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Evaluation of Vibration Effects of Massage Machines on Muscles Fatigue

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Abstract

Automated massage machines have been widely used in family for the past few years, but there was limit scientific evidence to support for them positive effects. This paper aims to evaluate the massage effects on recovery of muscle fatigue and explore the optimal massage machine design parameters. Two subjects participated in prone bridge exercises to make the erector spinae muscles fatigue before and after massage at six levels of speed. The surface electromyography (sEMG) signals were recorded from erector spinae muscles only during PB exercises. The vibration velocity of beat massage and subjective massage comfort (SMC) were measured at six massage speed. Based on the test data, empirical models were established between vibration velocity, sEMG and SMC. Results indicated that vibration velocity of beat massage had a significant impact on sEMG and SMC. This represents the positive effects of the massage machine on recovery of post-exercise local muscles fatigue.

***Keywords**: sEMG, muscle fatigue, subjective evaluation, vibration velocity, massage machine*

1. Introduction

With the raise of economical and living level, health demands increase subsequently. Numerous massage service industries emerge as the times require. Thus, various types of automated massage devices, especially massage chairs, have been developed and marketed, which simulated several types of manual massage techniques [1, 2]. Since the speed, vibration frequency and body pressure of automated massage chairs can be controlled by electromechanical technology and control strategy [3], it may be more suitable for quantitative analysis of the safe massage effects [4] and restriction the number of variables in experimental study than manual massage [5].

Study on the effects of automated massage become an important issue as the goal of health that demands adequate ergonomic interventions. Zullino et al. [6] tested the effects of general muscle and psychophysiological relaxing properties with an automated massage chair on the back muscle, using questionnaires, sEMG, skin conductance and peripheral skin temperature, but the actual massage effects may be overstated. Durkin et al. [7] used sEMG, NIRS and skin temperature as physiological parameters and psychological scales to demonstrate the beneficial effects of lumbar massage systems on seating comfort, muscle fatigue and so on during prolonged driving tasks. Franz et al. [8] used questionnaire and sEMG to demonstrate that the massage system in automobile seat increased comfort and reduced muscle activity during driving. However, there was little published literature on comfortable or fitted range of pressure, vibration and speed of automated massage.

The present pilot study aimed to examine the massage effects of fatigue recovery based on sEMG for an automated massage chair with beat massage technique in comparison with sitting still on the same massage chair without massage [9]. Furthermore, vibration velocity, SMC and sEMG were measured under six levels of massage speed. Finally, the empirical models of sEMG, SMC and vibration velocity were constracted to determine the fitted vibration velocity of automated massage.

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2. Experiment Methods

2.1. Participants

In order to reduce cost and time, and improve the quality and efficiency of main study, a small scale pilot study was carried out in the ergonomics laboratory. Two male postgraduates participated in the experiment. None of them had any cardiovascular, skeletal muscle and respiratory system diseases. During the experiment, no injury or health problems occurred. The demographic details of subjects are shown in Table 1.

Table 1. Demographic Detail of the Participants

Subject	Age	Height (mm)	Weight (kg)
No. 1	28	1780	70
No. 2	25	1670	62
Mean	26.5	1720	66

2.2. Apparatus and Material

Surface EMG was measured using Flexcomp Infinity by Thought Technology. A certain type of automated massage chair was provided by iRest Equipment Co,.Ltd. The detailed parameters and settings of above two apparatus were the same as [9].The vibration velocity of actual beat massage was measured using the vibration meter (SMART SENOR AR63B).

Rating scales are assessment tools capable of quantifying subjective comfort. In this study, only one part of body was measured so that the SMC rating scale for local muscle massage was adapted from LC&OCRS [10], only to evaluate local comfort perception. A line of fixed 10 cm length was rated from 0 to 10, matching along with discomfort to comfort. The massage contact position was labeled on a human muscle image in this scale.

2.3. Objective and Subjective Measures

The objective measures were composed of six phases. In each phase, subjects were asked to finish three steps, namely prone bridge (PB) exercise to induce fatigue, recovery on massage chair and redo prone bridge (Re-PB) exercise as shown in Figure 1. Only while subjects performed PB and Re-PB, Surface EMG signals were detected. During the recovery steps, subjects sat on the massage chair at different massage speeds in six phases, and the actual speeds were measured by SMART SENOR.

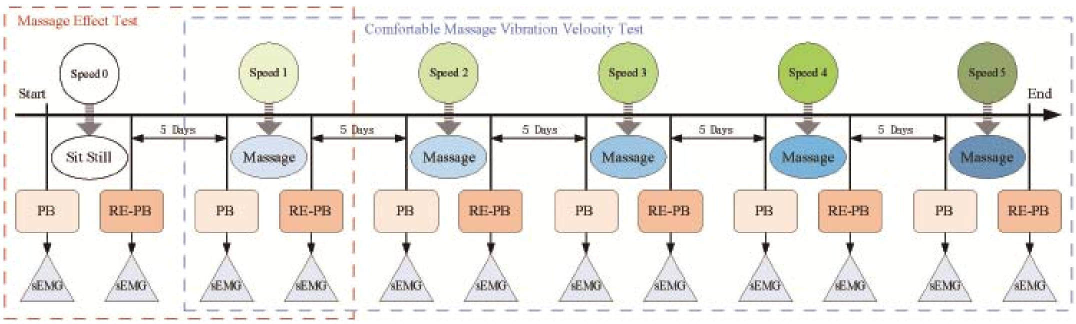

Figure 1. The Experimental Procedure

The massage effect test in Figure 1 was finished in previous study [9]. The sEMG electrodes were placed bilaterally over the greatest convexity of the thoracic erector spinae muscle at the L1–L2 level. In each phase, the sEMG activity with erector spine muscles tested against PB was the benchmark for that against Re-PB. It was hypothesized that the sEMG activity during Re-PB was affected by the effect of fatigue recovery, so the massage effect can be evaluated by comparing sEMG activity during PB and Re-PB in accordance with participants sitting still without massage or massage at 5 level of speeds. Furthermore, the most comfort vibration velocity was selected by the result of sEMG measures and SMC measures.

The subjective measures were carried out after finishing all objective measures. Participants were asked to sit on the massage chair and receive massage on erector spine muscles at 5 levels of speeds in random sequence, confidential to them. At the end of massage at each level of speed, they need fill in SMC rating scale to determine the comfort scores.

The experiments were carried out in September from 9:30 AM every 5 days and lasted for a month. Participants were not allowed to participate in fierce exercises during period of that time in order to ensure adequate rest as far as possible.

2.4. Data Processing of sEMG Indices

Root Mean Square (RMS) as time domain index was the valid sEMG-based fatigue assessment indices [11]. $RMS_{F\text{-}PB}$ and $RMS_{F\text{-}Re\text{-}PB}$ were respectively defined as the average RMS value obtained during first 20 seconds of PB and Re-PB, after the debug time of motion at the beginning of the RMS graphs. $RMS_{B\text{-}PB}$ and $RMS_{B\text{-}Re\text{-}PB}$ were respectively defined as the average RMS value obtained during last 20 seconds, before the debug time of motion at the end of the RMS graphs. ΔRMS was defined as the difference between the average RMS value of front and back experimental sessions [12]. $\Delta RMS_{PB} = RMS_{F\text{-}PB} - RMS_{B\text{-}PB}$, $\Delta RMS_{Re\text{-}PB} = RMS_{F\text{-}Re\text{-}PB} - RMS_{B\text{-}Re\text{-}PB}$. If ΔRMS value was positive, the EMG activity and fatigue tented to decrease; if ΔRMS value was negative, the EMG activity and fatigue tented to increase [12]. The lower ΔRMS was, the more intense EMG activity tended to and more fatigue muscles produced.

Pearson's correlation coefficient (R^2) was used to estimate significant correlation between sEMG, SMC and vibration velocity indice. The linear model, quadratic model and cubic model were used for regression analysis to confirm the optimal fitted curves by the max R^2.

3. Results and Discussion

3.1. Assessment of sEMG Indices

The participants' RMS of PB and Re-PB were shown in Figure 2 and Figure 3: (a) PB speed 0, (b) Re-PB speed 0, (c) PB speed 1, (d) Re-PB speed 1, (e) PB speed 2, (f) Re-PB speed 2, (g) PB speed 3, (h) Re-PB speed 3, (i) PB speed 4, (j) Re-PB speed 4, (k) PB speed 5, (l) Re-PB speed 5. The red lines represented the RMS of left erector spinae muscles, and the blue line represented the right. The values of RMS indices were calculated as shown in Table 2.

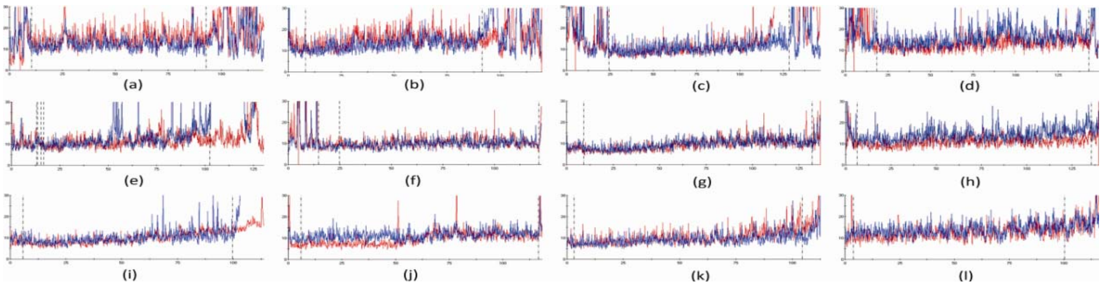

Figure 2. Participant NO.1 RMS

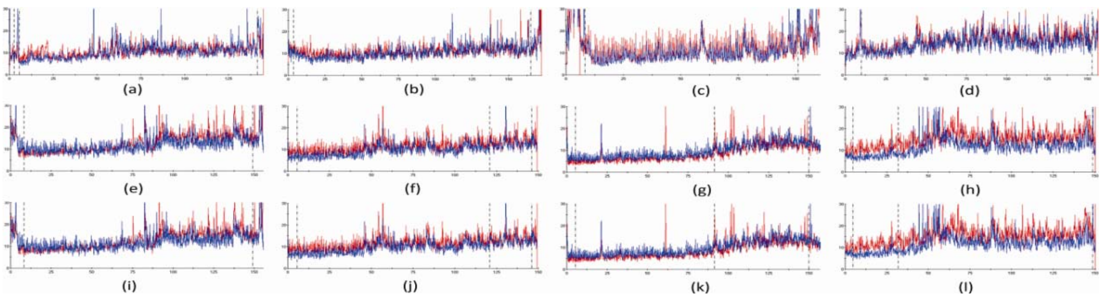

Figure 3. Participant NO.2 RMS

Table 2. Values of RMS Indices

Speed	Subject	$RMS_{F\text{-}PB}$	$RMS_{B\text{-}PB}$	$RMS_{F\text{-}Re\text{-}PB}$	$RMS_{B\text{-}Re\text{-}PB}$	ΔRMS_{PB}	$\Delta RMS_{Re\text{-}PB}$
0	No. 1	12.18	13.705	11.61	14.87	-1.525	-3.26
	No. 2	14.685	15.395	12.78	16.08	-0.71	-3.3
1	No. 1	8.625	9.84	12.07	12.395	-1.215	-0.325
	No. 2	8.41	14.16	10.89	14.31	-5.75	-3.42
2	No. 1	9.83	12.985	9.015	10.655	-3.155	-1.64
	No. 2	6.48	12.595	9.395	13.02	-6.115	-3.625
3	No. 1	7.225	10.505	10.61	12.755	-3.28	-2.145
	No. 2	8.42	11.835	8.96	10.46	-3.415	-1.5
4	No. 1	7.845	10.135	8.96	10.455	-2.29	-1.495
	No. 2	8.945	15.74	8.115	13.42	-6.795	-5.305
5	No. 1	7.935	9.815	11.755	13.31	-1.88	-1.555
	No. 2	6.07	13.43	9.425	15.465	-7.36	-6.04

The *Δ(ΔRMS)*index was proposed to determine the fatigue recovery degree at different massage speeds. $\Delta(\Delta RMS) = \Delta RMS_{PB} - \Delta RMS_{Re\text{-}PB}$. Positive *Δ(ΔRMS)* values implied that the fatigue degree of PB was lower than that of Re-PB, and fatigue recovery was not obvious. Comparatively, negative *Δ(ΔRMS)* values implied that the fatigue degree of PB was higher than that of Re-PB, and the methods of fatigue recovery were effective. Moreover, the lower *Δ(ΔRMS)* value was, the more effective fatigue recovery appeared before Re-PB exercises. Six *Δ(ΔRMS)* values at different massage speeds were shown in Figure 4.

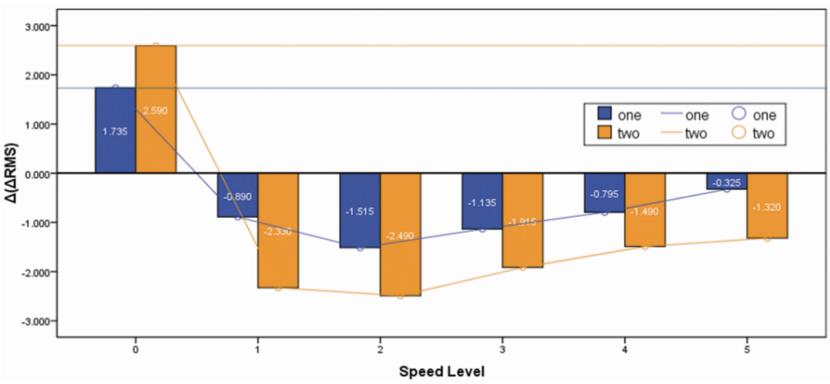

Figure 4. *Δ(ΔRMS)* Values at Six Levels of Speed

3.2. Vibration Velocity of Beat Massage

The 1-5 levels of beat massage vibration velocity were measured. The values of each level were collected every 1 min during 20 min. The descriptive statistics were shown in Table 3.

Table 3. The Descriptive Statistics of Vibration Velocity

Speed Level	Min (mm/s)	Max (mm/s)	Mean (mm/s)	Std	N
1	21.7	25.3	23.645	1.0405	20
2	34.1	38.8	35.825	1.2969	20
3	51.5	53.8	52.575	0.5495	20
4	72.4	74.9	73.690	0.7779	20
5	96.4	97.8	97.095	0.4298	20

3.3. Subjective Evaluation of Massage Comfort

The SMC rating scales were tested by Cronbach's α coefficient (α = 0.983), demonstrating good reliability. The results of SMC evaluation were shown in Figure 5.

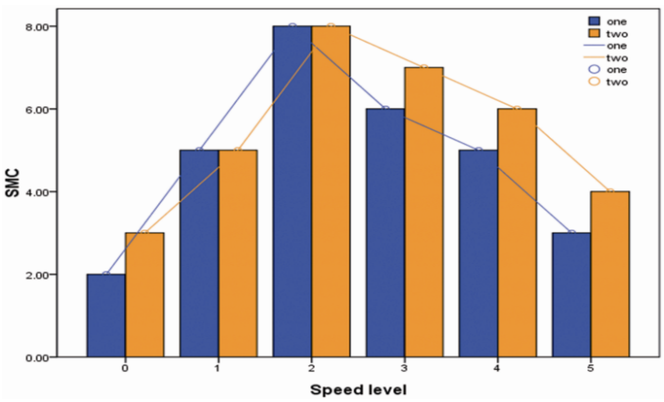

Figure 5. The Scores SMC at Six Levels Speed

3.3. Empirical Modeling and Analysis

This was an interesting finding that highest scores at speed level 2 and lowest scores at level 5 of SMC coincided with those of *Δ(ΔRMS)* values. There was also a highly significant positive correlation (R^2 = 0.976) between SMC scores of two participants. Thus, it was indicated that vibration velocity of beat massage ranged from 34.1 to 38.8 mm/s (speed level 2) produced optimal effects on recovery of muscle fatigue, while vibration velocity ranged from 96.4 to 97.8 mm/s produced minimal effects among speed 1-5.

(1) Regression analysis for RMS and SMC. The scatter plot in Figure 6 was used to establish the link between physiological and psychological indices by the statistics-based curve estimation in SPSS. The cubic model performed best in that R^2 was highest (0.690) and Std. Error of the estimate (1.270) was least among three models.

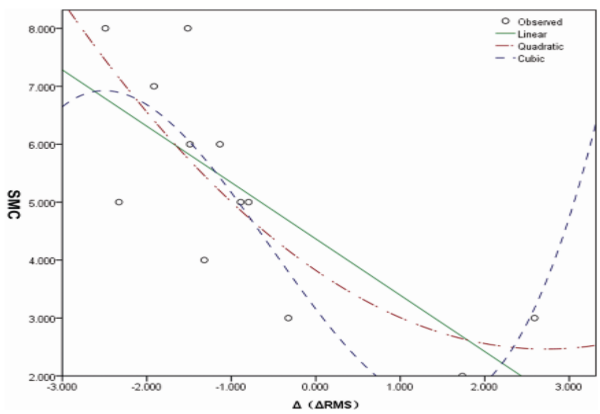

Figure 6. The Scatter Plot and Curve Estimation of *Δ(ΔRMS)* and SMC

(2) Regression analysis for vibration velocity and RMS. The model between vibration velocity of beat massage and *Δ(ΔRMS)* values was established in Figure 7. The cubic model performed best among three models (R^2 = 0.891, Std. Error = 0.594, P = 0.000).

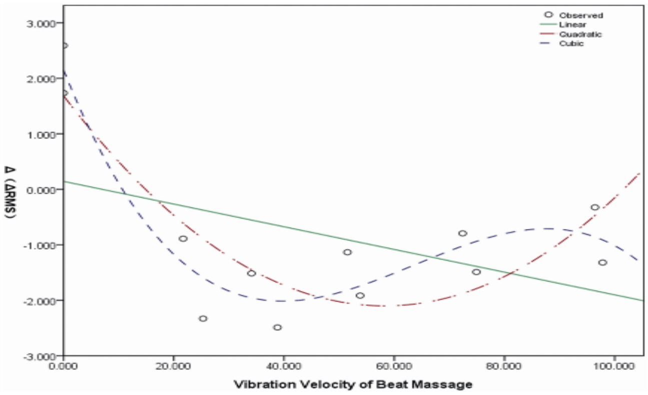

Figure 7. The Scatter Plot and Curve Estimation of Vibration Velocity and *Δ(ΔRMS)*

(3) Regression analysis for vibration velocity and SMC. The relationship between vibration velocity of beat massage and SMC scores was shown in the curve fit chart, Figure 8. Both quadratic and cubic models followed the shape of the data.(Quadratic model: R^2 = 0.795, Std. Error = 0.974, P = 0.001; cubic model: R^2 = 0.814, Std. Error = 0.984, P = 0.003).

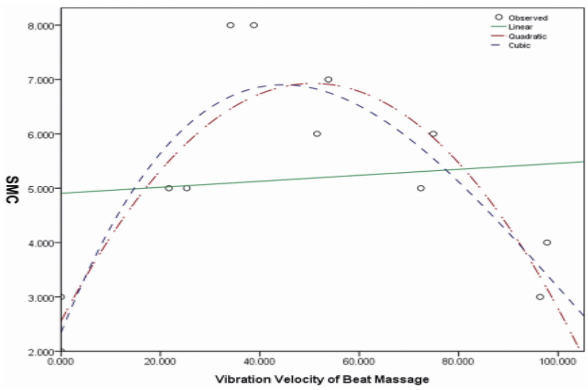

Figure 8. The Scatter Plot and Curve Estimation of Vibration Velocity and SMC

Among three empirical models, the cubic model between vibration velocity of beat massage and *Δ(ΔRMS)* performed best, due to all objective data. It can be said that the variations of RMS index of sEMG of PB exercises before and after massage were influenced by different speed levels of beat massage. In this experimental automated massage machine provided by iRest, the speed level 2 of beat massage technique, mean of vibration velocity 35.825 mm/s, was the most comfort and effective massage speed to relax the fatigue of erector spine muscles for two subjects participated in the study. Moreover, the correlation between vibration velocity of beat massage and SMC was strong in quadratic and cubic models, so the subjective evaluation of massage comfort at different speeds was verified to be reliable and valid.

3.4. Discussion

The experimental study involved physical, physiological and physiological variables. The automated massage techniques such as beat, knocking, and shaking, can be physically described as vibration velocity variable. The *Δ(ΔRMS)* index of sEMG was proposed to indicate the fatigue degree between PB and Re-PB. Only when two participants sat still in massage chair without massage, *Δ(ΔRMS)* values were positive. From the mean of vibration velocity 25.7 mm/s to 97.8 mm/s, *Δ(ΔRMS)* values were all negative, which demonstrated the automated beat massage had beneficial effects on fatigue recovery of erector spine muscles in Re-PB exercises. The most comfort massage speed was determined by the consistency of *Δ(ΔRMS)* values and SMC scores. Three models between vibration velocity, *Δ(ΔRMS)* and SMC were established with strong correlation. The experimental results showed different vibration velocity of beat massage influenced the sEMG and SMC in manners of cubic curve-fitting equations. Overall, the proposed experimental methods were feasible in ergonomic evaluation of massage effects for automated massage machines.

However, there were some limitations in this study. Other massage techniques in automated massage machines, such as effleurage, kneading, shiatsu, roll-stretch and so on, simulating manual massage, were difficult to be translated directly into physical indices. The sEMG-measured muscles were restricted within the location the massage device working, although the the FlexComp Infiniti encoder can record multichannel sEMG, so a multipoint massage machine is required to measure more universal physiological information, if possible.

4. Conclusion

In general, we established empirical models between vibration velocity, sEMG and SMC, and demonstrated quantitatively that the beneficial physiological and psychological effects of post-exercise local muscles fatigue recovery resulted from automated beat massage. In future studies, we should enlarge the sample sizes, including the number of subjects, muscles, the kinds of massage techniques and the range of vibration, to develop more accurate prediction models, which enable manufacturers to produce massage devices in terms of human factors.

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References

[1] Terashima K, Kitagawa H, Miyoshi T, et al. Modeling and massage control of human skin muscle by using multi-fingered robot hand. *Integrated Computer-Aided Engineering*. 2006; 13(3): 233-248.
[2] Xiaoqin Y, Yonggen X, Lüzhong M, et al. Choosing Optimum and Kinematical Analysis of End-effectors of Chinese Massage Robot. *China Mechanical Engineering*. 2010; 21(24): 2899-2903.
[3] Teramae T, Kushida D, Takemori F, et al. *Control Strategy for the Massage Chair Based on Human Skin Elasticity*. SICE 2007 Annual Conference. Takamatsu. 2007: 631- 636.
[4] Zeng H, Butterfield TA, Agarwal S, et al. An engineering approach for quantitative analysis of the lengthwise strokes in massage therapies. *Journal of Medical Devices*. 2008; 2: 041003.
[5] Field T, Diego M, Hernandez Reif M. Massage therapy research. *Developmental Review*. 2007; 27(1): 75-89.
[6] Zullino DF, Krenz S, Frésard E, et al. Local back massage with an automated massage chair: general muscle and psychophysiologic relaxing properties. *Journal of Alternative & Complementary Medicine: Research on Paradigm, Practice, and Policy*. 2005; 11(6): 1103-1106.
[7] Durkin JL, Harvey A, Hughson RL, et al. The effects of lumbar massage on muscle fatigue, muscle oxygenation, low back discomfort, and driver performance during prolonged driving. *Ergonomics*. 2006; 49(1): 28-44.
[8] Franz M, Zenk R, Vink P, et al. The effect of a lightweight massage system in a car seat on comfort and electromyogram. *Journal of Manipulative and Physiological Therapeutics*. 2011; 34(2): 107-113.
[9] Yang Zhongliang, Sun Shouqian, Chen Yumiao. A pilot study on ergonomics evaluation model of massage chair performance based on sEMG. *China Mechanical Engineering*. 2012; 23(2): 220-224.
[10] Zhongliang Y, Shouqian S, Zenggui G, et al. *Correlation model of overall and local sitting comfort based on rating scales*. Computer-Aided Industrial Design & Conceptual Design (CAIDCD). Yiwu. 2010; 1: 624-628.
[11] Mannion AF, Connolly B, Wood K, et al. The use of surface ENIG power spectral analysis in the evaluation of back muscle function. *Development*. 1997; 34(4): 427-439.
[12] Kolich M, Taboun SM. Combining psychophysical measures of discomfort and electromyography for the evaluation of a new automotive seating concept. *International Journal of Occupational Safety and Ergonomics*. 2002; 8(4): 483-496.