Journal of Ergonomics

Spyropoulos et al., J Ergonomics 2015, 5:2
DOI: 10.4172/2165-7556.1000139

Research Article Open Access

Muscle Fatigue Estimation in Repetitive Lifting Task Using Surface Electromyography-Based Analysis

Elias Spyropoulos[1], **Elisabeth Chroni**[2] **and George Athanassiou**[3*]

[1]*Department of Mechanical Engineering and Aeronautics, Division of Management & Organization studies, Laboratory of Ergonomics, University of Patras, Rion 26500, Greece*

[2]*Department of Neurology, University Hospital of Patras, Rion 26504, Greece*

[3]*Department of Mechanical Engineering and Aeronautics, Biomedical Engineering Laboratory, University of Patras, Rion 26500, Greece*

[*]**Corresponding Author:** George Athanassiou, Department of Mechanical Engineering and Aeronautics, Biomedical Engineering Laboratory, University of Patras, Rion 26500, Greece; Tel: +30 2610 969490; Fax: +30 2610 969464; Email: gathan@mech.upatras.gr

Received date: June 10, 2015; **Accepted date**: July 22, 2015; **Published date**: July 29, 2015

Abstract

Background: Workers in industry often perform repetitive and monotonous tasks with light weights, resulting in low back disorders.

Objective: The objective of this study was to quantitatively estimate when the muscle fatigue of the lower back muscles becomes substantial during a repetitive lifting task.

Methods: sEMG of the erector spinae muscle was recorded during the procedure of repetitive load lifting of 13.84 kg ± 4.22 kg from the floor to a 0.75 m height table. The fatigue rate determined by the surface Electromyography recordings was compared with the participant's self-evaluated fatigue level values. Eight healthy male subjects executed sixty-four load lifts divided in four lifting trials with a five minutes rest-break between each lifting trial.

Results: Analysis of surface Electromyography frequency domain parameters indicated that the fatigue accumulation was minimized after a rest break in the first three lifting trials while at the beginning of the 4th lifting trial, the fatigue accumulation level was high, implying the substantial fatigue onset. The fatigue rate values were found to be -0.417 Hz/Load Lift at the end of the 3rd lifting trial and -0.637 Hz/Load Lift at the beginning of the 4th lifting trial implying the substantial fatigue accumulation onset.

Conclusions: The findings showed that there was a 25% time lag to the participant's self-evaluated substantial fatigue level perception. A new index was introduced for the determination of the Time to Substantial Fatigue Onset in comparison with the corresponding one established by NIOSH lifting analysis.

Keywords: Electromyography; Muscle fatigue; Time to Substantial Fatigue Onset; Repetitive lifting task

Introduction

Workers in some industries are exposed to ergonomically unfavorable working conditions (repetitive motions, dynamic working postures) leading to work-related musculoskeletal disorders (MSDs) [1]. Intensive studies of fatigue in dynamic conditions were performed only during the last decade and showed the lack of methodology to record and quantitatively describe the process of muscle fatigue accumulation [2]. Repetitive and monotonous tasks with even lightweights result in accumulated local muscle fatigue which is a serious problem in the workplace, and can cause muscle injuries [3]. Such injuries may be caused by repetitive motion and cumulative fatigue, rather than heavy loading [3,4]. Therefore, estimating cumulative fatigue due to repetitive workload is an essential issue to prevent workers from experiencing musculoskeletal injuries [5].

The onset of muscle fatigue is a non-measurable somatic condition, which is best described by the state of temporary lowered capacity or restriction of the ability of the muscles to perform certain work caused by this work itself [6,7]. The muscle fatigue threshold cannot be defined as a simple function of muscle load magnitude and timing, because muscle characteristics and capabilities vary from person to person. Undetected fatigue can cause injury-often irreversible-to the subject and besides the pain and suffering it is a financial burden to industry and society [8].

As fatigue accumulation is a continuous and on-going process, there is a need to assess fatigue and to detect the time point in this process, at which injury risk could be considered to have risen above a baseline level [9,10]. At present, there is no consensus in the literature concerning the adoption of a specific methodology for determining this baseline level. Therefore, we introduced the Time to Substantial Fatigue Onset (TSFO) factor which determines the time moment where the local fatigue accumulation becomes so crucial to induce reduction in the maximal capacity to generate force or power output [11]. Other investigators have proposed several fatigue indices derived from surface electromyographic (sEMG) measures to address this goal [12]. A time-to-fatigue indicator has been suggested to determine a baseline level of fatigue accumulation, using EMG-based methodology [9]. However, these previous methodologies do not have an holistic approach since they have not associated the fatigue threshold objective measurements with the participant's self-evaluated fatigue level (Borg's scale), which should expresses the tiredness feeling and the perceived fatigue of the individuals during the task performance.

Significant biochemical and physiological changes in muscles during fatiguing can be detected by sEMG signals properties measurements as these changes are reflected by changes in myoelectric signals [13]. The sEMG parameters associated with either onset or occurrence of fatigue are the signal amplitude, the power, the mean and median frequencies of the power density spectrum, the number of zero crossings and spike properties [14,15]. Muscle fatigue during submaximal, isometric contractions, has been shown to be accompanied by increase in the EMG signal amplitude and decreases in the mean power frequency (MPF) and/or median power frequency (MF) [16,17]. A number of studies have noted that the frequency based EMG variables, as opposed to the time domain ones, are more sensitive to fatigue related changes [18].

To help prevent the accumulation of excessive fatigue, work/rest schedules have been studied by many researchers. Kim used EMG to observe MPF of the erector spinae muscle during isometric trunk extension. He found that more than 60% of the cycle time should be used for muscle recovery to avoid the accumulation of muscle fatigue [19]. Other researchers used EMG to estimate the proper muscle recovery time depending on the lifting/lowering rate and they found that the right and left erector spinae muscles were recovered from fatigue after 5 minutes rest break [3]. Shin and Kim studied a symmetric lifting/lowering task with 3 minutes duration and with a lifting rate of 4 lifts/min. They found that fatigue would accumulate, during moderate lifting tasks, when the recovery time was shorter than 3 minutes [3].

It is evident that in the literature cited above, there is little research carried out on the implementation of detecting and predicting of substantial muscle fatigue in the workplace. This work is an effort to quantitatively estimate the low back fatigue. In particular, the content of sEMG of the dynamically contracted erector spinae muscle was studied in three classes of fatigue (Fatigue, Rest break and new Fatigue) and the features of the sEMG were related to the status of the fatigued erector muscle spine. Additionally in this study, using the Borg'scale of different fatigue sense values of the volunteers, the subjective assessment of the fatigue level was correlated with the corresponding fatigue values determined objectively using the data derived from sEMG measurements. Thus the present approach lays our methodology more holistic as it takes into account a cognitive parameter, the volunteer's sense of fatigue in conjunction with the objective measurements of sEMG. Subsequently, despite the variability of the muscle characteristics from person to person and the multifactorial phenomenon of fatigue process the index of time to substantial fatigue onset (TSFO) was introduced which determines the crucial time period where the muscle fatigue becomes substantial. The proposed index was compared with the well-established NIOSH index. The validation of TSFO according to the NIOSH index would add importance of TSFO approach to further enhance the field of occupational ergonomics and contribute as a useful tool for the design of work/rest ratios. Such tool is very useful to the workers who perform the lifting work tasks and may help to identify ways to reduce the risk of muscle injury.

Material and Methods

Subjects

Eight healthy male subjects voluntarily participated in this study. The average age was 27.66 years (SD=1.76 years) and the average Body Mass Index (BMI) was 25.7 (SD=1.1). It is important to note that the volunteers had similar morphological characteristics namely similar weight and similar height. Although other investigators failed to find any gender differences in EMG [20] in this study was assumed that the same gender as well as the almost same age of participants reduced the variability of the muscle characteristics from person to person. None of the participants had a lower extremity injury, physical disability or discomfort problem and they reported no symptoms of pain during the experiment. The study protocol has been approved by the Research Ethics Committee of University of Patras and all volunteers read and signed an informed consent before participating.

Experimental protocol

The protocol consisted of the electromyographic recording of only one side of the erector spinae muscle, during the procedure of repetitive load lifting from the floor to a 0.75 m height table (lifting was performed vertically). The volunteers stood at a distance of 30 cm from the table and the lifting frequency was set to 4 lifts per minute. They lifted a metal box with dimensions (50 × 30 × 25) cm and the lifting weight was set as the 20%*(Maximum Voluntary Weight Lift) (MVWL) for each volunteer correspondingly. They performed a symmetric, stoop lifting in the sagittal plane by coupling the box from its handles using industrial gloves as shown in Figure 1.

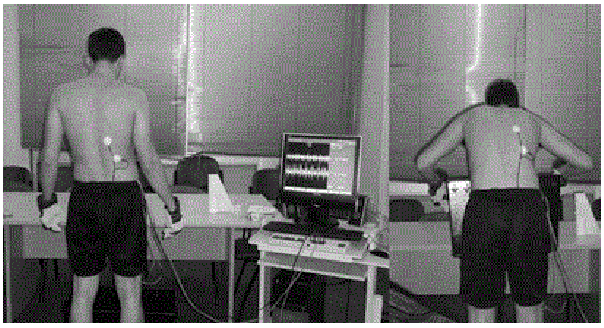

Figure 1: Location of the surface electrodes on a typical subject, box coupling.

Maximum voluntary weight lift

For each volunteer the MVWL value, in Nt, was measured. The lifting weight, used in this protocol, was set as the 20%*MVWL for each volunteer correspondingly. In order to measure the MVWL value, the following experimental setup was used. A dynamometer was connected to the ground. A lifting belt was adjusted to the volunteer and to the dynamometer in order to allow the vertical lifting of the dynamometer by the use of their trunk. Volunteers were asked to pull the dynamometer three times, exerting their maximum without using their hands. There was two (2) hours rest period before each of the three MVWL trials in order to measure the non-fatigued maximum. MVWL value was calculated as the average value of the three MVWL values for each volunteer correspondingly. Therefore, the mean lifting weight value was found to be 13.84 kg ± 4.22 kg (Table 1).

Volunteers	MVWL (Nt)			MVWLmean (Nt)	20%*MVWL$_{mean}$ (Nt)
	Trial 1	Trial 2	Trial 3		
1	990	1020	1210	1070	215
2	650	670	710	677	135
3	470	540	720	577	115
4	430	530	550	503.3	100
5	540	530	550	540	108
6	670	710	730	703.3	140
7	810	880	1140	943.3	189
8	400	530	650	526.6	105
					Mean=$138.4 \pm 42.2_{Nt}$

Table 1: Statistics on the weights lifted by volunteers.

Questionnaire study

Each participant self-evaluated his fatigue level as Perceptible Fatigue (PF) which expressed their discomfort level using Borg's clinical rating scale of general and local fatigue (CR-10), every 1 load lift (LL) [21]. Under this ten-grade scale, '1' represented total absence of fatigue and '10' complete inability to continue the lifting task (Table 2).

1–10 Borg rating of perceived fatigue level	
0	Rest
1	Really easy
2	Easy
3	Moderate
4	Sort of hand
5	Hard
6	Hard
7	Really hard
8	Really hard
9	Really, really, hard
10	Maximal

Table 2: Borg's clinical rating scale of general and local fatigue.

Lifting trials

The work lifting task encompassed 4 lifting trials (LT) and after each LT the participants received a five minute rest-break. Every LT involved 16 load lifts. In the 1st LT, all volunteers began the task without any warm-up. During the 4th LT due to substantial discomfort, none of the volunteers was able to continue the performance of the lifting task even after taking a five-minute rest-break. Thus the 4th LT was defined to be the last LT of the lifting task for the demands of the present study (Figure 2).

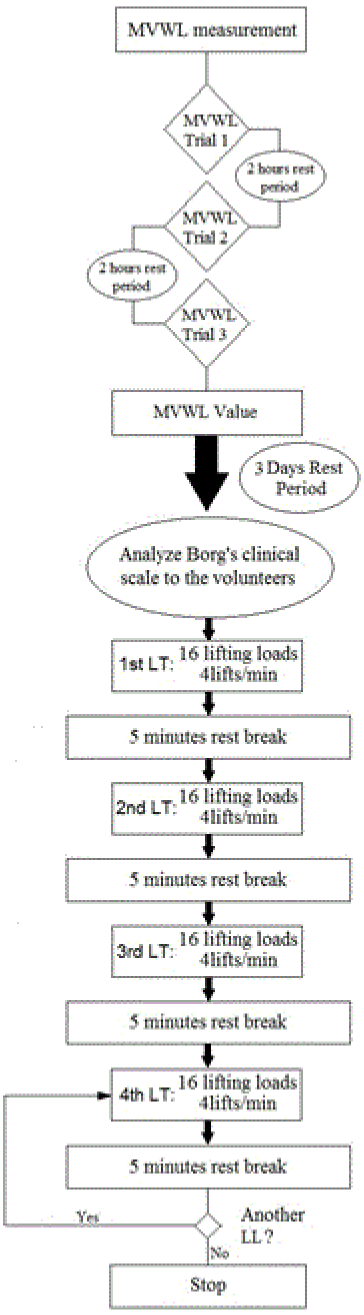

Figure 2: Experimental flow chart.

sEMG acquisition

For this study only the erector spinae muscle (right side of the body) was considered as the main contributor to the trunk motion during the lifting [5]. This muscle is fairly large and easy to identify on the participants (Figure 1). Assuming that both left and right side of the body erector spinae muscles contribute the same to the task performance, cause of the human body symmetry, we chose for simplicity of the analysis to record the EMG signal of only the right erector spinae muscle. sEMG signal was recorded at a sampling frequency of 6000 Hz using EMG recorder (Dantec-Keypoint, 6-channel amplifier) with a pair of surface Ag/Agcl electrodes. The spacing between the electrodes was 3 cm. Before placing the recording electrodes, the skin was shaved, gently abraded and cleaned with alcohol to avoid impedance and therefore to improve the signal-noise ratio. Skin resistance was maintained as low as 20 kΩ. A ground surface electrode was placed on the volunteer's right ankle. During the five minutes rest-breaks the electrodes were not removed from the volunteer's body in order to achieve experimental consistency in measurements.

Signal processing

sEMG raw data were filtered using a 4th order Butterworth filter with a pass band of 20 Hz -500 Hz. AC line interference was eliminated using a 2nd order Notch filter at 50 Hz [5]. The produced filtered sEMG signals were analyzed following standard procedures in the time and frequency domains. For the time domain analysis the EMG signals were full wave rectified. For the frequency domain, the MPF and the MF of the filtered signals were found using Fast Fourier Transform (FFT) with a 50 ms window. MPF and MF changes can be analyzed by linear regression [12]. The negative inclination or slope of the MF regression line will indicate fatigue rate [16,22]. All sEMG data was processed off-line with Matlab 7.0.1 (MathWorks Inc).

Muscle activation measurement

Muscle activation (MACT), which is determined by the Normalized Median Frequency (NMF), estimated the muscle recovery after each LT using equation 1, where the MF values at the beginning of each LT were compared to the non-fatigued state after a five minutes rest break was received by the volunteers. In particular MACT was determined as:

$$MACT = \frac{MF_{ni} - MF_{11}}{MF_{11}} \times 100 \rightarrow (1)$$

i=2-4, number of LT. n=1, 1st lifting load of each LT. MF11=non-fatigue state (muscle MF value of the 1st lifting load of the 1st LT).

Individual MF regression line slopes analysis, TSFO determination

The MF regression line slope of each LT was analyzed for every four load lifts to better focusing on the fatigue rate detecting changes. The values of the slopes were compared with each other. The TSFO factor was determined by comparing the regression line slopes in every 4 LLs and was estimated as the highest negative regression line slope, in each LT correspondingly.

Statistical test

Data obtained by the time domain and the frequency domain analysis of the raw sEMG signal were tested using Kolmogorov-Smirnov and Shapiro-Wilk tests, to determine if they are normally distributed. Due to the small sample size (<50 samples) Pearson test was performed on mean amplitude, MPF and MF to determine whether these features, which were extracted from sEMG signals, were significantly different between the LTs. The significance level of all statistical analysis tools was set to 0.05. Nonlinear changes of MF slopes values which may imply onset of substantial fatigue accumulation were compared to the corresponding values of fatigue sense which the volunteers expressed according to Borg's scale.

NIOSH lifting analysis

The recommended weight limit (RWL) and the lifting index (LI) were calculated for each volunteer correspondingly according to the NIOSH lifting guide [23]. RWL values were calculated using equation 2 and LI values were calculated using equation 3. Furthermore the recovery time (RT) was calculated based on equation 4 and we compared the RT results with the corresponding derived from the TSFO factor. Lifting duration is classified into three categories: short-duration, moderate duration and long duration. Short-duration defines lifting tasks that have a work time (WT) of one hour or less, followed by a RT equal to 1.2 times the WT (i.e., at least a 1.2 recovery-time to work-time ratio RT/WT) [22].

$$RWL_i = LC_i \times HM_i \times VM_i \times DM_i \times AM_i \times FM_i \times CM_i \rightarrow (2)$$

i=1-8, number of volunteers,

$$LI_i = \frac{LoadWeight(Li)}{RWLi} \rightarrow (3)$$

i=1-8, number of volunteers,

$$RT = 1.2 \times WT \rightarrow (4)$$

Results

Questionnaire study

The results obtained by Borg's clinical rating scale were correlated with attributes of subjects namely body mass index, age and the number of load lifts, using Spearmans correlation. Square of correlations, r^2, between the Borg's scale and the attributes is shown in table 3. The number of load lifts (r^2=0.862) show a high correlation with Borg's scale, where age (r^2=0.062) and BMI (r^2=0.008) do not show any correlation. Borg's scale was gradually increased from the beginning to the end of each LT as shown in Figure 3. [Table 3, Figure 3].

sEMG study

Statistical analysis results of MF data normality distribution are shown in table 4. All data in all LTs were normally distributed (p>0.05). The frequency domain parameters, MPF and MF, obtained by the erector spinae muscle, for all the volunteers, are shown in figure 4. Statistical correlation of MF values between the LTs are shown in table 5. High correlation occurred between the 1st, 2nd and 3rd LTs. In contrast the 4th LT correlates only with the 3rd LT. (Tables 4 and 5; Figure 4).

Regression line slopes, shown in table 6, indicate that fatigue gradually increases during the performance of the LTs 1, 2 and 3. The TSFO factor was determined by comparing the regression line slopes in every 4 LLs and was estimated as the highest negative regression line slope, in each LT correspondingly. The TSFO factor was found to be between 9th and 12th LL in the 1st LT. In the 2nd and 3rd LTs the TSFO factor was found to be between load lifts 13 and 16. In contrast, in the

Citation: Spyropoulos E, Chroni E, Athanassiou G (2015) Muscle Fatigue Estimation in Repetitive Lifting Task Using Surface Electromyography-Based Analysis. J Ergonomics 5: 139. doi:10.4172/2165-7556.1000139

4th LT the TSFO factor was found to be between the 1st and 4th LL (Figure 5; Table 6).

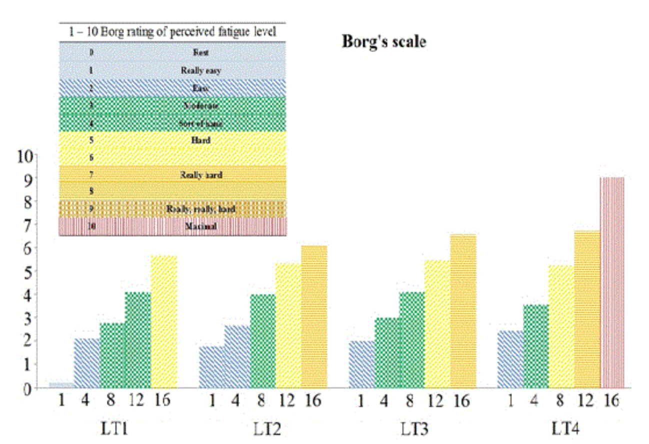

Figure 3: Change of Borg's clinical rating scale in relationship with load lifts.

Variables	Correlation with Borg's scale (r^2)
Age (years)	0.062
Body mass index	0.008
Number of load lifts	0.862

Table 3: Correlation (r^2) of Borg's clinical rating scale with various attributes of the volunteers.

	Kolmogorov-Smirnov	Shapiro-Wilk
	Sig.	Sig.
1st LT	0.200	0.719
2nd LT	0.200	0.621
3rd LT	0.200	0.540
4th LT	0.134	0.062

Table 4: Median Frequency data distribution test.

	1st LT	2nd LT	3rd LT	4th LT
1st LT	--	0.000	0.006	0.123
2nd LT	0.000	--	0.003	0.076
3rd LT	0.006	0.003	--	0.056
4th LT	0.123	0.076	0.056	--

Table 5: Correlation of MF parameters values between LTs (Pearson correlation, p<0.05).

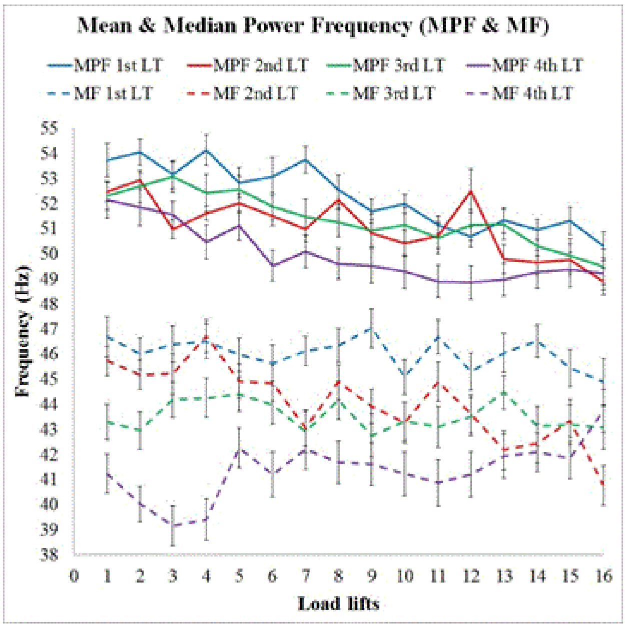

Figure 4: Mean and Median power frequency parameters obtained by erector spinae muscle. Mean average of all volunteers in all LTs. Negative regression line slopes in all LTs and in both MPF and MF diagrams.

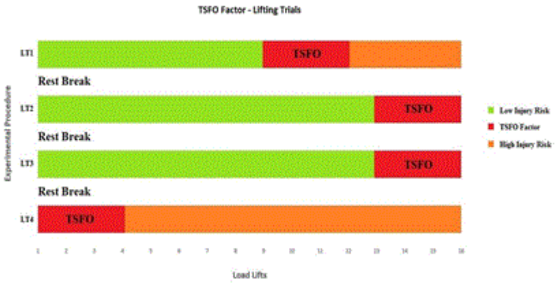

Figure 5: TSFO factor in the LTs.

Fatigue Rate (FR) Hz/LL	Load Lifts (LL)							
	1-4	R2	5-8	R2	9-12	R2	13-16	R2
LT 1	-0.016	0.005	0.162	0.488	-0.514	0.623	-0.451	0.676
LT 2	0.299	0.29	-0.189	0.671	0.074	0.018	-0.328	0.757
LT 3	0.411	0.667	-0.176	0.119	0.201	0.656	-0.417	0.631
LT 4	-0.637	0.787	-0.069	0.032	-0.158	0.471	0.519	0.557

Table 6: Fatigue rate (FR) in every 4 load lifts in all 4 Lifting Trials. Mean values of all volunteers.

Figure 6 showed that muscle activation was the lowest in the 4th LT despite the fact that a five-minute rest-break elapsed.[figure 6]

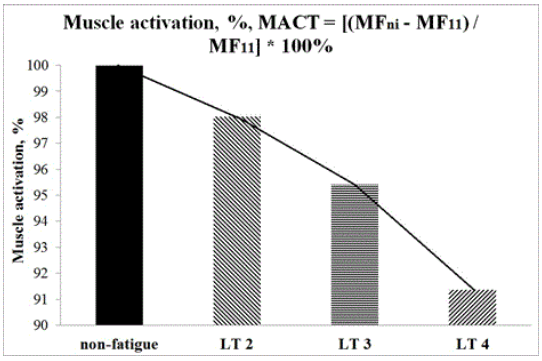

Figure 6: MACT, based on MF values, at the beginning of each LT, compared to the non-fatigued state, after a five-minute rest-break.

NIOSH analysis

The RWL, LI, RT values are shown in table 7. Using the equation 3, the results of the LI at the origin of the lift were found to range between 0.733-1.133, and at the destination of the lift were found to range between 1.412-2.093. Using the equation 4, the recovery time was calculated as RT=4.8 minutes. [Table 7].

Discussion

The present study was part of a larger research to quantitatively estimate low back fatigue accumulation during a repetitive light weight lifting task using different methodologies and interdisciplinary biomechanical approach [11]. In this work the surface EMG represented a fairly non-invasive source of information of the state of erector spinae muscle in a dynamic light weight lifting task. Regarding the variability of muscle characteristics it is evident from the results that a high correlation was found between the number of load lifts and volunteers' discomfort level (r^2=0.862). Thus, the longer the volunteers' working time is, the greater will be the prevalence of low back pain in them. Poor correlation was obtained between Borg's clinical scale results and the volunteer's age (r^2=0.062) (Table 3). This could be due to the young age of the volunteers, to the low standard deviation of their mean age (SD=1.76 years) as well as to the fact that they were healthy, with no signs or symptoms of musculoskeletal disorders.

	NIOSH Results				
	RWL (kg)		LI		RT (min)
	Origin of the lift	Destination of the lift	Origin of the lift	Destination of the lift	
Participant 1	9.53	5.16	1.133	2.093	4.8
Participant 2	9.53	5.16	1.049	1.938	4.8
Participant 3	10.19	4.54	0.927	2.082	4.8
Participant 4	10.23	5.31	0.831	1.600	4.8
Participant 5	9.53	5.16	1.049	1.938	4.8
Participant 6	9.53	4.89	0.913	1.779	4.8
Participant 7	9.53	4.89	0.839	1.636	4.8
Participant 8	10.23	5.31	0.733	1.412	4.8

Table 7: NIOSH analysis results for each volunteer.

The frequency domain results showed that the slopes are negative in all LTs in both MPF and MF diagrams, indicating the appearance of muscle fatigue (figure 4). This finding was in good agreement with previous, in frequency domain, studies which had hypothesized that decrease in median frequency signifies onset of muscle fatigue and was associated with the negative slope of the regression line [24-27]. Unlike our frequency domain analysis, other investigators used different approaches, such as time domain analysis, found that fatigue occurred when time domain parameters such as mean amplitude and root mean square (RMS) amplitude increased [28,29]. In those studies, positive slopes, of time domain parameters, signified the fatigue rates [26,30].

The detecting/prediction of the substantial fatigue onset, which signifies a potential injury risk, is the main stream in the research of occupational health and ergonomics as it is the fundamental inquiry for muscle injury prevention. Many researchers showed that frequency domain analysis of myoelectric signal recorded from erector spinae muscle can be used to detect LBP problems [31]. At the present work for better assessment of the fatigue rate within each LT, the MF regression line slopes were analyzed in every 4 load lifts aiming to determine the TSFO factor (table 6). As shown in table 6 the TSFO factor in the first 3 LTs was found in the second half of the task. In particular TSFO factor was found to be between 9th and 12th LL in the 1st LT and between load lifts 13 and 16 in the 2nd and 3rd LTs. On the contrary, in the 4th LT the TSFO factor appeared immediately after the rest-break, in all participants (Figure 5), signifying high fatigue accumulation despite the fact that the participants had received a rest break. This finding implied that the muscle fatigue at the end of the 3rd LT was in such a high level where it may require a longer rest break for the muscle to recover to pre-exercise level.

Namely the TSFO results showed that the rest period of 5 minutes was not enough for muscle recovery, during the fourth lifting trial. The volunteers were not able to continue their task after 5 minutes rest brake. The corresponding to the rest period recovering time determined by NIOSH is constant for the all duration of 1 hour task and equal to 4.8 minutes (Table 7). This NIOSH finding is not in agreement with the TSFO results. From our experiments it is induced clearly that the rest break, corresponding to the recovery time of the NIOSH approach, should increase progressively with the lifting trials.

In the present work only four lifting trials, till the appearance of the first maximum fatigue accumulation, were studied. Further experiments must be conducted for the determining the progressive increase of the rest period duration so that to correlate the needed time for muscle recovery with rest break duration after the first appearance of the maximum fatigue accumulation.

The results obtained from the values of the TSFO factor were in agreement with the muscle activation results depicted in figure 6. Muscle activation was lower in the 4th LT compared to the muscle activation of the previous two LTs. This finding may imply that the recruitment of motor units of the erector spinae muscle was lower in the 4th LT and according to [32] this LT is identified as the Transition-to-Fatigue stage, which is the fatiguing state before complete exhaustion occurs. Additionally it could be assumed that low recruitment was due to excessive fatigue accumulation which might lead to muscle injury. Other researchers hypothesized that repetitive and low-intensity tasks increase the risk of MSDs and this is caused by the lack of regeneration of the low-threshold motor units (MUs) due to substantial fatigue accumulation resulting eventually in permanent muscle damage [33-35]. This hypothesis may be one of the explanations for the origin of muscle damage caused by substantial fatigue accumulation when performing low-intensity tasks.

The correlation of the fatigue values derived from EMG data, with the corresponding values derived from Borg's clinical rating scale results, showed that there is no coincident between the substantial fatigue onset time period derived from the EMG data and the corresponding derived from the participant's self-evaluated fatigue level values. The fatigue perception, as a sense of discomfort, according to the Borg's clinical scale results, delayed approximately 24.3% ± 4.6% compared to the EMG results. This is a notable finding of the comparison between the TSFO factor and Borg's clinical scale results which confirmed our consideration that the quantitative methods for human fatigue must include also cognitive parameters, as the participant's perceptive fatigue for a holistic approach. Consequently the participants did not perceive early enough the onset of substantial fatigue as determined by the TSFO factor and continued executing the LT. The delayed perception of muscle activity limits may be associated with action of beta-endorphin which is released into the circulation during exercise or work tasks, having a role to improve neuromuscular function and to delay muscle fatigue [36]. This biological mechanism which caused subject excitement may be the main reason for the delayed perception of fatigue by the volunteers who continued the task for approximately another 25% after the TSFO had occurred [37]. This 25% time lag between the TSFO and the Borg's clinical fatigue perception is a significant finding which would help the worker, to stop a potentially dangerous for the muscle task.

The relative limitations of the present study concerned the volunteers involved and the task setting. Since all participants in this study were young and healthy, the TSFO factor results that were found could be used as a safe maximum limit for similar lifting tasks. As the current experiments were performed in a well-controlled laboratory environment, the application of these results to the workplace will require careful consideration of specific working conditions.

In summary, it appears that the final rest-break, before the onset of the 4th LT, did not effectively reduce fatigue accumulation. This finding justifies our definition of TSFO factor since the rest-break had no effect on MF regression line slope. The time period of fatigue accumulation onset assessed by MACT, matched with that calculated from MF regression line slopes. It is suggested that TSFO factor appears to be a reliable index useful for work design of the work/rest ratio and for evaluating the fatigue during repetitive and monotonous tasks in work place.

Conclusion

These findings are important because they showed that the TSFO factor remained almost constant during the last rest-break, implying non-decrease of the fatigue accumulation and thus possible high injury risk. This time period of the task, where the fatigue rate doesn't change during a rest-break, is proposed to be the TSFO which should be considered to the design of the work/rest ratio to avoid muscle injury.

Acknowledgments

This study was financed by the Basic Research Program "K. Karatheodoris", University of Patras. Natus Medical Incorporated, 1501 Industrial Road, San Carlos, CA 94070 USA.

References

1. Forde MS, Punnett L, Wegman DH (2002) Pathomechanisms of work-related musculoskeletal disorders: conceptual issues. Ergonomics 45: 619-630.
2. Cifrek M, Medved V, Tonkovic S, Ostojic S (2009) Surface EMG based muscle fatigue evaluation in biomechanics. Clin Biomech (Bristol, Avon) 24: 327-340.
3. Shin HJ, Kim JY (2007) Measurement of trunk muscle fatigue during dynamic lifting and lowering as recovery time changes. International Journal of Industrial Ergonomics 37: 545-551.
4. Potvin JR, Norman RW (1993) Quantification of erector spinae muscle fatigue during prolonged dynamic lifting tasks. European journal of applied physiology and occupational physiology 67:554-562.
5. Balasubramanian V, Dutt A, Rai S (2011) Analysis of muscle fatigue in helicopter pilots. Appl Ergon 42: 913-918.
6. Armstrong TJ, Buckle P, Fine LJ, Hagberg M, Jonsson B, et al. (1993) A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scand J Work Environ Health 19: 73-84.
7. Sommerich CM, McGlothlin JD, Marras WS (1993) Occupational risk factors associated with soft tissue disorders of the shoulder: a review of recent investigations in the literature. Ergonomics 36: 697-717.
8. Kumar DK, Pah ND, Bradley A (2003) Wavelet analysis of surface electromyography to determine muscle fatigue. IEEE Trans Neural Syst Rehabil Eng 11: 400-406.
9. Nussbaum MA (2001) Static and dynamic myoelectric measures of shoulder muscle fatigue during intermittent dynamic exertions of low to moderate intensity. European Journal of Applied Physiology 85: 299-309.
10. Al-Mulla MR, Sepulveda F, Colley M (2011) A review of non-invasive techniques to detect and predict localised muscle fatigue. Sensors (Basel) 11: 3545-3594.
11. Spyropoulos E, Chroni E, Katsakiori P, Athanassiou G (2013) A quantitative approach to assess upper limb fatigue in the work field. Occupational Ergonomics 11: 45-57.

12. Merletti R, Lo Conte LR, Orizio C (1991) Indices of muscle fatigue. J Electromyogr Kinesiol 1: 20-33.
13. De Luca CJ (1984) Myoelectrical manifestations of localized muscular fatigue in humans. Crit Rev Biomed Eng 11: 251-279.
14. Basmajian JV, Luca Carlo J De (1985) Muscles Alive: Their Functions Revealed by Electromyography. (5th edn.) Williams & Wilkins, Baltimore.
15. Potvin JR, Bent LR (1997) A validation of techniques using surface EMG signals from dynamic contractions to quantify muscle fatigue during repetitive tasks. Journal of electromyography and kinesiology: official journal of the International Society of Electrophysiological Kinesiology 7:131-9.
16. Balasubramanian V, Jayaraman S (2009) Surface EMG based muscle activity analysis for aerobic cyclist. J Bodyw Mov Ther 13: 34-42.
17. de Oliveira CG, Nadal J (2004) Back muscle EMG of helicopter pilots in flight: effects of fatigue, vibration, and posture. Aviat Space Environ Med 75: 317-322.
18. Petrofsky JS (1979) Frequency and amplitude analysis of the EMG during exercise on the bicycle ergometer. Eur J Appl Physiol Occup Physiol 41: 1-15.
19. Kim JY (2002) The study of trunk muscle fatigue and recovery time during isometric extension tasks. Journal of the Ergonomics Society of Korea 21: 25-33.
20. Cramer J, Housh T, Evetovich T, Johnson G, Ebersole K, Perry S, et al. (2002) The relationships among peak torque, mean power output, mechanomyography, and electromyography in men and women during maximal, eccentric isokinetic muscle actions. European journal of applied physiology 86:226-32.
21. Borg G (1982) A category scale with ratio properties for intermodal and interindividual comparisons. (1st edn.) VEB Deutscher Verlag der Wissenschaften, Berlin.
22. Gaudreault N, Arsenault AB, LariviÃ¨re C, DeSerres SJ, Rivard CH (2005) Assessment of the paraspinal muscles of subjects presenting an idiopathic scoliosis: an EMG pilot study. BMC Musculoskelet Disord 6: 14.
23. Waters TR, Putz-Anderson, V, Garg A (1994) Applications Manual for the Revised NIOSH Lifting Equation. US Department of Health and Human Services (NIOSH), Cincinnati, Ohio.
24. Cardozo AC, Goncalves M, Dolan P (2011) Back extensor muscle fatigue at submaximal workloads assessed using frequency banding of the electromyographic signal. Clinical Biomechanics 26: 971-976.
25. De Luca CJ (1997) The use of surface electromyography in biomechanics. Journal of Applied Biomechanics 2: 135-163.
26. Hagg GM, Luttmann A, Jager M (2000) Methodologies for evaluating electromyographic field data in ergonomics. J Electromyogr Kinesiol 10: 301-312.
27. Lariviere C, Arsenault AB, Gravel D, Gagnon D, Loisel P (2003) Surface electromyography assessment of back muscle intrinsic properties. J Electromyogr Kinesiol 13: 305-318.
28. Berzuini C, Maranzana Figini M, Bernardinelli L (1985) Evaluation of the effectiveness of EMG parameters in the study of neurogenic diseases--a statistical approach using clinical and simulated data. IEEE Trans Biomed Eng 32: 15-27.
29. Lariviere C, Gravel D, Arsenault AB, Gagnon D, Loisel P (2003) Muscle recovery from a short fatigue test and consequence on the reliability of EMG indices of fatigue. Eur J Appl Physiol 89: 171-176.
30. Lariviere C, Gagnon D, Loisel P (2000) The comparison of trunk muscles EMG activation between subjects with and without chronic low back pain during flexion-extension and lateral bending tasks. Journal of Electromyography and Kinesiology 10: 79-91.
31. Roy SH, De Luca CJ, Snyder-Mackler L, Emley MS, Crenshaw RL, et al. (1990) Fatigue, recovery, and low back pain in varsity rowers. Med Sci Sports Exerc 22: 463-469.
32. Al-Mulla MR, Sepulveda F, Colley M, Kattan A (2009) Classification of localized muscle fatigue with genetic programming on sEMG during isometric contraction. Conf Proc IEEE Eng Med Biol Soc 2009: 2633-2638.
33. Maas H, Baan GC, Huijing PA (2004) Muscle force is determined also by muscle relative position: isolated effects. J Biomech 37: 99-110.
34. Thorn S, Forsman M, Zhang Q, Taoda K (2000) Low-threshold motor unit activity during a 1-h static contraction in the trapezius muscle. International Journal of Industrial Ergonomics 30: 225-236.
35. Zennaro D, Laubli T, Krebs D, Klipstein A, Krueger H (2003) Continuous, intermitted and sporadic motor unit activity in the trapezius muscle during prolonged computer work. J Electromyogr Kinesiol 13: 113-124.
36. Schwarz L, Kindermann W (1992) Changes in beta-endorphin levels in response to aerobic and anaerobic exercise. Sports Med 13: 25-36.
37. Feldreich A, Ernberg M, Lund B, Rosen A (2012) Increased β-endorphin levels and generalized decreased pain thresholds in patients with limited jaw opening and movement-evoked pain from the temporomandibular joint. J Oral Maxillofac Surg 70: 547-556.