 1 minute		Stand in a relaxed posture 2 minutes	
first 1.7 seconds epoch	last 1.7 seconds epoch		last 1.7 seconds epoch

Table 3. Study flow of IEMG recordings for each sit period.

Minute 1	Minute 5	Minute 10
first 15 second	last 15 seconds	last 15 seconds

Two-Way repeated Analysis of Variance (ANOVA) was conducted for the sit period data with two factors: History (back pain and normal) and Chair Order (six orders). The two repeated measures were Time and Chair. Time was nested within Chair.

Two-Way repeated ANOVA was conducted on the stand period with two factors, History of back pain (normal and abnormal) and Chair Order (six orders). The two repeated measures were Stand Period and Time. Time was nested within stand period.

THE SIT PERIOD

The analysis of IEMG activity (RMS microvolts) during the sit periods demonstrated a highly significant chair effect for both the left and the right sides at the L3 muscle site (Wilkes Lambda, F= 10.8683, P>.0l). See Figure 1. No significance was observed for the C4, T6 and TlO sites. Pair-wise comparisons indicated that IEMG activity was significantly higher for the Balans chair for both the left and right L3 site when compared to the Back UP and Office chairs. No significant differences were observed between the Back Up and Office chairs.

The L3 data also indicates that there was a highly significant interaction between Chair and History (Wilkes' Lambda, F=14.70, P=.0l). Pair-wise comparisons indicate that the muscle activity for the back pain group was significantly higher than the normal group while sitting on the Balans chair. No significant differences were observed for the Back Up and the Office chairs.

A significant time effect was observed for the three sit periods at the L3 site (Wilkes' Lambda, F=7.3649, P=.O2). A pair-wise comparison indicated that there was a significant difference between minute 1 and minute 10. A step-wise increase in IEMG activity from minute one to minute ten is shown in Figure 3. No significant time effect was observed for the other three muscle sites. A significant Chair and Time interaction was observed for the L3 site (Wilkes' Lambda, F=14.3951, P=.0l) A pair-wise comparison analysis indicated that the Balans chair IEMG values were significantly higher than both the Back Up and Office chairs for all three time periods. The Office chair was significantly higher for minute 5 and minute 10 compared to minute 1. See Figure 4.

FIG. 1 MEANS DURING WRITING
AT L3 SITE
(B=BALANS, U=BACK-UP, O=OFFICE)

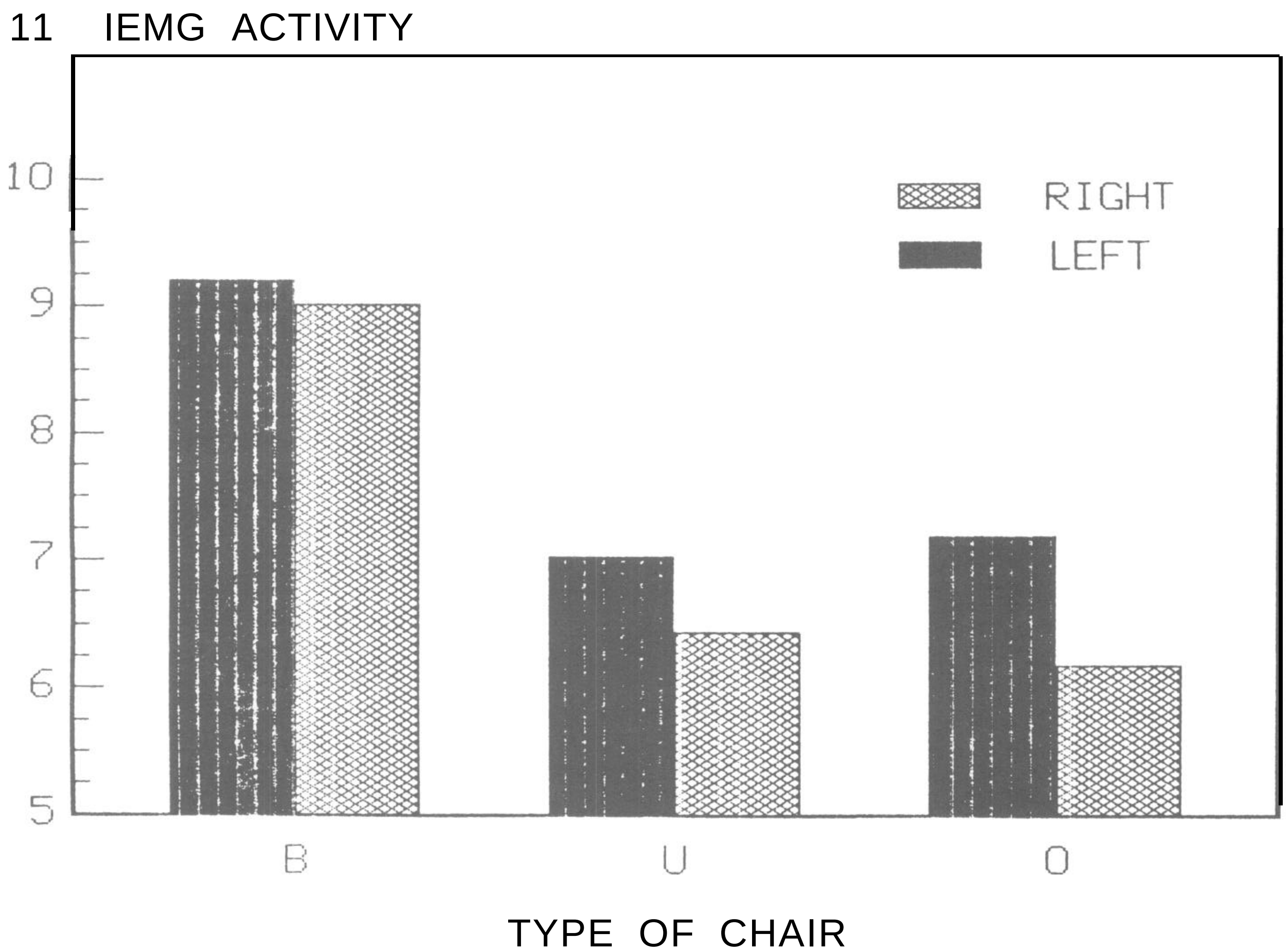


FIG 2. MEANS DURING WRITING
AT L3 SITE
(B=BALANS, U=BACK UP, O=OFFICE)

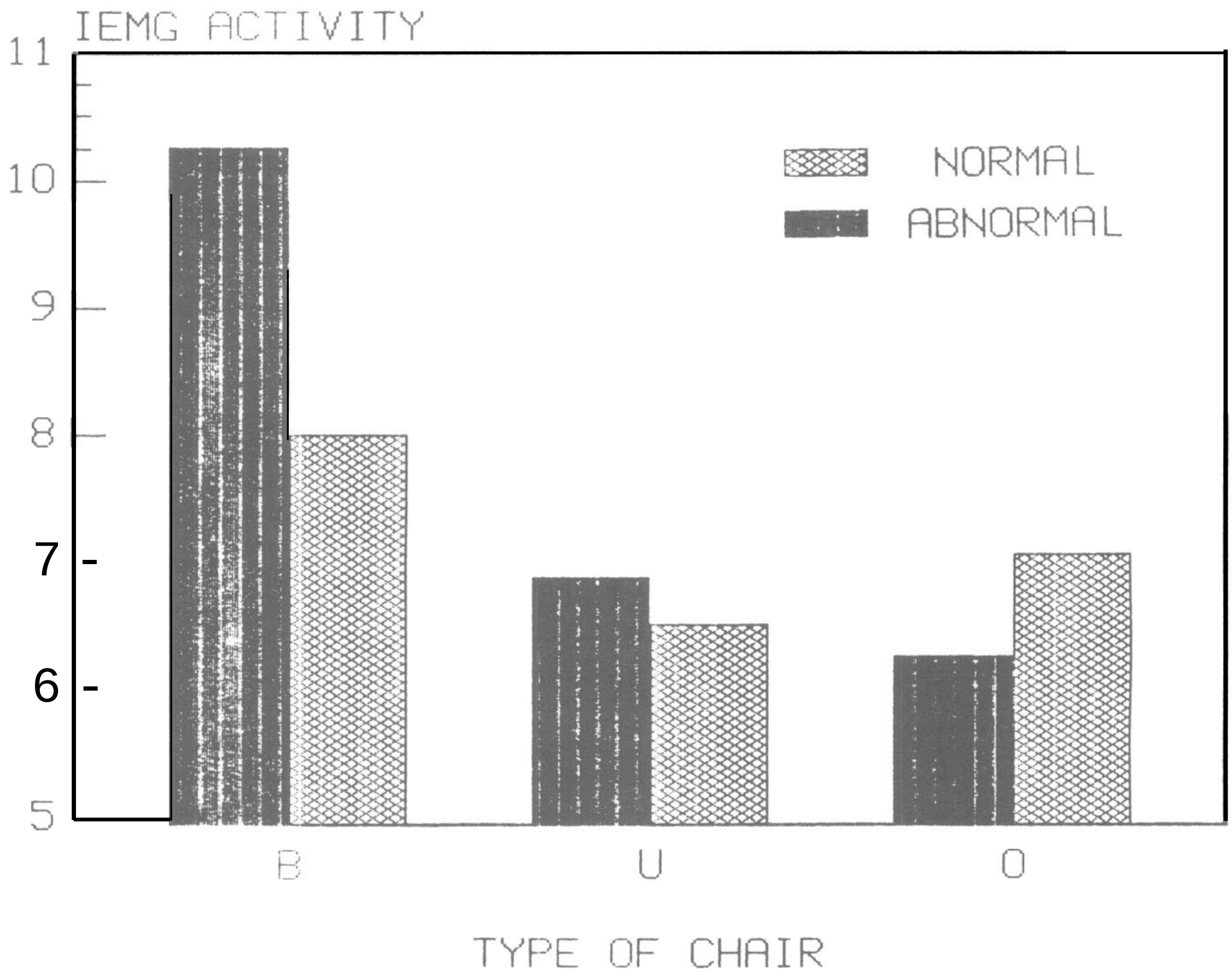


FIG 3. MEANS DURING WRITING
AT L3 SITE

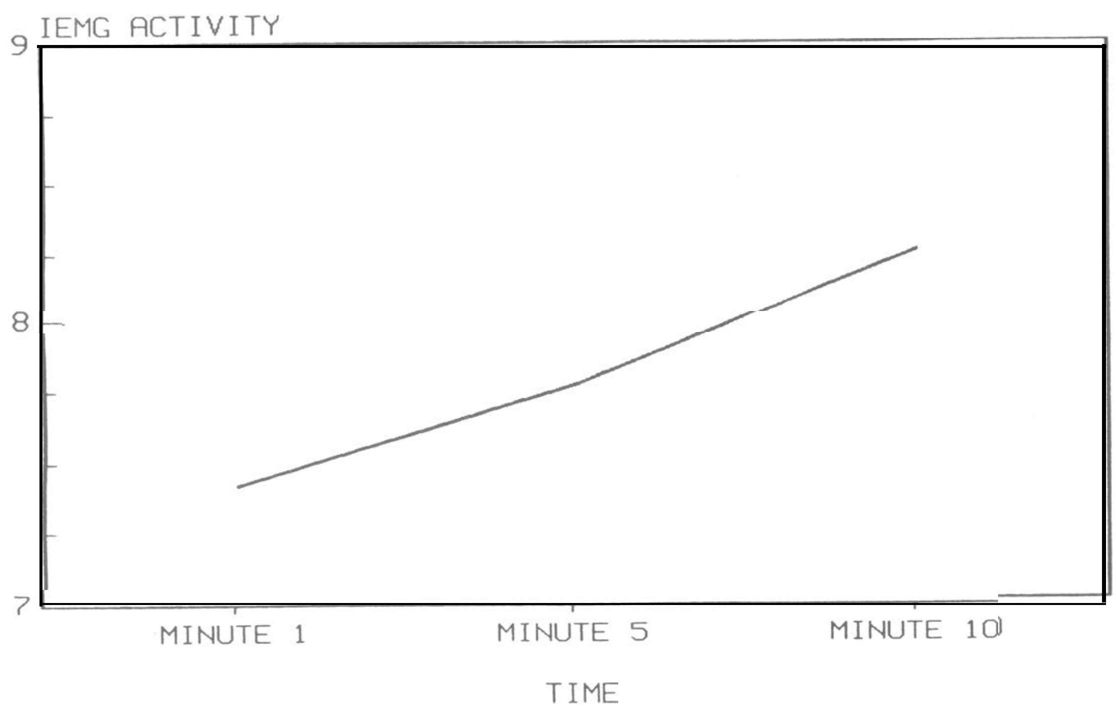
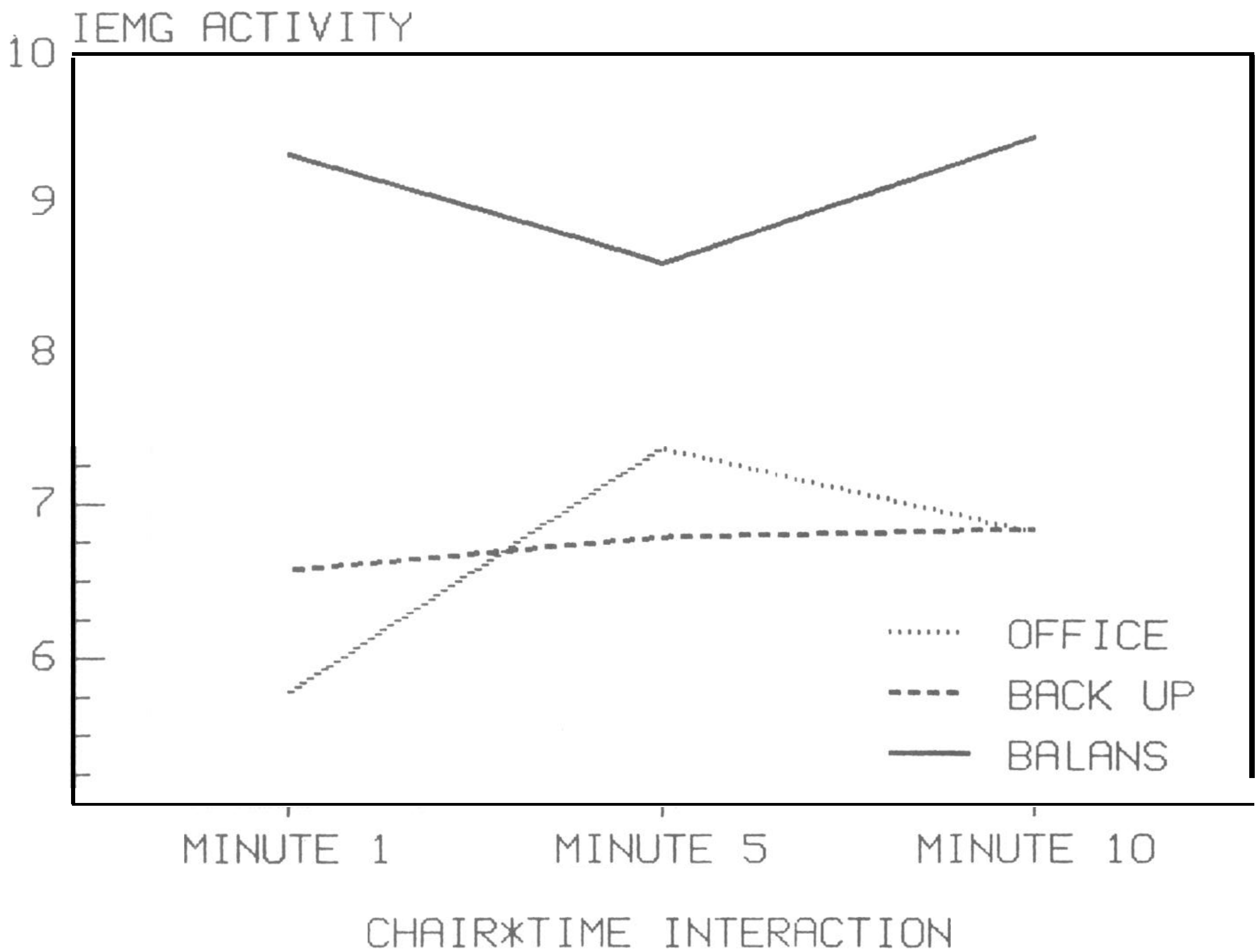


FIG. 4 MEANS DURING WRITING
IN THREE CHAIRS
AT THE L3 SITE



THE STAND PERIOD

The median frequency analysis was performed on the change in median frequencies between the beginning of the stand period and the end of the first minute. See Table 2. This is referred to as DP (DP referring to the "difference during the period"). The median frequency shift for stand periods one through four were denoted as DPl through DP4. The median frequency analysis for the four stand periods demonstrated a significant Period effect (Wilkes' Lambda, F=5.12, p> .Ol). This analysis indicated larger and larger drops in the median frequency over repeated stand periods. In addition, an Order effect for-both the left and right sides at the L3 muscle site was observed (Wilkes' Lambda, F=3.09: P=.O2). A pair-wise comparison indicated highly significant differences between order OBU (Office, Balans and Back-Up) and the following three chair orders OUB (Office, Back-Up and Balans), UBO (Back-UP, Balans and Office) and BUO (Balans, Back-Up and Office). The largest downward shift in median frequency was observed for the chair order OBU (Office first, Balans second and Back-Up third), and the smallest for orders OUB (Office, Back-Up and Balans), UBO (Back-Up, Balans and Office) and BUO (Balans, Back-Up and Office) consecutively. See Figure 5.

A separate analysis of variance was conducted on the overall difference in the median frequency between the beginning of stand period one and the end of stand period four. The values were obtained by subtracting the median frequency values at stand period one from stand period four. This measure reflected the overall fatigue at the L3 site. The results indicated a significant Order effect (F= 3.08, p> ,02). Pair-wise comparisons show significant differences between order OBU (Office, Balans and Back- Up), and orders UBO (Back -Up, Balans and Office), BOU (Balans, Office and Back-UP) and OUB (Office, Back-Up and Balans). See Figure 6.

FIG. 5 MEDIAN FREQUENCY DURING STANDING
DIFFERENCE BETWEEN BEGINNING AND END
OF STAND PERIOD 2, 3 AND 4 AT L3 SITE
(B=BALANS, U=BACK-UP, O=OFFICE)

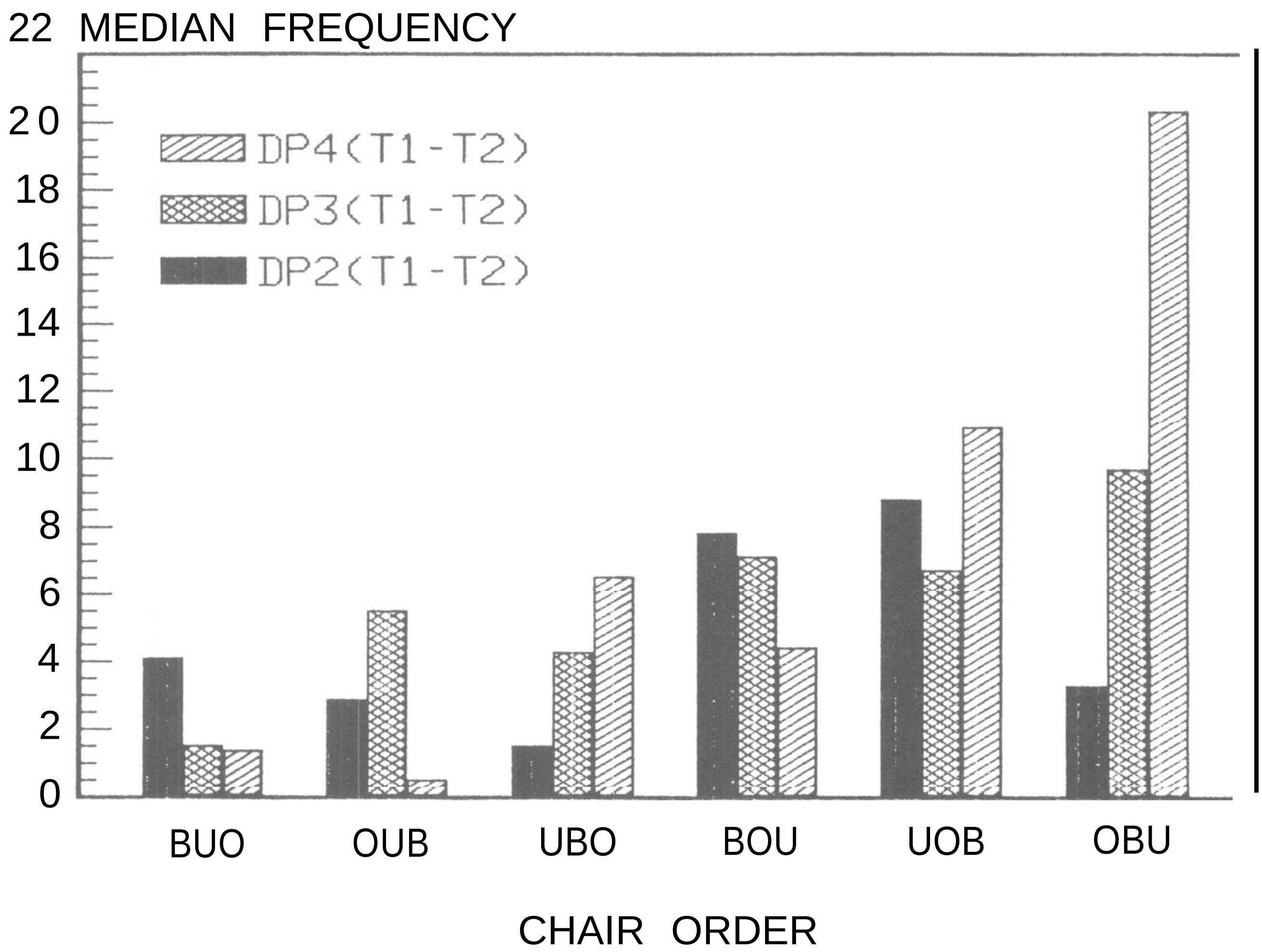
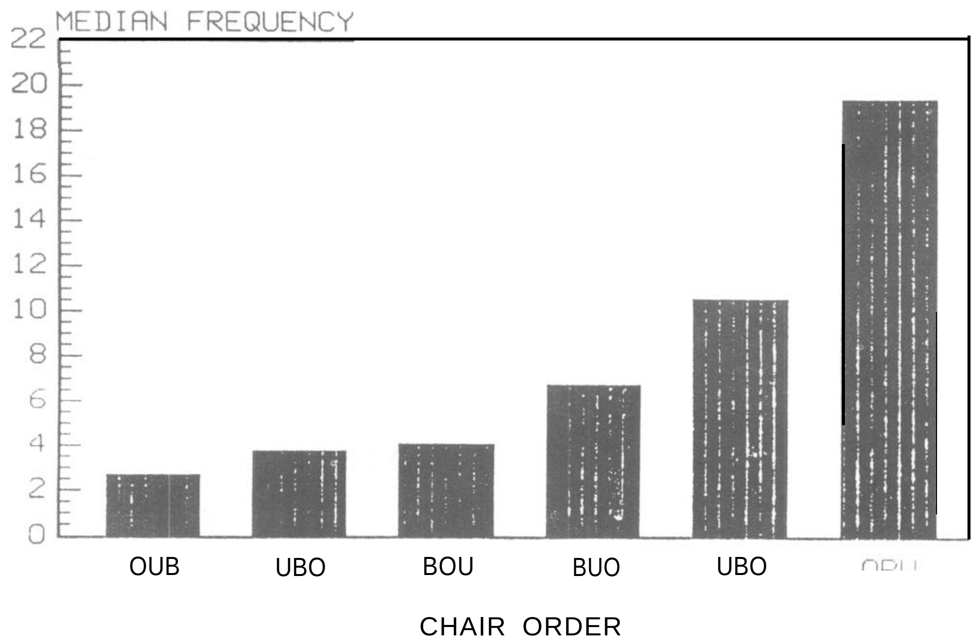


FIG. 6 MEDIAN FREQUENCY DURING STANDING
DIFFERENCE BETWEEN STAND 1 & 4 (DPl-DP4)
AT THE L3 SITE
(B=BALANS, U=BACK-UP, O=OFFICE)



DISCUSSION

The two overall consistent findings observed in this study were: First, the type of chair one sits on differentially recruits muscle activity. Secondly, this prolonged isometric recruitment differentially effects muscle fatigue in at least two postures.

The data analysis during sitting indicated that the vast majority of muscular support observed during the seated writing task occurs at the base of the spine (L3), rather than at the TlO, T6, or C4 levels. In addition, the significant Chair effect indicated that the Balans chair required significantly higher levels of recruitment to stabilize the pelvis and spine compared to the Back-Up or the Office chairs. This prolonged increased in the level of recruitment ultimately increases the propensity for muscle fatigue and slouching in the low back. Anderson et al. (1988) have showed similar findings during a typing task, where the Balans chair required higher levels of recruitment compared to the Office chair.

In addition, a highly significant interaction of Chair and History of back pain was observed at the L3 muscle site while performing the writing task in the Balans chair. The data indicates that subjects with a history of back pain exhibit significantly higher levels of IEMG activity compared to normal subjects. It appears that individuals who suffer from back pain have irritable joints and tissue which require them to pull up their own muscular corset, when inadequate support is given. In other words, they over recruit the erector spinae to stabilize the spine when there is lack of back support.

A significant increase in IEMG activity over the ten minute sit period was also observed at the L3 site. This is clearly displayed in Figure 3. Additional recruitment or synchronization of motor units bring about the increased level of IEMG associated with the onset of fatigue (Basmajian and De Luca, 1985). In addition, a significant interaction of Time and Chair was noted. This may be seen in Figure 4. The findings for Balans chair suggested erratic and unpredictably high levels of IEMG compared to both the Back Up and Office chairs. This in part may be attributable to unnatural way in which the Balans chair offers support to the back. Another contributor to these high values would be the adverse impact of the Balans chair on the IEMG activity of the back pain patient sample.

In Figure 4, it will be noted that the increase in IEMG activity from minute one through minute five was the greatest for the Office chair. This finding strongly suggests that over time, subjects sitting in the Office chair must rely more and more on their muscles for stabilization and support of the pelvis. This increase in IEMG is associated with the increased recruitment and synchronization of motor unit activity indicative of fatigue. Further support for the fatigue hypothesis comes from the observed drop in IEMG occurring between minute five and ten. As fatigue sets in, the muscle tissue is no longer capable of meeting the metabolic requirements needed to sustain the contraction. Thus the initial increase in muscular support is followed by a reduction of muscle force (the failure point), along with a reduction of IEMG activity levels. The pattern of recruitment we see with the Office chair. Interestingly enough, the Back Up chair shows very little changes in IEMG activity over the ten minute period, thus suggesting little in the way of either fatigue or failure. The IEMG results indicate that the mechanical support offered by the Back Up is associated with the least amount of muscle fatigue compared to the Office and Balans chairs. Overall, the Back Up chair requires less energy to sit.

In the sitting period, greater IEMG activity was recorded on the left side of the body for all muscle sites in all three chairs, These finding are consistent with those reported by Bennett et al., (1989). This left sided dominance in the low back is related to the fact that the majority of the subjects in the study were right handed. During writing the task, subjects would lean forward and rotate slightly to the right to support their right upper extremities on the desk. This posture would cause a left sided asymmetrical pattern.

Overall, the pattern of IEMG recruitment observed during the writing task is best explained using biomechanical principles. The Balans chair, for example, does not provide the mechanical support necessary to support the trunk during this prolonged forward flexion task. The Back Up chair, on the other hand, mechanically supports and stabilizes the pelvis and lower spine with the padded sling, thus lowering the need for supplemental muscular efforts. While the office chair "allows" for support of the pelvis and spine, it requires the user to sit in it properly. Thus, while the Office chair "might" provide adequate support initially, this may change over time. Lastly, it is important to note that other researchers also reported that the erector spinae tended to fatigue faster when sitting without the proper back support (Anderson et al., 1988 and Flayed and Roberts, 1958).

A second level of assessment of muscle fatigue utilized a standardized assessment procedure similar to that of Beiderman (1990) and Roy et al. (1988). Here, the low back muscles were placed into a sustained isometric contraction using a cantilever effect from holding a 2.2 Kg weight at full arms length out in front of the body while standing. One of the strengths of this procedure is that it was conducted in a posture and activity different to the writing task which we are studying. Using this type of assessment for fatigue, we observed a significant drop in the median frequency at the L3 muscle site over the course of the four stand periods. This finding suggests that as one sits for longer and longer periods of time, that the back muscles become more and more fatigued in general.

The analyses of median frequency shift within each stand period indicated a significant Order effect. Further investigation of this Order effect included a separate analysis of the overall level of muscle fatigue observed during standing. This was computed by subtracting the drop in the median frequency during the first stand period (DPl) from the drop in the median frequency during the last stand period (DP4). Again, a significant Order effect was observed. In both analysis of the Order effect, when the Office chair was used first and Balans was used second, the downward shift in the median frequency was substantially larger than in any other chair order. In addition, the results indicate that in three out of four chair orders in which the Back-Up chair was either first or second, the downward shift in the median frequency was the smallest. While this is not a clear Chair effect, it is suggestive that the order in which the chairs were sat in leads to greater or lesser levels of muscle fatigue. Perhaps a larger number of observations (subjects) would have led to a frank Chair effect.

In summary, the results of this study indicate that the more one sits in a chair which offers mechanical support to the pelvis and lower spine, the less supplemental muscular effort required for the sitting task. In addition, the better support to the pelvis and lower spine while sitting, the less general muscular fatigue to the lumbar muscles one will experience. Thus far, the data presented above suggests that the Back-Up chair clearly provides the greatest amount of support to the pelvis and lower back. Thereby the Back Up chair gives rise to the least amount of fatigue in the Lumbar region in general while both the Balans and the Office chair are associated with an increase in energy expenditure and fatigue in the low back muscles.

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