ORIGINAL ARTICLE

MUSCLE ACTIVITY AND POSTURAL ANALYSIS OF A COMPUTER NUMERICAL CONTROL MACHINING TASK

Muhammad Syafiq SYED MOHAMED, Isa HALIM, Akmal Hafiz AZANI, Mohanathas NADRAJAH, Siti Khadijah KHALIL,

Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, Duriang Tunggal, 76100 Melaka, Malaysia

ABSTRACT

Computer Numerical Control CNC machining center is equipped with advanced features to achieve high accuracy, reliability, repeatability and productivity. However, CNC machining centers still expose machinists to ergonomics risk factors such as awkward postures, repetitive movements, heavy lifting and prolonged standing especially during manual material handling. The aim of this study is to redesign the existing CNC machining center to improve work posture and reduce muscle activity of the lower back. Muscle fatigue survey, Rapid Upper Limb Assessment (RULA) analysis and surface electromyography (SEMG) were used to assess subjective muscle fatigue, posture and muscle activity respectively. All machinists reported to experience muscle fatigue on the lower back area. Based on RULA analysis, the redesigned CNC machining center has improved the working posture of machinists as shown by a lowered RULA score from 7 to 3 for both right and left body side. SEMG results showed a significant decrease in muscle activity of the lower back. Therefore, this study concluded that the redesign of CNC machining center has shown has successfully reduced muscle fatigue and improved the work posture for the machinists.

Keywords: *muscle fatigue, RULA, SEMG, CNC*

INTRODUCTION

The application of computer numerical control (CNC) technology in manufacturing industries has revolutionized the production process and progressed significantly over the past 20 years. Operators of CNC machines can rely on the machines to produce high quality parts while exerting less physical forces than manual machining operations. Therefore it should be expected that ergonomic issues coming from the physical exertion while operating manual machining operations will be eliminated, but that is not the case. Machining operations still require operators to load and unload workpieces manually into the CNC machines, and they often have to resort to awkward postures and forceful exertions when doing that. These two risk factors are among four common risk factors, which resulted in the occurrence of musculoskeletal disorders (MSDs) when performing machining task via CNC technology (Khan, 2012).

Due to this, musculoskeletal disorders (MSDs) are still widespread among manufacturing operators since manual materials handling is common. The prevalence of this occupational health concern can reach up to 94% of operators (Rasotto et al., 2015). Upper limb regions such as neck, shoulders, upper and lower back are among of the most common MSD regions reported in the manufacturing sector (Hembecker et al., 2017; Lu et al., 2016; Sarkar et al., 2016). The upper limb is frequently affected due to manual material handling (MMH) demands in manufacturing process such as loading and unloading (Yahya & Zahid, 2018; Li et al., 2017; Andriolo, 2016). High repetition nature of MMH task overloads the muscle fibers resulting in muscle fatigue, which is a decline in muscle ability to generate force (Rashedi & Nussbaum, 2016). The severity of muscle fatigue increases with higher workload level, threating the quality of life and performance at work (Arellano, 2015). Non-neutral work postures have been proven to increase the risk of MSD in previous studies (Fazi et al., 2017; Shah et al., 2016).

Since MSDs are commonly related to poor work postures and muscle fatigue, ergonomics assessment in the workplace is usually done using several methods such as postural analysis and muscle fatigue and activity analysis. Surface electromyography (SEMG) is a typical muscle activity tool used to assess the muscle fatigue of workers

(Santos et al., 2016; Gonçalves et al., 2015). Postural analysis tools such as Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) are commonly used to evaluate the risk of MSD based on work posture (Abdullah et al., 2017; Kamat et al., 2017). Based on the assessment, countermeasures can be taken to improve the ergonomics in the workplace. Redesign of workstation is one of the common cost-effective countermeasures for ergonomic intervention to improve work posture and muscle activity (Kamat et al., 2018; Krishnan et al., 2017; Arce et al., 2016; Baril, 2015).

The aim of this study is to redesign the CNC machining center to improve the working posture and reduce muscle activity of the machinists while they perform machining operations.

METHODOLOGY

A cross-sectional study was conducted on 30 machinists operating DECKEL MAHO DMF-250 5 Axes 2008 CNC machine (DMG MORI, USA) at Universiti Teknikal Malaysia Melaka (UTeM). Permission was given through written consent by the university prior to the experiment.

Questionnaire

Thirty machinists participated in the actual questionnaire survey. The finalized questionnaire was separated into five parts (A, B, C, D and E): background of the machinist, information related with existing design of the CNC machining center, the requirements needed in the technical specifications, ergonomics issues that are related with the existing design of the machine, and ergonomics features requirements. A pilot study on ten machinists was done prior to the actual questionnaire survey to assess the reliability of the Likert-scale questions using Cronbach's alpha test via Statistical Packages for the Social Science (SPSS) software. The questionnaire consists of Likert type ratings for each body part (lower back, shoulder, upper arm, thigh, wrist/hand, neck, upper back, foot and calf.) Criteria of acceptable levels of alpha qualify a value of 0.8 and higher as good, and above 0.7 as satisfactory (Brinkman, 2009). All tested questions showed scores between 0.7 and 0.8, indicating good reliability.

SEMG procedures

A bi-polar differential Ag/AgCl SEMG electrode with a diameter of 20 mm and an inter-electrode distance of 25 mm (TeleMyo 2400T G2, Noraxon, USA) were affixed to subject's lumbar erector spinae muscle on both right and left sides. The skin attached to the electrodes was shaved, washed, gently abraded, and scrubbed with alcohol prior. The common mode rejection rate (CMMR) was 100 dB. The band pass filter was in between 85 Hz to 500 Hz. The EMG sampling rate was 1000 Hz. All the electrodes were connected to a data logger and its associated software above. Both right and left muscles were concurrently measured during workpiece lifting activity to obtain muscle fatigue with different weight of load and holding time. The average of readings were calculated and tabulated.

RULA analysis protocol

The RULA analysis was performed via the CATIA V5 software (Dassault Systèmes S. E., France). The human anthropometric was standardised to Malaysian population for manikin development. The manikin was then adjusted to posture from observational survey. The colour code built in the software indicates the stress level experienced by each designated body parts as well as the body in general when in a posture, increasing in intensity from green, yellow to red. Both the left and right side postures were analysed during the workpiece lifting task. The final score was calculated before and after study.

Redesigning of CNC machine

A morphological box was developed by putting the criteria on the left side of the box with options for each criterion. More options provided indicated a better design. Each of these options was combined to achieve the design concepts of material handling tool based on the machinist requirements. Evaluation of each of the concepts was done by using relative comparison of design concepts. The selection of matrix was prepared by placing the criteria needed such as the height of the table lifter that can be adjustable and more on the left-side of the box for each of the concepts obtained. The weighted percentage for each criterion was calculated to show the importance of the concepts. The concepts were ranked from 1 to 5 in the order from worst to best quality. The total score for each concept was calculated multiply the weight of criterion with the rank of the concept. Criterion with the highest total score was incorporated the conceptual design. A technical drawing of material handling tool was created according to ergonomics features like table lifter with roller conveyer using CATIA V5 software. This drawing used actual anthropometry dimension of the ergonomics features in CNC machining centre workstations in mm obtained from the survey.

RESULTS

A. Background information of respondent

Six variables on respondent background were collected as shown in Table 1. The majority of the machinists are Malaysian males between the ages of 30 and 39 years old with working experience using the CNC machine less than 10 years.

Table 1 Socio-demographic background

Variables	Category	n
Designation	Production manager	2
	Technical expert	7
	Operator	3
	Others	17
Gender	Male	24
	Female	4
Age	20-29	11
	30-39	15
	40-49	2
	50 and above	2
Nationality	Malaysian	24
	Others	6
Working experience (years)	0-9	20
	10-19	8
	20-29	2
Education level	Diploma	7
	Bachelor degree	11
	Master degree	6
	Others	6

Survey data analysis

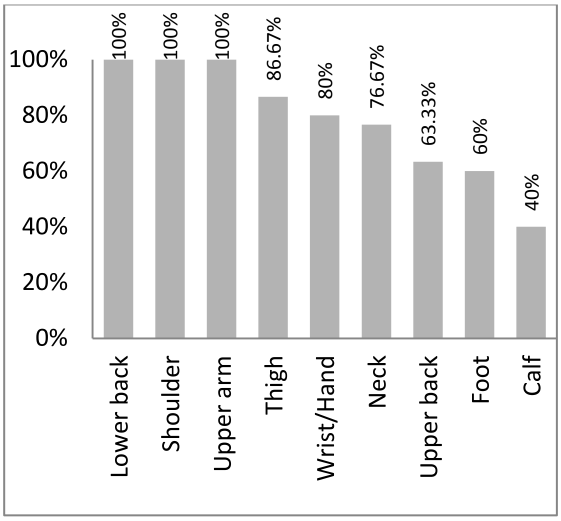
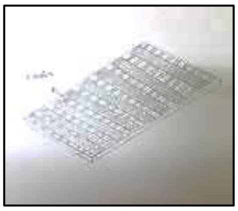
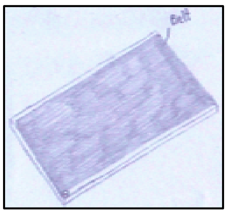
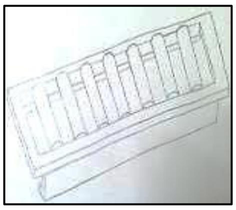


Fig. 1 The percentage of respondents experienced muscle fatigue on different body parts (N=30)

Based on Fig. 1, all machinists (100%) experienced some level of muscle fatigue at the lower back, shoulder and upper arm when using the CNC machining center. The lower back was mostly affected due to the bending posture. In descending order, the thigh (86.67%), wrist/hand (80%), and neck (76.67%) were also largely afflicted with muscle fatigue. The least affected site was the calf at 40%.

Table 2 Concept scoring in screening and selection process

		Concept scoring					
		Chain Conveyor		Belt Conveyor		Roller Conveyor	
							
		(Design A)		(Design B)		(Design C)	
Selection criteria	Weight	Rank	Weighted score	Rank	Weighted score	Rank	Weighted score
Cost	15	2	30	3	45	5	75
Material	15	3	45	4	60	5	75
Ease of maintenance	10	1	10	2	20	4	40

Ease of manufacturing	10	2	20	3	30	5	50
Safety	10	3	30	2	20	3	30
Noise reduction	15	4	60	3	45	4	60
Space consuming	10	2	20	5	50	4	40
	Total score	215		270		370	
	Rank	3		2		1	
	Continue	No		No		Develop	

B. New design of conveyor

Three conceptual designs were compared based on the criteria required by the designer and machinists. The analysis of the criteria towards the design concept by rating and weighted the value. The highest net score obtained was 370 by Design C which is roller conveyor. Meanwhile, the lowest value was design A followed by design B with the value of 215 and 270 respectively. Thus, design C was selected. The sketches of Design A, B, and C are included in Table 2. Fig. 2 represents the replicated model of design C in CATIA V5 software.

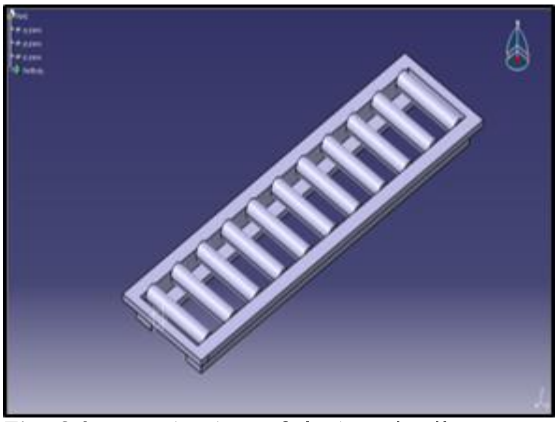


Fig. 2 Isometric view of designed roller conveyor belt

C. Muscle activity analysis

Comparison between initial and final muscle activity readings showed significant decrease in amplitude for both left and right lumbar erector spinae after design implementation as shown in Table 3.

Postural analysis

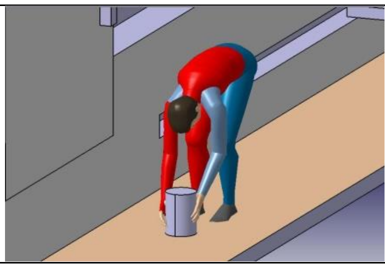
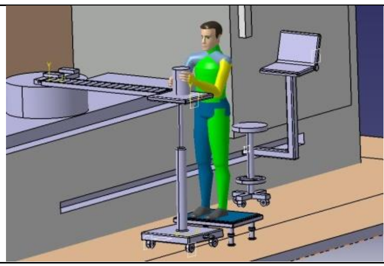
Work posture was significantly improved based on decrease in RULA score from 7 to 3 in Table 4. The initial posture which involved bending forward was changed to final posture which a neutral posture with an adjustable manual lifting device, a roller conveyor belt and a standing platform. The initial RULA analysis for the left side of the machinist showed that six parts of the body exhibited red colour which signified that they were in an unsafe state. The body parts included the (1) upper arm, (2) muscle, (3) wrist and arm, (4) posture B, (5) leg, (6) neck, trunk and leg. Only one part of the body was in a safe state which was the wrist twist displayed in green colour. The right side showed more number of body parts that had unsafe posture than the left side which was seven parts displayed in red colour. Red colour surfaces indicate that investigation and changes are required urgently, while green colour surfaces indicate the posture is acceptable if it is not maintained. The seven body parts were the (1) upper arm, (2) posture A, (3) muscle, (4) wrist and arm, (5) leg, (6) posture B and (7) neck, trunk and leg. The part with the safest posture was the same as left side displayed in green colour. The final RULA analysis for both left and right sides showed almost the entire body parts were in good condition where they were indicated by either green or yellow colour. Only the muscle was in red colour since the muscle had to provide the necessary force to hold the workpiece and transferring it from the lifting table to the roller conveyor.

Table 3 Initial and final muscle activity readings of lumbar erector spinae

Side of the body	Initial reading (uV)	Final reading (uV)
Right	67.72378	33.58769
Left	60.88907	36.15532

Table 4 RULA analysis before and after design implementation

	Initial posture	Final posture

		
Side of the body	Initial score	Final score
Right	7	3
Left	7	3

DISCUSSION

The data from survey, muscle activity and postural analyses supported a correlation between the lower back muscle fatigue and the forward bending posture of machinist during the workpiece lifting at CNC machining center. Awkward posture such as forward bending had been shown to cause lower back pain (Anap et al., 2017). Bending forward at the spine stretches the lumbar erector spinae. High repetition of the lifting generates a lot of tension to these muscles as they flex, which in times causes muscle fatigue (Ghosh, 2017).

Design C was selected among the designs in Table 2 mainly based on its highest score which is contributed by high ranks of its criteria as compared other designs. Design C was easy to manufacture at low cost with less materials solely based on the highest rank 5.

The highest weighed score for this design was for cost and material at 75, indicating the best criteria selected were cost and material. Rollers help to reduce the needed force to push the workpiece into the CNC machine as they provide less friction between the surface of workpiece and the conveyor.

In the final design of the workstation in shown in final posture of Table 4, an adjustable lift table and a standing platform were included. The lift table transports the workpiece before the workpiece is pushed into the CNC machine via the roller conveyor. The adjustable height eliminates most degree of forward bending posture. The standing platform elevates the machinist to appropriate height of the setup of lift table and conveyor. The combination of all devices in the final setup eliminates the bending of the lower back entirely as the machinist lifts the workpiece onto the conveyor in a neutral upright standing posture.

After the setup was tested, significant decrease was observed in muscle activity of the lower back based on Table 3, which indicates less tension was generated by the muscles as the bending posture was eliminated. Decrease in muscle activity lowers the risk of MSDs including muscle fatigue (Mondal et al., 2018). Drastic decline of RULA total score from 7 to 3 in Table 4 confirmed the new design eliminated bending posture in work practice which improved the work posture (Abdullah et al., 2017; Kamat et al., 2017). These two results verified that work posture improvement by design in this study was effective in reduction of muscle fatigue risk.

CONCLUSION

This study concluded that ergonomic intervention by design improved work posture from bending to standing and reduced muscle activity of lumbar erector spinae. Significant decrease in muscle activity and RULA scores indicated reduction of highly reported muscle fatigue risks of the lower back among machinists.

ACKNOWLEDGMENT

The researchers would like to thank the Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka for funding this study by the University High Impact Short Term Grant (PJP/2017/FKP/H19/S01527).

REFERENCES

1. Abdullah, Z., Norazman, N. S., Chew, C. S., Ghazaly, M. M., Jaafar, R., & Maidin, S. (2017). Design and analysis on sitting posture in quality checking workstation of a manufacturing company. *Proceedings of Innovative Research and Industrial Dialogue 2016*, *1*, 77-78.

2. Abdullah, Z., Samsuddin, N. A., Stephen, A. A., Hambali, R. H., Arep, H., & Akmal, S. (2017). Improvement of workstation in manufacturing industry for manual handling worker. *Proceedings of Innovative Research and Industrial Dialogue 2016*, *1*, 81-12.
3. Anap, D. B., Iyer, C., & Rao, K. (2017). Work related musculoskeletal disorders among hospital nurses in rural Maharashtra, India: a multi-centre survey. *International Journal of Research in Medical Sciences*, *1*(2), 101-107.
4. Andriolo, A., Battini, D., Persona, A., & Sgarbossa, F. (2016). A new bi-objective approach for including ergonomic principles into EOQ model. *International Journal of Production Research*, *54*(9), 2610-2627.
5. Arce, A., Angulo, J., Garcia, V., Quijada, M., & León, J. (2016). Redesign of workstations to reduce ergonomic risk factors in an electronic manufacturing company. *Ergonomía Ocupacional Investigaciones y Aplicaciones*, *9*, 202-213.
6. Arellano, J. L. H., Martinez, J. A. C., Perez, J. N. S., & Alcaraz, J. L. G. (2015). Relationship between workload and fatigue among Mexican assembly operators. *International Journal of Physical Medicine & Rehabilitation*, *3*(06), 1-6.
7. Baril, J. (2015). Ergonomic Study and Redesign of a Medical Device to Enhance Usability in Laparoscopic Surgical Populations.
8. Brinkman, W. P. (2009). *Handbook of Mobile Technology Research Methods*. New York, NY: Nova Publisher.
9. Fazi, H. M., Mohamed, N. M. Z. N., Ab Rashid, M. F. F., & Rose, A. N. M. (2017). Ergonomics study for workers at food production industry. In *MATEC Web of Conferences* (Vol. 90, p. 01003). EDP Sciences.
10. Geldhof, E., Clercq, D.D., Bourdeaudhuiji, I.D. and Cardon, G. (2007). Classroom postures of 8-12 year old children. *Ergonomics*, 50(10): 1571-1581.
11. Ghosh, T. (2017). Assessment of Postural effect on Work Related Musculoskeletal Disorders and Back Muscle Fatigue among the Goldsmiths of India. *International Journal of Occupational Safety and Health*, *5*(2), 16-22.
12. Gonçalves, R., Guedes, J. C., & Baptista, J. S. (2015). Muscle fatigue: Evaluation by electromyography at different thermal environments. *Occupational Safety and Hygiene III*, 349.
13. Hembecker, P. K., Reis, D. C., Konrath, A. C., Gontijo, L. A., & Merino, E. A. (2017). Investigation of musculoskeletal symptoms in a manufacturing company in Brazil: a cross-sectional study. *Brazilian journal of physical therapy*, *21*(3), 175-183.
14. Kamat, S. R., Ani, M. F., Hadi, N. A. A., Rayme, N. S., Ito, M., & Fukumi, M. (2018, March). Redesign Materials Handling System by Using Ergonomic Approaches to Reduce Back Pain Risk. In *International Conference on Kansei Engineering & Emotion Research* (pp. 592-602). Springer, Singapore.
15. Kamat, S. R., Hamid, M. H. A., Shamsuddin, S., Fukumi, M., Ito, T., & Husain, K. (2017). Ergonomics Study Of Working Postures In Demould Process At Aerospace Manufacturing. *Age*, *25*, 5-0.
16. Kamat, S. R., Zula, N. M., Rayme, N. S., Shamsuddin, S., & Husain, K. (2017, June). The ergonomics body posture on repetitive and heavy lifting activities of workers in aerospace manufacturing warehouse. In *IOP Conference Series: Materials Science and Engineering* (Vol. 210, No. 1, p. 012079). IOP Publishing.
17. Khan, I. A. (2013). Multi-response ergonomic design of human–CNC machine interface. *International Journal on Interactive Design and Manufacturing* (IJIDeM), 1-19.
18. Krishnan, R., Vishnu, R. S., Mohan, T. H., & Bhavani, R. R. (2017, April). Design and fabrication of a low-cost rice transplanting machine. In *Technological Innovations in ICT for Agriculture and Rural Development (TIAR), 2017 IEEE* (pp. 14-17). IEEE.
19. Li, X., Komeili, A., Gül, M., & El-Rich, M. (2017). A framework for evaluating muscle activity during repetitive manual material handling in construction manufacturing. *Automation in Construction*, *79*, 39-48.
20. Lu, J. M., Twu, L. J., & Wang, M. J. J. (2016). Risk assessments of work-related musculoskeletal disorders among the TFT-LCD manufacturing operators. *International Journal of Industrial Ergonomics*, *52*, 40-51.
21. Mondal, K., Soin, S., Chatterjee, S., Sen, S., & Majumdar, D. (2018). Biomechanical Responses of Young Indians During Performing Manual Weight Lifting Tasks. *Humanizing work and work Environment (HWWE 2016): English*, 405.

22. Rashedi, E., & Nussbaum, M. A. (2016). Cycle time influences the development of muscle fatigue at low to moderate levels of intermittent muscle contraction. *Journal of Electromyography and Kinesiology*, *28*, 37-45.
23. Rasotto, C., Bergamin, M., Simonetti, A., Maso, S., Bartolucci, G. B., Ermolao, A., & Zaccaria, M. (2015). Tailored exercise program reduces symptoms of upper limb work-related musculoskeletal disorders in a group of metalworkers: A randomized controlled trial. *Manual therapy*, *20*(1), 56-62.
24. Santos, J., Baptista, J. S., Monteiro, P. R. R., Miguel, A. S., Santos, R., & Vaz, M. A. (2016). The influence of task design on upper limb muscles fatigue during low-load repetitive work: a systematic review. *International Journal of Industrial Ergonomics*, *52*, 78-91.
25. Sarkar, K., Dev, S., Das, T., Chakrabarty, S., & Gangopadhyay, S. (2016). Examination of postures and frequency of musculoskeletal disorders among manual workers in Calcutta, India. *International journal of occupational and environmental health*, *22*(2), 151-158.
26. Shah, Z. A., Amjad, A., Ashraf, M., Mushtaq, F., & Sheikh, I. A. (2016). Ergonomic risk factors for workers in garments manufacturing-a case study from Pakistan. Kuala Lumpur: International Conference on Industrial Engineering and Operations Management.
27. Yahya, N. M., & Zahid, M. N. O. (2018, March). Work-related musculoskeletal disorders (WMDs) risk assessment at core assembly production of electronic components manufacturing company. In *IOP Conference Series: Materials Science and Engineering* (Vol. 319, No. 1, p. 012036). IOP Publishing.