

Risk of Upper Extremity Biomechanical Overload in Automotive Facility

Angela SANCINI¹, Assunta CAPOZZELLA¹, Tiziana CACIAR¹, Francesco TOMEI¹, Nadia NARDONE¹, Barbara SCALA¹, Maria FIASCHETTI¹, Carlotta CETICA¹, Lara SCIMITTO¹, PierAgostino GIOFFRÈ¹, Federica SINIBALDI¹, Claudia Di PASTENA¹, Paola CORBOSIERO¹, Maria Pia SCHIFANO¹, Gianfranco TOMEI^{2, #}, and Manuela CIARROCCA¹

1. University of Rome "Sapienza", Department of Anatomy, Histology, Medical-Legal and Orthopedics, Unit of Occupational Medicine, Viale Regina Elena 336, 00161 Rome, Italy; 2. University of Rome "Sapienza", Department of Psychiatric and Psychological Science, Piazzale Aldo Moro 5, 00185 Rome, Italy

Abstract

Objective To assess the risk factors for upper extremity-work-related musculoskeletal disorders (UE-WMSD) on 13 production lines in an airbag factory using the threshold limit values-American conference of industrial hygienists- hand activity level (TLV-ACGIH-HAL) method and introduce the ergonomic improvement to reduce the repetitiveness and the peak force (Pf).

Methods Professional exposure level on 13 production lines in a automobile factory was measured using the TLV-ACGIH-HAL method and a further risk was assessed according to the ergonomic improvement.

Results The first assessment of 9 production lines showed that the professional exposure level was above the TLV or HAL limit. The second assessment showed that the professional exposure level was below the AL limit on all production lines except 1, in which the professional exposure level was between TLV and HAL.

Conclusion The assessment of UE-WMSD-related risk can identify the riskiest emplacements and evaluate the reduction of risk in professional exposure through interventions of structural-organizational type.

Key words: Repetitive activity; Work-related musculoskeletal disorders; Assessment of work-related risk; Threshold limit values-American conference of industrial hygienists; Hand activity level.

Biomed Environ Sci, 2013; 26(1):70-75

doi: 10.3967/0895-3988.2013.01.009

ISSN:0895-3988

www.besjournal.com(full text)

CN: 11-2816/Q

Copyright ©2013 by China CDC

INTRODUCTION

The development of upper extremity work-related musculoskeletal disorders (UE-WMSD) is a major health problem in industrialized countries, which is linked to many working activities characterized by repetitiveness of movements and request for intense peaks force (Pf) and constitute^[1].

UE-WMSD can appear as alterations in joints,

nerves, tendons, muscles, tending to associate with each other^[1].

Multiple working activities are related to risk and pathologies originated or worsened by a working biomechanical overload of the upper extremity, including prearranged and/or high rate line production in the auto, engineering and electromechanical industries, manual polishing or use of lapping machine in woodwork or bodywork, upholstery works and coverings in the industrial and

[#]Correspondence should be addressed to Prof. Gianfranco TOMEI. Tel: 39-0649912540, Fax: 39-0686203178, E-mail: franc.tomei@alice.it

Biographical note of the first author: Angela SANCINI, Ph.D candidate, majoring in occupational medicine.

Received: December 20, 2011;

Accepted: June 4, 2012

handicraft fields, etc.

As far as the automotive industry is in particular concerned, there is clear evidence that the presence of ergonomic stressor is correlated with the final assembly phases^[2]. Epidemiological studies showed that musculoskeletal disorders are associated with the type of activities in the above mentioned factories^[2-4].

In addition, there are a series of occupational factors (such as repetitive, forceful, or prolonged exertions of the hands, frequent or heavy lifting, pushing, pulling, or carrying of heavy objects) and prolonged awkward postures that must be taken into consideration in the genesis of pathologies affecting the upper extremity and that have been identified through several patterns of study though not quite validated^[5].

Nowadays, different methods are used to assess the risk factors for UE-WMSD, such occupational health and safety administration (OSHA) checklist, Moore and Garg's strain index (SI), occupational repetitive action (OCRA) index threshold limit values-American conference of industrial hygienists (TLV-ACGIH) and hand activity level (HAL)^[6-10].

This study was to assess the risk factors for UE-WMSD on 13 production lines in an airbag factory using the TLV-ACGIH-HAL method and introduce the ergonomic improvement to reduce the repetitiveness and the peak force (Pf).

The TLV-ACGIH, related to the hand-wrist-forearm zone, is a quantitative method that can be applied to manual activities involving the performance of repetitive and similar actions or movements for at least 4 h a day^[11]. Combined mean hand activity level (HAL) and normalized Pf assessed on scales 0-10, can compare the assessments with the TLV (the level beyond which the prevalence of musculoskeletal disorders becomes manifested).

MATERIALS AND METHODS

Description of Working Operations

The present study was carried out on 13 production lines in a semiautomatic assembly with automotive components. Each line is a group of machines, equipments and work stations, along which the assembling of complete airbag modules takes place. A manufacturing cycle is intended as the working process necessary for the production of a complete airbag module which lasts in a medium of 1.5 min (from a minimum of 1 min to a maximum of

2 min).

The working places, the type of components and the materials used on the 13 production lines are not identical. Such a diversity was defined based on the production of different types of airbag, and the different risk factors for UE-WMSD on each of the 13 production lines. According to the type of production and the realization modality of the complete airbag modules, the production lines were divided into two groups, the first group was composed of 3 workers (production lines 1, 2, 9) while the second one was composed of 4 workers (production lines 3, 4, 5, 6, 7, 8, 10, 11, 12, 13). Specific tasks were carried out along each station:

Production lines 1, 2, 9:

Station 1: Bench assembling,

Station 2: Bending,

Station 3: Packaging.

Production lines 3, 4, 5, 6, 7, 8, 10, 11, 12, 13:

Station 1: Bench assembling,

Station 2: Bending,

Station 3: Pressing,

Station 4: Packaging.

The stations mentioned above were described as follows:

Bench assembling: The subunits were positioned by the operator on a bench for the assembling operation of gas generator and cushion. The operator assembled the two components, first inserting and then screwing a metal ring. This station also consists of preparing the subunits, screwing or unscrewing them.

Folding: A cushion made of synthetic cloth was put on the bending machine, where a pre-printed plastic sheath is placed to contain the cushion after bending. After this, the operator started the manufacturing cycle, which is thoroughly automated and consists of bending the cushion and inserting it into the sheath. At the end of operation, the operator took the subunits from the machine and pulled the borders of the cushion out of the buttonholes of the sheath through a manual operation.

Pressing: The gas generator, called "inflator", is included inside a metal tube named "manifold". The task of the operator was to pre-insert and put the components (manifold and gas generator) inside the pneumatic press and start the cycle. Finally, the operator were extracted, the subunits from the pneumatic press and were put into a proper container.

Packaging: The final product was packaged into

carton boxes or metal containers and transported by the operators to the areas arranged for dispatching.

The working activity was carried out on 3 shifts (8-hour for each) for a total of 40 h per week per operator, while shift was rotated (turnover) on a weekly basis (morning, noon, night). For the production lines 1, 5, 6, 7, 8, 9, 12, each shift lasted 480 min with a 60-min break, including a 30-min meal break, a 20-min rest break and a 10-min clean-up of machines at the end of shift. Operators on production lines 2, 3, 4, and 10, more complex in terms of production, have a 80-min break, including a 30-min lunch break, a 40-min break, and a 10-min clean-up of machines.

Analysis of Risk Factors

The risk factors for UE-WMSD were assessed using the following data.

Collection of general information: The number of operators, organizational and operating modalities (age, sex, height, weight, temperature in workplaces, contact stresses, vibrations, posture, work shifts, work breaks). The group of exposed workers was composed of 39 workers including 8 females and 31 males (age=31.5±4.17 years, seniority=4.5±1.98, BMI=25.1±1.99). The shifts lasted 480 min (as previously described). Workers were not exposed to vibrations and contact stresses. The activity analyzed in our study aimed at the production of automotive components. The study was carried out in December when the workplace temperature was 20 °C.

Identification and analysis of working tasks and assessment of characteristics of equipments and materials employed, repetitive actions, presence of recovery and rest periods, force applied by the workers and effort required by the upper extremity.

Analysis of the working processes by the direct observation of technicians and video recording of working operations. The video was registered for each station of the 13 production lines during and at the end of manufacturing cycles, which are the representative of the production process.

Examination of video recordings with count of the following:

A: Working tasks and relative manufacturing cycle;

B: Identification of each single task;

C: Quantification of frequency and duration of each cycle;

D: Calculation of the single movements and assessment of the mean frequency of hand

movement;

E: Count of the number of units processed during each cycle;

F: Registration of the official and non-official breaks.

For the methodological organization of collected data, specific socio-communicative competences relative to the development of tools, suitable for the collection of information and the analysis of data were used.

The exposure to the risk was assessed on the basis of the above data and all tasks/positions at work were considered in accordance with the data collected during the site visits and video recordings.

The process was balanced on the work activities of each operator and optimized the working time. The frequency and the duration of each cycle, the count of each movements and the average frequency of the hand movements were focused in this study, on the count of the number of processing units for each cycle and the recording of official and unofficial breaks.

The assessments were specifically performed by measuring the professional exposure level with the ACGIH TLV method (HAL method)^[6,11].

The first improving intervention, advised even before the assessment of the risk in order to reduce repetitiveness, is related to operators turnover among different stations so that each operator of the line is employed for an equal period of time on every station. The occupational exposure level was measured according to the rotation of operators from one to another station every 2 h.

The TLV- ACGIH (HAL method) method was used to measure the HAL by assessing the mean frequency of hand movements and the duration of "duty cycle" (percentage of working cycle where the force is over 5% of the maximum) by a trained technician, namely by assessing the distribution of work and rest/recovery periods (Table 1)^[6].

The method selected for this study was the HAL method, which is most suitable for the study of the working activities on the 13 production lines since it takes into account the Pf and the repetitiveness of movements.

The peak "normalized" manual force was calculated according to the ratio between the strength required to carry out the job and the ability to exercise a force by general population employed in the same job on a scale ranging from 0 to 10, which corresponds respectively to 0% and 100% of the reference force applicable by normal population.

Table 1. HAL Calculation Scale Relative to Strain Frequency and to “Duty Cycle” (ACGIH. 2001)

Frequency (effort/sec)	Period (sec/effort)	Duty Cycle (%)				
		0-20	20-40	40-60	60-80	80-100
0.125	8.0	1	1	-	-	-
0.25	4.0	2	2	3	-	-
0.5	2.0	3	4	5	5	6
1.0	1.0	4	5	5	6	7
2.0	0.5	-	5	6	7	8

The Pf relating each station was counted by two trained technicians who worked separately^[12]. The use of surface electromyography in case of conflicting assessments was arranged. The video recordings on each of the 13 production lines were analysed and the movements made by the workers on the spot were considered even if they were unreasonable and/or unwarranted.

The final value for each line was obtained by calculating the average of the appraisals carried out at each single station. Afterwards, the resulting values were expressed on Cartesian axes. The combination on Cartesian axes of the resulting values provided the exposure level in the analysed position.

Since it was impossible to guarantee that the TLV value could protect all workers, the HAL method was also taken into account of the action limit (AL), acquiring the meaning of a further safety level.

The occupational exposure level, namely the entity of exposure of the upper extremity to repetitive movements and/or efforts on each line, was measured with the HAL method, and configured it above TLV, between TLV and AL or below AL.

Some stations have more duties carried out by the same worker. In this case, the assessment of risk at the station was reported.

Ergonomic Improvements

Furthermore, in the second phase of this study, another risk was assessed for the 13 production lines and stations according to the ergonomic improvement, in order to reduce the repetitiveness and Pf, without compromising the productivity.

Participants provided their informed, and data were collected and processed anonymously. Participants were specifically asked to give adhesion to the screening program and individually informed of their results. All data were collected and handled

in accordance with the principles of Helsinki Declaration.

RESULTS

The results of the risk assessment are shown in Table 2 and Figure 1, indicating the mean values of HAL and AL, with workers turnover every two hours and at each station. The HAL, Pf and occupational exposure levels were higher on production lines 1, 4, 6, 7, 9 than the TLV level.

Manual screwdriving, fixed worktop, components of manual lifting, manual data entering, manual labeling, and airbag manual folding were the work risks.

Table 2. Mean Values of Occupational Exposure for the 13 Evaluated Production Lines

Production Lines	Evaluation		
	HAL	Pf	
1	6.60	3.20	Beyond TLV
2	5.30	2.70	Above AL
3	4.30	2.60	Beneath AL
4	6.00	3.60	Beyond TLV
5	5.50	2.60	Above AL
6	5.90	4.10	Beyond TLV
7	6.10	4.10	Beyond TLV
8	6.40	2.80	Above TLV
9	6.60	3.30	Beyond TLV
10	5.10	3.50	Between TLV and AL
11	5.40	2.60	Above AL
12	6.00	3.00	Above TLV
13	5.80	3.30	Above TLV
Mean	5.76	3.18	
SD	0.64	0.53	

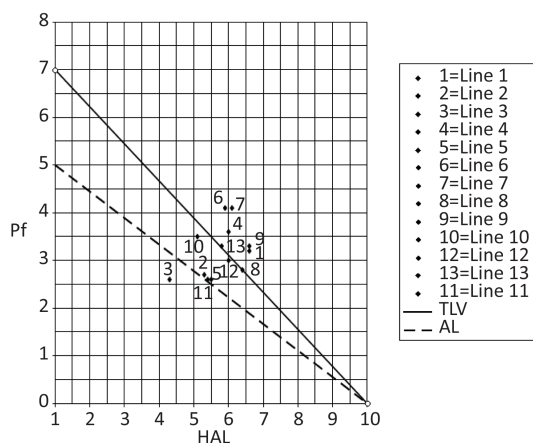


Figure 1. Lines of evaluation of HAL and Pf, taking into account workers turnover among each station.

In order to reduce the manual repetitiveness, we suggested the introduction of a series of measurements on all lines presenting high levels of repetitiveness: use of automatic screwers, application of optical readers operated by workers and fixed to a support of automatic systems.

In addition, the reduction of the upper-middle Pf, observed at some stations, was advised through the automation and/or auxiliation of many critical phases of each working cycle, by means of mechanical help with the auxiliation suggested for the station of bending on production lines 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, and 13 consisting the introduction of small presses.

An occupational exposure level was presented only on production line 10 in TLV and AL.

The results of the risk assessment, carried out on the basis of ergonomic improvement for the reduction of repetitiveness and Pf, and through the introduction of the above mentioned technical interventions, are shown in Table 3, with the mean values for HAL and Pf of occupational exposure level on each production line and station composed of TLV and AL indicated. The results of the reduced Pf and repetitiveness are shown in Figure 2.

No contrasting assessments are available between the two technicians with regard to the PF for both assessments.

DISCUSSION

The etiopathogenetic model, UE-WMSD, is not widely known and universally acknowledged, because of the strong conditioning caused by elevated multi-factoriality and lack of scientific data^[13]. This is

Table 3. Mean Values of Occupational Exposure Level for the 13 Production Lines Evaluated after Reduction of Repetitiveness and Pf

Production Lines	Evaluation		
	HAL	Pf	
1	6.60	1.90	Above AL
2	5.30	1.50	Beneath AL
3	4.30	2.60	Beneath AL
4	6.00	2.00	Beneath AL
5	5.50	2.60	Above AL
6	5.90	1.30	Beneath AL
7	6.10	1.30	Above AL
8	6.40	1.60	Beneath AL
9	6.60	2.20	Between TLV and AL
10	5.10	2.00	Beneath AL
11	5.40	1.30	Beneath AL
12	6.00	2.00	Beneath AL
13	5.80	2.00	Beneath AL
Mean	5.70	1.86	
SD	0.64	0.44	

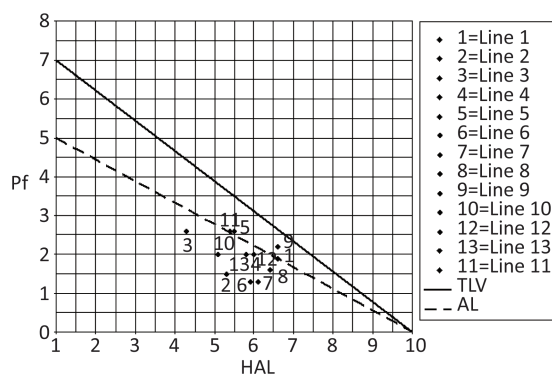


Figure 2. Evaluation of HAL and Pf after ergonomic improvement.

why there are numerous methods to assess UE-WMSD, each one previewing the appraisal of a different number of risk factors^[5,14]. The method used in this study takes into account both repetitiveness and Pf^[6]. In this study, all production lines were analyzed focusing on the different working methods. Our ultimate aim was to reduce the risk related to the UE-WMSD, without reducing the productivity, through an ergonomic organization of the manual systems, to pursue through standardization of work, balanced rotating among different stations of the same production line and a

thorough search of the best ergonomic conditions for each station.

Using the HAL method in this study, it was able to assess the risk related to the UE-WMSD in real working conditions to which the workers in an automotive industry having duties characterized by repetitiveness and Pf are exposed.

It was not necessary to use the surface electromyography, because no contrasting assessments between the two technicians were available.

The analysis of video registrations showed that the production lines with the highest recorded risks were 1, 4, 6, 7, 9, which, in fact, demand long-term repetitive movements and upper-middle Pf above all the pressing process.

Turnover alone, without reducing Pf and repetitiveness, is not enough to reduce occupational exposure level below the TLV. Turnover of workers among different stations redistributes work but may increase individual risk. It is important to introduce improvements that reduce both repetitiveness and Pf, since the presence of high Pf and repeated movements increases considerably the final risk level. In order to reduce the risks related to repetitive activities, being typical of automotive industry, measures should be taken for ergonomic control allowing a better organization of work but not decreasing the productivity^[14-16].

It was able to identify the stations where the risk related to UE-WMSD was higher on the 13 analysed production lines. The assessment and identification of risks can introduce improvement interventions so as to reduce occupational exposure levels and verify the efficacy of the proposed interventions.

As to the solutions suggested to decrease Pf, their application turned out to be more complex against movement repetitiveness than the proposed solutions. Such a complexity was linked to the type of materials used, shape and dimensions of the subunits employed. Since such subunits are supplied by external companies, it is necessary to modify the product by not alter its functionality and security.

Adjustable worktops and mechanical arms, which allow to operate on the posture (standing position), were not introduced in this study for financial reasons.

In conclusion, the assessment of risk factors related to UE-WMSD can identify the related risks and the riskier stations, thus creating the scientific basis for interventions of structural-organizational type like modifications of work stations, and

introducing the mechanized instrumentation to reduce the occupational exposure level.

REFERENCES

1. Capodoglio, EM, Facioli, M, Bazzini, G. La valutazione del rischio connesso ad attività lavorative ripetitive: sperimentazione di diversi metodi proposti in letteratura. *G Ital Med Lav Erg*, 2001; 23, 467-76.
2. Punnett, L. Ergonomic stressors and upper extremity disorders in vehicle manufacturing: cross sectional exposure-response trends. *Occup Environ Med*, 1998; 55, 414-20.
3. Fransson-Hall, C, Bystrom, S, Kilbom, A. Self-reported physical exposure and musculoskeletal symptoms of the forearm-hand among automobile assembly-line workers. *J Occup Environ Med*, 1995; 37, 1136-44.
4. Fransson-Hall, C, Bystrom, S, Kilbom, A. Characteristics of forearm-hand exposure in relation to symptoms among automobile assembly line workers. *Am J Ind Med*, 1996; 291, 15-22.
5. Violante FS, Baracco A, Bovenzi M, et al. Work-related musculoskeletal disorders and diseases of the arm. *G Ital Med Lav Ergon*, 2005; 27(1), 74-7.
6. American Conference of Governmental Industrial Hygienists (ACGIH). TLV and BEI Ergonomics, statement on work-related musculoskeletal disorders, hand activity level. 2001, 107-12.
7. Moore JS, Garg A. The strain index: a proposed method to analyse jobs for risk of distal upper extremity disorders. *Am Ind Hyg Assoc J*, 1995; 56, 443-58.
8. Occhipinti E. OCRA: a concise index for the assessment of exposure to repetitive movements of the upper limbs. *Ergonomics*, 1998; 41, 1290-331.
9. Occupational Health And Safety Administration (OSHA) (2000). available from: www.osha-slc.gov/ergonomics-standard/index.html
10. Ciarrocca M, Caciari T, Capozzella A, et al. The evaluation of the upper extremity biomechanical overload. *Prevent Res*, 2012; 2(1), 19-26.
11. Violante FS, Isolani L, Raff GB. Case definition for upper limb disorders. In: *Occupational Ergonomics. Work related musculoskeletal disorders of upper limb and back*; (Armstrong T, Kilbom A, Eds). 2000, P 120-128 Taylor and Francis, London and New York.
12. Borg G. Borg's Perceived exertion and pain scales. *Human Kinetics eds. Champaign*, 1998. USA.
13. Aptel M, Aublet-Cuvelier A, Cnockaert JC. Work-related musculoskeletal disorders of the upper limb. *Joint Bone Spine*, 2002; 69, 546-55.
14. Sala E, Albini E, Borghesi, et al. Work-related musculoskeletal disorders of the upper extremity in spinning: lack of risk or of adequate methods for assessing risk? *G Ital Med Lav Ergon*, 2005; 27(1), 8-20.
15. Martmelli R, Tobia L, Lupi A, et al. Longitudinal study of a population exposed to risk of biomechanical overload of the upper limb. *G Ital Med Lav Ergon*, 2005; 27(2), 237-9.
16. Nicoletti S, Battevi N. Upper-limb work-related musculoskeletal disorders (UL-WMSDs) and latency of effect. *Med Lav*, 2008; 99, 352-61.