RISK ASSESSMENT OF DEVELOPING DISTAL UPPER EXTREMITY DISORDERS BY STRAIN INDEX METHOD IN AN ASSEMBLING ELECTRONIC INDUSTRY

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Abstract- The strain index (SI) is a substantial advancement and has been devised to analyze ergonomic risks for distal upper extremity (DUE) disorders. This semi-quantitative tool allows for the measurement of hazards and does not require unduly lengthy training to begin to use it accurately. Uses of the strain index include analysis of a current job to assess whether it is safe or hazardous, quantification of the risks, and assistance in the initial design of a job or in the redesign of a job. The aim of this study was to assess and analyze risk of developing DUE disorders in different jobs as well as hazard classification in an assembling electronic industry through SI method. Also, DUE disorders prevalence, work-related absenteeism and turnover extracted from SI results were compared and assessed by those obtained by Nordic musculoskeletal questionnaire (NMQ). The findings of this study showed that more than 50% of investigated jobs are categorized as "hazardous" and there is a significant difference between SI mean in hazardous and safe jobs ($P < 0.0001$). In addition, significant difference was found between prevalence of DUE disorders in "safe" and "hazardous" jobs ($P < 0.049$). But, no significant difference ($P = 0.3$) was obtained between mean absenteeism in "safe" and hazardous jobs. Also, no significant difference statistically was found between turnover in "safe" and hazardous jobs ($X^2 = 0.133$, $P = 1$) and high prevalence of DUE disorders is due to low turnover rate of workers.

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Key words: Risk factors, risk analysis ergonomics, distal upper extremity, musculoskeletal disorders, strain index method, Nordic musculoskeletal questionnaire

INTRODUCTION

Musculoskeletal disorders (MSDs) of upper extremities are associated with highly repetitive occupational activities, especially those involving high force, extreme joint postures and exposure to vibration.

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High automation increases those disorders. Mechanization and automation decrease workload, but increse work pace and forces to be exerted on small anatomic elements such as wrist and hand.

By utilizing quantitative methods in MSDs investigations and other related occupational health studies in which risk assessment is involved, one of the assets of the method is to assist the user in identifying the specific aspect of the job that is driving the method towards a hazardous assessment and therefore allows for a targeted approach to best eliminate or lower the risk. One of the methods for exposure assessment of musculoskeletal stressors of distal upper extremity (DUE) is strain index (SI), which were proposed by Moore and Garg (1). The SI is a semi-quantitative job analysis methodology based upon principles of physiology, biomechanics and epidemiology (2). Its purpose is the identification of jobs that place workers at increased risk of developing disorders in the DUE (elbow, forearm, wrist, hand). Application of the SI methodology results in a numerical score (the SI score) that, based on interpretation guidelines, predicts whether a job exposes workers to increased risk of developing DUE disorders, *i.e.* if the job is a "problem". Several researches such as More and Grag (1, 3) and Hegmann *et al.* (4) have shown the application of SI in analyzing jobs for DUE disorders in different workplaces. Enough evidence of external validity (generalizibility) and predictive validity of this method have also been reported by Moore *et al.* (5), Knox *et al.* (6), Wands *et al.* (7) and Rucker and Moore (8).

This cross-sectional and descriptive-analytical study assesses and analyses risk of DUE disorders through both Nordic musculoskeletal questionnaire (NMQ) and SI method together with hazard classification in an assembling electronic industry.

MATERIALS AND METHODS

NMQ was used to determine the prevalence of MSDs symptoms (9). NMQ comprises general information about age, weight, height, smoking habit, work experience and shift type and also includes body part-specific questions (neck, shoulders, elbows, forearm, wrist, upper and lower back). A body "map" was also used to make it easier for workers to understand and to pinpoint problems in each body area.

Consistent with physiological, biomechanical and epidemiological principles, the SI methodology is based on multiplicative interactions among its task variables. The SI score represents the product of six multipliers that correspond to six task variables. The six task variables include intensity of exertion, duration of exertion, exertions per min, hand/wrist posture, speed of work and duration of task per day. Intensity of exertion, hand/wrist posture and speed of work are estimated through rating criterions as presented in tables 1 to 3. Duration of exertion, exertions per min and duration of task per day are measured. Based on these estimated or measured data, each of the task variables are rated according to five ordinal levels using table 4.

The user finds the column heading corresponding to the appropriate task variable, moves down to the appropriate row within that column, then follows the row to the first column on the left hand side to identify the appropriate rating. The multipliers for each task variable are determined from the ratings using table 5. The user finds the column heading corresponding to the appropriate task variable and the row corresponding to the appropriate rating, then identifies the multiplier at the intersection of the task variable column and rating row. The SI score is the product of the six multipliers.

In this study 25 job groups and 35 jobs of single task were chosen only for SI assessment (multiple tasks is not considered and accounted in this method) and 69 workers filled out NMQ questionnaire. In SI method each job was broken into the tasks and task variables estimated for both hands of qualified workers through SI scoring. Risk of developing DUE disorders were accounted as "hazardous" for those having SI criterion more than 5 for classification jobs in one of both sides (left and right). Jobs in which obtained SI scores were less than 5 for both sides were accounted as "safe".

Table 1. Rating criterion for estimation of intensity of exertion (an estimation of the strength required to perform task)

Rating criterion	Percent of MS	Borg scale*	Perceived effects
Light	< 10	≤ 2	Barely noticeable
Somewhat hard	10-29	3	Noticeable or definite effort
Hard	30-49	4-5	Obvious effort: changes facial expression
Very hard	50-79	6-7	Substantial effort: changes facial expression
Near maximal	≥ 80	> 7	Uses shoulder or trunk to generate force

Abbreviation: MS, maximal strength
* Compared to Borg CR-10 scale (10)

Table 2. Rating criterion for estimation of hand/wrist posture (an estimation of the position of the hand or wrist in comparison with neural position)

Rating criterion	Wrist extension*	Wrist flexion*	Ulnar deviation*	Perceived effects
Very good	0°-10°	0°-5°	0°-10°	Perfectly neutral
Good	11°-25°	6°-15°	11°-15°	Near neutral
Fair	26°-40°	16°-30°	16°-20°	Non-neutral
Bad	41°-55°	31°-50°	21°-25°	Marked deviation
Very bad	> 60°	≥ 50°	> 25°	Near extreme

* Derived from Stetson *et al.* (11).

Table 3. Rating criterion for estimation of speed of work (an estimation of how fast the worker is working)

Rating criterion	Compared to motion and time*	Perceived effects
Very slow	≤ 80°	Extremely relaxed pace
slow	81-90%	"taking one's own time"
Fair	91-100%	"normal" speed of motion
Fast	101-115%	Rushed, but able to keep up
Very fast	> 115%	Rushed and barely or unable to keep up

* Derived from Barnes (12).

Table 4. Rating for the strain index task variable are assigned by finding the row within the column that corresponds to the datum for each task variable, then recording the rating value listed in the first column (left hand side)

Rating	Intensity of exertion	Duration of exertion (percent of cycle)	Efforts/ minute	Hand/ wrist posture	Speed of work	Duration per day (hrs)
1	Light	< 10	< 4	Very good	Very slow	≤ 1
2	Somewhat hard	10-29	4-8	Good	Slow	1-2
3	Hard	30-49	9-14	Fair	Fair	2-4
4	Very hard	50-79	15-19	Bad	Fast	4-8
5	Near maximal	≥ 80	≥ 20	Very bad	Very fast	≥ 8

Table 5. Multipliers for each strain index task variable are determined by finding the intersection of the appropriate rating row with the appropriate task variable column

Rating	Intensity of exertion	Duration of exertion (percent of cycle)	Efforts/ minute	Hand/ wrist posture	Speed of work	Duration per day (hrs)
1	1	0.5	0.5	1.0	1.0	0.25
2	3	1.0	1.0	1.0	1.0	0.5
3	6	1.5	1.5	1.5	1.0	0.75
4	9	2.0	2.0	2.0	1.5	1.0
5	13	3.0*	3.0*	3.0	2.0	1.5

* If duration of excretion is 100%, then efforts/ minute multiplier should be set to 3.0.

A digital chronometer, Handhart Stops-star 2 model, recorded job observation times and a goniometer was used for measuring wrist flexion/extension angles at different positions with respect to natural position. Six task variables were measured and calculated based on More and Garg method (2).

Total observation times were measured based on 5-10 job cycle and then its average was accounted as mean average of total observation time in terms of seconds. Also, duration of exertion was calculated by measuring the duration of all exertions during an observation period, then dividing the measured duration of exertion by the total observation time and multiplied by 100. Effort per minutes were measured by counting the number of exertions occurring during an observation period, then dividing the number of exertions by the duration of observations period in terms of minutes. The SI computed by SI software, a computerized system that is prepared by Occupational Health Logic (13). NMQ results were then standardized and together with all obtained SI data analyzed and compared using SPSS software version 10.0 on a personal computer.

RESULTS

Distal upper extremity disorders prevalence data were collected and analyzed through 69 workers based on their jobs and frequencies as presented in table 6. Initial information showed that among 69 workers, 46.4% (32 workers) and 53.6% of them were male and female, respectively and mean average of work experience 3.8 years (SD = 3.2) in the range of 1-17 years. Mean average of age is 29 years (SD = 5.79) and 30.4% of 69 workers belong to age group of less than 25 years whilst 7.2% of them are grouped into > 40 years old. Absence rate (*x*= 1.07, SD= 7.22) and turnover (5.8%) were found to be low within 1 year and 61 workers (88.4%) work with right hand. Of the 69 workers, 67 (97.1%) had DUE disorders.

Table 7 represents absolute and relative frequencies of DUE disorders and clearly shows that more than 50% of disorders belong to hand and wrist.

Table 8 summarizes the data of task variable and Strain Index scores for each of the 35 jobs in 68 sides (right and left). It shows the task variables ratings for intensity of exertion, duration of exertion, efforts per minute, hand/wrist posture, speed of work, and as well as duration task per day.

The Strain Index score is also reported along with “hazard” and “safe” classification. The obtained strain index scores for 68 sides varied from a minimum score of 0.5 to a maximum of 18.9. Investigation of the results showed that 20 (57.1%) jobs were “hazardous” and 15 (42.9%) were to be “safe” and this mean that the jobs of 46 workers (66.7%) are categorized as "hazardous" and 23 workers (33.3%) have "safe" jobs in comparison with Strain Index criterion of 5 as proposed by Moore and Garg (2). Also, the mean average of Strain Index score for all jobs was 7.3 (range: 1.5-18.9) and this for “hazardous” and “safe” jobs were 9.3 (SD = 3.61) and 3.3 (SD = 0.8), among 46 and 23 workers, respectively. This difference was also statistically significant ($P < 0.0001$). Chi Square test showed that no significant difference existed in work turnover between “safe” and “hazardous” jobs (X^2=0.133, $P = 1$).

Table 6. Absolute and relatively frequencies of workers in each job

Job category	Number of worker	Relative frequency (%)	Job category	Number of worker	Relative frequency (%)
VCD3	1	1.4	Screen lamp installment	3	4.3
Rolling pin press	1	1.4	Chassis installment	2	2.9
APT1	3	4.3	RGB installment	3	4.3
Cut and clinch	3	4.3	Final Control	2	2.9
Manual assembling	8	11.6	Horizontal and vertical screen adjustment	2	2.9
Soldering	1	1.4	Screen adjustment and white balance	2	2.9
Wire cutting	2	2.9	Focus and convergence adjustment	2	2.9
Soldering check	4	5.8	Final quality control (QC2)	6	8.7
APT2	2	2.9	Cabinet enclosing	3	4.3
Working	5	7.2	Cleaning whole TV	2	2.9
TV cabinet preparation	2	2.9	Labeling	2	2.9
Power switch Installment	2	2.9	Packing	4	5.8
AV socket installment	2	2.9	**Total**	69	100

Table 7. Absolute and relative frequency of DUE disorders

DUE disorders	Number of workers
Hand	51
Wrist	56
Forearm	33
Elbow	24

Abbreviation: DUE, distal upper extremity.

Figure 1 shows absolute and relative frequencies of DUE disorders between "hazardous" and "safe" jobs and it is revealed that relative frequencies of DUE disorders in "hazardous" jobs for hand and wrist are 58% and 56.6%, respectively and this for elbow decreases to 21.7%.

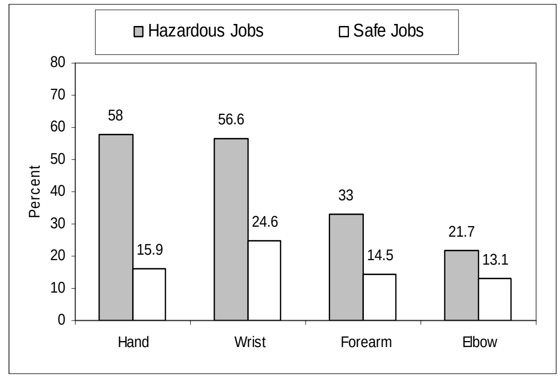

Fig. 1. Relative distal upper extremity disorders in various part of the body among hazardous and safe jobs.

Table 8. Strain index variables for 35 jobs within TV assembling facilities

Job category	Side	Intensity of exertion	Duration of exertion	Effort per minute	Hand/ wrist posture	Speed of work	Duration per day	Strain index score	Hazard classification (H/S)
VCD3	R	1	16.7	6.8	2	3	4	1	S
	L	1.4	18	6.8	2	3	4	1.7	S
Rolling pin press	R	1	48	12.7	2	3	4	2.25	S
	L	1	63.5	19.9	2	3	4	4	S
APT1	R	1.4	50.8	16.4	2	3	4	6.8	H
	L	1	51.4	10.2	2	3	4	3	S
Cut and clinch 1	R	1	100	24.8	2	3	4	9	H
	L	1	84	22.6	2	3	4	9	H
Cut and clinch 2	R	1	100	27.2	2	3	4	9	H
	L	1	100	27.2	2	3	4	9	H
Cut and clinch 3	R	1	84.5	21.4	2	3	4	9	H
	L	1.2	100	23.8	2	3	4	11.7	H
Manual assembling 1	R	1.2	61	22.8	2	3	4	7.8	H
	L	1	48	19.3	2	3	4	3	S
Manual assembling 2	R	1.24	63.8	13.6	2	3	4	4.2	S
	L	1.23	50.6	16.1	2	3	4	5.6	H
Soldering	R	1	40.9	13.6	2	3	4	2.25	S
	L	1.23	50.2	13.8	2	3	4	4.2	S
Wire cutting	R	1.2	92.2	13.8	2	3	4	11.7	H
	L	1	92	84.7	2	3	4	1.5	S
Soldering check 1	R	1.1	69.4	2.8	2	3	4	10.8	H
	L	1.1	56	65.7	2	4	4	10.8	H
Soldering 2	R	1.03	86	60.2	2	4	4	9.45	H
	L	1.06	75	60.2	2	3	4	6.6	H
APT2	R	1	39.5	11.7	2	3	4	2.25	S
	L	1.1	56.4	11.7	2	3	4	3.6	S

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Table 8. Strain index variables for 35 jobs within TV assembling facilities (continued)

Job category	Side	Intensity of exertion	Duration of exertion	Effort per minute	Hand/ wrist posture	Speed of work	Duration per day	Strain index score	Hazard classification (H/S)
Working	R	1.02	66	20.1	2	3	4	6.18	H
	L	1.05	29.2	15.1	2	3	4	2.16	S
TV cabinet preparation	R	1.23	59	16.9	2	4	4	8.4	H
	L	1	53	16.9	2	4	4	6	H
power switch installment	R	1.2	66.6	28.3	2	4	4	11.7	H
	L	1	47	22.7	2	4	4	6.75	H
AV socket installment	R	1.5	93.4	27.8	2	3	4	17.1	H
	L	1	70.4	17.1	2	3	4	4	S
screen lamp installment	R	2.16	49.7	13.3	3	3	4	11.5	H
	L	1.2	22.7	11.8	2	3	4	1.95	S
chassis installment	R	1.54	86.9	18.4	3	3	4	18	H
	L	1	41.5	9.2	2	3	4	2.25	S
RGB1 installment	R	1	68	22.4	2	4	4	9	H
	L	1.06	47	15.3	2	4	4	4.95	S
RGB2 installment	R	1	62.4	10.7	2	3	4	3	S
	L	1	61	13.6	2	3	4	3	S
Final control	R	1	35.3	8.4	1	3	4	1.5	S
	L	1	11.9	6.3	1	3	4	1	S
Horizontal and vertical	R	1	24.8	21.1	2	2	4	3	S
screen adjustment	L	1	8.4	8.4	2	2	4	0.5	S
Screen adjustment and	R	1	55.3	17.5	2	3	4	4	S
white balance	L	1	62	13.1	2	3	4	3	S
Focus and convergence	R	1	28.3	13.4	2	3	4	1.5	S
adjustment	L	1	52.8	17.5	2	3	4	4	S
Quality control (QC1-2)	R	1	49.9	28.6	2	3	4	4.5	S
	L	1	11.5	6.5	2	3	4	1	S
Cabinet enclosing 1	R	1.23	93	34.3	2	3	4	18.9	H
	L	1	67.6	17.1	2	3	4	4	S
Cabinet enclosing 2	R	1.27	87	16.4	2	3	4	9	H
	L	1	15.7	18	1	3	4	4	S
Final quality control	R	1	53.4	18	2	3	4	4	S
(QC2)1	L	1	16.8	3.7	2	3	4	0.5	S
Final quality control	R	1.1	35	12.1	2	3	4	2.7	S
(QC2)2	L	1	30.5	12.1	2	3	4	2.25	S
Cleaning whole TV	R	1	89	16	2	3	4	6	H
	L	1	67	9.1	2	3	4	3	S
Labeling	R	1	32	15.2	2	3	4	3	S
	L	1	65	21.7	2	3	4	6	H
Packing 1	R	1.1	42	18.6	2	3	4	3.6	S
	L	1	22	15.5	2	3	4	2	S
Packing 2	R	1	37	14.7	2	3	4	2.25	S
	L	1	28	14.7	2	3	4	1.25	S

Abbreviations: R, right; L, left; H, hazardous; S, safe.

DISCUSSION

A cross-sectional and descriptive analytical study of risk assessment and analysis of developing DUE disorders was conducted in an assembling electronic industry. DUE disorders prevalence data were collected among 69 workers through NMQ questionnaire and SI as proposed by Moore and Garg (3) was applied for 25 job groups and 35 jobs' risk assessment and hazard classification.

Investigation of the results of two methods of NMQ and SI which were applied to this study can be categorized into the following:

NMQ method results

Results showed that in spite of DUE disorders among female assemblers being higher than male workers, no significant difference was observed statistically. Also, during 1 year, absenteeism rate and turnover among workers were found to be low. In addition, significant difference was obtained between DUE disorders prevalence in "safe" and "hazardous" jobs ($P = 0.049$).

SI method results

Extraction of SI findings highlighted that of 35 jobs, 20 jobs and 15 jobs were categorized as "hazardous" and "safe", respectively. Obtained results showed that mean average of SI scores for all and "hazardous" jobs (7.3; range 1.5-18.9 and 9.3; range 6-18.9, respectively) are more than accepted criterion of 5, proposed by Moore and Garg (2), and any variations in task variables (effort per minute, duration of exertion, intensity of exertion) is able to change job categorization from "safe" into "hazardous".

SI statistical results clearly revealed that there is a significant difference between mean SI in "safe" and "hazardous" jobs ($P < 0.0001$) and they are in good agreement with Moor and Garg results (2), but no significant difference was observed between absenteeism and SI ($P = 0.3$) as well as between turnover and SI ($X^2 = 0.1333$, df = l, $P = 1$).

Relationship between SI and NMQ results

Comparison between DUE disorders prevalence results ($P = 0.049$) extracted from NMQ questionnaire with obtained SI data ($P \leq 0.0001$) in "hazardous" jobs clearly highlighted the validation of SI in job risk assessment as "safe" and "hazardous" at TV assemblers; they are also in good agreement with previous works (1-4).

In conclusion, the findings of current study showed that 20 jobs were hazardous and 15 jobs were safe. Results of statistical test clearly revealed that there is a significant difference between mean SI in hazardous and safe jobs. Also significant difference was observed between DUE disorder prevalence in safe and hazardous jobs. Comparison between mean SI data and DUE disorders, work-related absenteeism and turnover showed that there was a good association between SI data and DUE disorders prevalence results obtained by NMQ questionnaire. Thus, it can be concluded that the SI has a good validity in assessing of DUE disorders risk assessment.

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