Biomechanical model to estimate recovery time on highly repetitive work in maquila operations

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Resumen: El propósito de este trabajo es desarrollar un modelo biomecánico que permita hacer estimaciones de los tiempos de recuperación, basado en un número importante de variables obtenidas de condiciones de trabajo reales, donde, el mismo grupo de músculos está expuestoal trabajo repetitivo y a bajos esfuerzos. Las variables independientes están relacionadas con las características de los trabajadores y del trabajo. Las variables de respuesta son el tiempo de recuperación y la fatiga percibida. Los datos se obtuvieron de industrias maquiladoras del noroeste de México.

Palabras clave: Modelo biomecánico, trabajo repetitivo, maquiladora

Abstract: The purpose of this research is development a biomechanical model allowing estimating the recovery time based on an important number of variables, obtained from real work conditions, where the same muscle group is exposed to repetitive work and low efforts. Independent variables are related to personal characteristics and work characteristics. Response variable are recovery time and perceived fatigue. Data were obtained from workers and work stations from Maquila industries in northwest Mexico. The research is based on considerations about anthropometrics from a Mexican population, genre and hour of work.

Keywords: Biomechanical modeling, repetitive work, cumulative effect of force, maquila

1. Introduction.

Assessment of human work has been a fundamental element on the ergonomics evolution, actually there is a wide variety of methods for the ergonomics assessment of work stations, however, at the moment that the ergonomist needs a tool, sometimes there is the constraint which results usually shows the most risky condition, in terms of a work muscle skeletal disorder, it means that shows a value qualifying a single moment of work, while the work remains continuous along the journey.

The work doing by the hands has been a very important factor on manufacturing industries, especially on development countries, but the human being and its physical characteristics at service of material transformation trough industrial process it is not an endless power supply, while time pass away, physical performance could be affected and modified.

As a result of frequent exposure to work there is a risk of musculoskeletal injuries, Bernard et al (1997) refers that it´s “were recognized as having occupational etiologic factors as early as the beginning of the 18th century. However, it was not until the 1970s that occupational factors were examined using epidemiologic methods, and the work-relatedness of these conditions began appearing regularly in the international scientific literature. Since then the literature has increased dramatically; more than six thousand scientific articles addressing ergonomics in the workplace have been published. Yet, the relationship between MSDs and work-related factors remains the subject of considerable debate.”

Continuous and repetitive tasks could lead to disorders on the soft tissues on joints. The tissues that frequently get injured as a result of exposure to occupational biomechanical hazards are ligaments, tendons and muscles. Other structures affected less frequently are cartilage and bones. All biological tissues are visco-elastic; hence, their mechanical properties are time- and strain rate-dependent. The tissue visco-elastic property determines the duration required for complete mechanical recovery, Kumar (2001).

Disorders on the soft tissues are well known as cumulative trauma disorders (CTD´s), it´s basically a combination of factors or occupational activities that leads to these injuries, Keyserling et al (1993) includes repetitive motions, forceful exertions, and awkward postures. Bernard et al (1997) presents an evaluation and summary of the epidemiologic evidence focuses on disorders affecting the neck and the upper extremity; including tension neck syndrome, shoulder tendinitis, epicondylitis, carpal tunnel syndrome, and hand-arm vibration syndrome, which have been the most extensivelystudied in the epidemiologic literature. Combination of these risk factors on the same activities increases the possibility of injuries in wrist and shoulder while neck disorders are related to awkward posture, for instance.

CTD´s cost days and money so there are relevant, the BLS (2005) reports 1,234,700 workdays lost in USA. In the same year there were 270,890 reported injuries in low back. Bernard et al (1997) reports 32% of injuries were due to excessive efforts or repetitive tasks. In specific, 65% of cases were caused by effort to lifts objects or materials, affecting low back, 52% were caused by pushing or pulling. But it´s not only low back injuries, the report includes 47,681 shoulder injuries and 92,576 injuries associated to repetitive movements, 55% of that affected wrist.

Muggleton et al (1999) refers to injuries related to work as typical injuries on XX century and consider it´s as the bigger of problems on occupational wealth. On United Kingdom, upper limb musculoskeletal disorders are the most frequent just below low back pain injuries. CTD external causes says, are related with the pressure on industry business for increasing productivity. In consequence, costs for; medical attention, incapacities days, lost workdays, employs rotation, absenteeism costs, have been increased too.

Viikari-Juntura (1997), notes the need of programs and strategies to prevent occupational injurieswhile lost days increases on industrial countries, as well as development countries. The European Union is working on rules and laws about occupational injuries, focusing in harmonizing it´s legislation.

In México, according to the IMSS (Mexican Institute for the Social Safety) in 2006 were reported 138,700 work injuries in hand-wrist and low back area. The Mexican legislation and rules doesn´t make any difference between accident and occupational injuries.
In northern México, in Border States the data are the follows:

Table 1. Work related injuries in Nothern Mexico..

State	Injuries	Hand-wrist	Low back
Nuevo León	29054	10425	3264
Baja California	16308	6025	2041
Sonora	12074	3678	2127
Tamaulipas	11823	3691	1734
Chihuahua	1762	453	239
Coahuila	1425	358	149

1.1 Occupational injuries. The risk factors are related with injuries in joints and soft tissues. There are several terms to name it, Grieco et al (1998) defines as “Work Musculoskeletal Disorders; WMSD”, but frequently is used as a synonymous “Cumulative Trauma Disorders (CTD´s)” or “Repetitive Strain Injuries (RSI)”. Grieco et al (1998) associate as characteristics of these injuries the follows: Its origin is due to several factors (occupational and personal), it take long time to develop the disorder, recovery are used to be slow and probably never at 100%, frequently involves groups of tendons and muscles and that one’s caused by nerves pressed are de lesser frequents but the painful and costly.

1.2 Ergonomic Risk Factors. To understand the musculoskeletal disorders problem, is required to identify the risk factors associated to these kinds of injuries. There is a wide literature about it and its don´t surprise, the problem has been studied for years and many point of views and results of research converge on the causes or risk factors, Colombini (1998) recognize mainly four risk factors; repetitive movements (frequency), force applied to the task, awkward postures and lack of enough recovery time on each work cycle. Muggleton (1999) includes vibration as a risk factor for the hand-wrist. McAtamney y Corlet (1973) refers to the risk factors as external factors, including a consideration for static work load on muscles. Furthermore, highly repetitive work may directly damage tendons through repeated stretching and elongation, as well as increase the likelihood of fatigue and decrease the opportunity for tissues to recover Keyserlin et al (1993).

The focus of this project is on the repetitive effect on recovery time based on manufacturing activities at high level of repetition which is the most of the tasks that operators perform on maquila industries in basically all Northern of México.

Is well known the wide ergonomics assessment techniques available in present, Liand Buckle (1999) mentioned that exposure to risks for potential work-related musculoskeletal injuries has been assessed using a variety of methods, including pen and paper based observation methods, videotaping and computer-aided analysis, direct or instrumental techniques, and various approaches to self-report assessment.

The purpose of this research is develop a model to describe the effect of repetitive task and predict the recovery time for continuous task and includes subjective factors as perceived fatigue, this last factor in order to explain the presence of tape on finger tips or wrist protections.

2. Method.

It is very relevant to the success of this project obtain the data from real conditions, that means going to the assembly production lines on maquilas and get the data. The first step consists tochoose the work stations, video recorder it, get data: anthropometric and operational and perceived fatigue.

We appreciate the support from the maquila, they let Us to see the process, mostly of it is confidential, for the first step 23 workstations were analyzed, the variables included are; height, weight, angle on shoulder (RH) to perform a sustained effort and the time on that posture. Additionally, a perceived fatigue questionnaire was ask to answer for, it qualifies from 0 to 3 presences of any symptoms like numbness, pain or stiffness, were 0 means no symptom at the end of the work shift, 1 means seldom times remember any symptom, 2 is related to occasionally feels any symptom and 3 are related to frequent symptoms. For each workstation were considered two activities involving shoulder posture.

On second step data were analyzed using 3D SSPP© and Rohmert formula to estimate recuperation time for each operator. The third step involves the linear regression analysis and the Bayesian approach to optimize the time recuperation model. WinBUGS is the tool for Bayesian.

3. Results

All collected data are at the end, summarizing, 46 data were analyzed for the 23 operators; it’s due to the use of two different exertion times. On each job the angle on shoulder was measured and every workstation was modeled using the 3D SSPP© software to obtain the moment on the shoulder. Moment and sustained effort time on seconds were used to introduce as data to Rohmert formula, the result is the recovery time for the shoulder, expressed on seconds on different posture, for every 60 seconds of work.

3.1 Statistical analysis. The analysis was made using SPSS© software. In the beginning, the moment on shoulder was considered as a variable, it’s give an excellent correlation r = .918 with an adjust r = .819 which means a high explanation to the variability of the data, but moment on the practice is not an easy data to calculate, that´s why we optioned a less efficient model but easy to use and understand.

Subtracting the moment the model summary is:

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.858[a]	.737	.708	5.52370

a. Predictors: (Constant), TESF, FatPer, Angulo, Estatura, Peso

The linear regression model obtained is shown as follows:

Coefficients[a]

Model		UnstandardizedCoefficients		StandardizedCoefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-28.025	29.563		-.948	.348
	Estatura	.220	19.919	.001	.011	.991
	Peso	-.115	.079	-.133	-1.454	.153
	Angulo	.466	.082	.436	5.684	.000
	FatPer	1.068	1.097	.077	.974	.335
	TESF	1.208	.128	.716	9.451	.000

a. Dependent Variable: TREC

Expressed on the mathematical form, the model is:

Recovery Time= -28.025 + .22*Height - .115*Weight + .466*Angle + 1.068*Perceived Fatigue + 1.208*Sustained effort time

3.2 Bayesian Analysis. The Bayesian analysis is included in order to optimize the linear regression model coefficients, on this approach; coefficients leave the parameter condition in the model becoming a variable on the model. WinBUGS is a tool developed to perform Bayesian, based on Markov Chain and Monte Carlo methods the software allows simulate a great number of repetitions.

There are some additional considerations to made; variables fit a normal distribution. On every variable the software run more than 10,000 iterations.

The linear regression model has change as follows:

Recovery Time= -44.13+ 5.22*Height -0.1227*Weight + 0.5464*Angle -0.02*Perceived Fatigue + 1.534*Sustained effort time

The resulting model is based on the original linear regression model but coefficients become variables with its own statistical distribution.

Bayesian analysis is a very useful tool when experiments are limited and especially when the data come from human characteristics and a cross functional approach are used on the research.

4. Discussion

The linear regression model optimized can now be used to estimate recovery times on repetitive operations but is necessary draw some limitations; to verify the accuracy of the model it was run with different exertion times, the model result on negative values for recovery time when the exertion timeis below 10 seconds and for exertion times higher than 30 seconds results are considerably greater that could made efficient on process get on low values, so it has and impact on costs.

In test stage, when exertion times are below 10 seconds, recovery time calculated by Rohmert formula result on values around 2 seconds or lower, that could be interpreted like low risk operations due to repetitiveness and classifieds on green codes. On the other hand exertion time over 30 seconds results on high repetition rates having an effect on sustain effort and consequently on a high risk for an occurrence of occupational injuries.

The application of the model is not complicated, the input variables are the predictors variables; the height is expressed on meters, the weight is in kilograms, the angle on the shoulder can be measured using a goniometer, perceived fatigue could be get asking to the operators for the presence of any symptom described before and exertion time can be measured by a chronometer or analyzing the video time counter. Once the data are collected, introduce it in the formula and the results are expressed on how many seconds per every 60 seconds cycle are needed to recover a group of muscles from fatigue due to the job.

The application of the model could be extensive on a future to other groups of muscles, for instance low back muscles or wrist articulation, increasing the focus of the research, increasing the analysis of different jobs when those are repetitive. At the end the final purpose is bringing a little more on safety on daily performance allowing to people return home with a little bit more energy to share with the family.

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DATA

Height	**Weight**	**Shoulder *Angle***	***Perceived Fatigue***	**T exer**	**T rec**
1.62	64	60	3	15	9.84
1.61	59	45	2	14	5.23
1.53	61	45	0	12	3.39
1.56	60	40	1	18	7.72
1.61	55	40	2	17	6.53
1.61	65	45	3	10	2.73
1.58	61	40	3	15	5.3
1.54	58	35	2	20	7.19
1.60	66	55	3	15	9.51
1.65	58	35	3	19	8.35
1.64	67	65	2	13	8.39
1.56	57	55	3	16	8.01
1.58	56	60	3	21	17.25
1.62	65	40	2	18	9.99

1.61	67	46	2	15	1.33
1.72	86	40	2	16	2.54
1.62	74	40	2	14	0.91
1.58	81	55	3	19	12.41
1.58	54	30	3	21	6.82
1.63	56	50	2	25	24.98
1.62	64	60	3	21	22.05
1.61	59	45	2	26	23.11
1.53	61	45	0	24	17.88
1.56	60	40	1	29	24.27
1.61	55	40	2	27	19.82
1.56	52	30	2	26	9.62
1.61	65	45	3	24	35.11
1.58	61	40	3	26	19.83
1.54	58	35	2	29	17.54
1.60	66	55	3	23	26.52
1.60	53	35	2	22	9.04
1.55	50	40	2	23	9.95
1.65	58	35	3	27	19.4

1.64	67	65	2	21	26.51
1.56	57	55	3	29	33.39
1.58	56	60	3	25	26.22
1.62	65	40	2	28	28.84
1.68	102	45	3	22	14.33
1.67	77	30	3	24	2.05
1.72	86	40	2	28	9.75
1.52	75	39	3	22	0.86
1.62	74	40	2	21	2.42
1.58	81	55	3	30	37.15