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THE RISK FACTORS ASSOCIATED WITH HAND-ARM VIBRATION AMONG WORKERS IN AIRCRAFT MANUFACTURING INDUSTRY: A CONCEPTUAL FRAMEWORK

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Abstract

This paper aims to identify the risk factors associated with hand-arm vibration while performing tasks using hand-held vibrating tools. The risk factors associated with hand-arm vibration exposure were identified based on the review from the selected previous studies. As a result, a conceptual framework is developed and proposed. The proposed conceptual framework is formulated with three significant elements; manual handling task risk factors, sources of hand-arm vibration and physiological responses. The risk of hand-arm vibrations mainly comes from manual handling activities. The factors involved are force, posture, repetition and task time. The factors such as the type of tool used, the frequency of vibration level, and the duration of vibration exposure are also included in the framework as these factors are found to influence the level of hand-arm vibration risk. All the mentioned factors are categorized as independent variables. Meanwhile, the dependent variable is the physiological response resulted from the handgrip strength and the muscle activities. The relationship between all these factors will be further investigated and verified through the experimental task study. The results will provide knowledge in managing risks of hand-arm vibration exposure and help to improve the safety and health of the workers in the workplace.

Keywords: hand-arm vibration, aircraft parts, assembly process

Introduction

Hand-held vibrating tools are widely used in multiples industries including construction, heavy equipment, automotive and many more including the aircraft manufacturing industry. There are several types of hand-held vibrating tools used in the industrial sectors such as drills, grinders, sanders, pneumatic hammers, pneumatic rivet guns, grinders, and more (HSE, 2019). Notably, the use of such hand-held vibrating tools greatly aids humans during the manual assembly task or work process. The tools help by expanding the capabilities in terms of accuracy, precision, requires less effort and saves production time. However, performing tasks using the hand-held vibrating tools could expose the workers to the risk of occupational injury collectively known as human vibration (Mansfield, 2005). As stated in the vibration directive (2002/44/EC), the European Agency for Safety and Health at Work, human vibration is classified as either whole-body vibration or hand-arm vibration (Donati et al., 2008).

This paper focusing mainly on the hand-arm vibration that is known as a mechanical

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vibration that is transmitted to the hand and arms of the workers during the operation of hand-held vibrating tools (DOSH, 2003). Hand-arm vibration was experienced by workers in various industries (Shen & House, 2017). According to vibration standard ISO 5349-1(2001), hand-arm vibration is a result of the manual handling task involved in rotating or percussive hand-held power tools. Prolonged and regular exposure to hand-arm vibration may affect the workers' health and lead to injuries known as hand-arm vibration syndrome (Holt, 2007; Shen & House, 2017).

The Department of Occupational Safety and Health (DOSH) established Guidelines on Occupational Vibration (2003) which intended to increase the awareness among the employees as well as employers to the risks and exposure of hand-arm vibration. It is estimated that 5.5 million workers in Malaysia at risk of developing hand-arm vibration throughout the activities in multiple industries (DOSM, 2020). Hand-arm vibration affected workers in many industries including construction (Clemm et al., 2019; Su et al., 2011), automotive (Barregard et al., 2003; Shamsul et al., 2016), manufacturing (Jorgensen et al., 2008; Orelaja et al., 2019; Pankaj & Singh, 2016) and aerospace (Joshi et al., 2006; Seri et al., 2014).

In the aerospace industry, aircraft parts manufacturing involved a mechanical joining process to assemble parts using fasteners such as screws, bolts, nuts, or rivets (Mori & Abe, 2018). Thousands of rivets are used to assemble and produce aircraft airframes (Sivakumar & Balaji, 2015). To perform the riveting task, several types of hand-held vibrating tools including a pneumatic drill gun and a pneumatic rivet gun are used. Both tools are used intensively to drill the hole and drive the rivet into the workpiece. The prolonged use of the vibrating tools will expose the workers to hand-arm vibration that could lead to several adverse health effects such as carpal tunnel syndrome, which is categorized as one of the work-related musculoskeletal disorders (WMSDs) injuries (Amaro et al., 2019; Nilsson et al., 2017). Since riveting is one of the main assembly processes, it is important to identify the main risk factors associated with hand-arm vibration exposure specifically in the aircraft manufacturing industry. Thus, in this paper, the risk factors due to hand-arm vibration exposure will be identified based on the review from the previous studies. A significant conceptual framework will be developed and proposed. The conceptual framework will be further investigated and validated through the experimental task evaluation in the next phase of this study. The knowledge on the risk factors can be used as a reference for manpower planning, task exposure time and job rotation to mitigate the risk of occupational injuries due to hand-arm vibration.

Review of Selected Previous Studies

Based on the literature search on the selected keywords, there were 35 studies found to be relevant to this study and 20 studies were found more significant for further review and compared as listed in Table 1. All previous studies are related to hand-arm vibration in various industrial sectors in several countries.

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Table 1: Summary of the Previous Studies on Hand-Arm Vibration

No	Title	Author	Year
1	Determination of hand-transmitted vibration risk on the human	Maedaa et al	2019
2	Dose-response relationship between hand-arm vibration exposure and vibrotactile thresholds among roadworkers	Clemm et al.	2019
3	Prediction on Hand Arm Vibration Exposure Cause-Effect among Grass-Cutting Workers in Malaysia	Mohamad et al.	2018
4	Prevalence of Hand-transmitted Vibration Exposure among Grass Cutting Workers using Objective and Subjective Measures	Nor Azali	2016
5	The Prevalence of Hand Arm Vibration Syndrome Among Automobile Assembly Workers	Shamsul et al.	2016
6	Effect of Hand Arm Vibration Exposure in Manufacturing Industry	Pankaj & Singh	2016
7	Study the Effect of the Foundation Surface on the Vibration Data at the Worker Arm Using Drilling Machine		2015
8	A Cross-Sectional Study on Hand-arm Vibration Syndrome among a Group of Tree Fellers in a Tropical Environment	Anselm et al.	2014
9	Effect of Working Posture and Hand Grip for Carpal Tunnel Syndrome among aerospace Workers	Seri et al.	2014
10	The vibration of Power Hand Tool and Discomfort Experience Among Malaysian Industrial Workers	Seri et al.	2013
11	The Effect of Vibration on Muscles Activity and Grip Strength Using an Electric Drill	Mirta & Siti Zawiah	2013
12	Evaluation of Protective Gloves and Working Techniques for Reducing Hand-arm Vibration Exposure in the Workplace	Milosevic & McConville	2012
13	The Effect of Hand-held Vibrating Tools on Muscle Activity and Grip Strength	Mirta & Siti Zawiah	2011
14	Hand-arm vibration syndrome: a common occupational hazard in industrialized countries	Heaver et al.	2011

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15	Reliability of a Malay-translated questionnaire for use in a hand-arm vibration syndrome study in Malaysia	Su & Hoe	2008
16	Vibration Reduction of Pneumatic Percussive Rivet Tools: Mechanical and ergonomic re-design approaches	John et al.	2009
17	Hand-transmitted Vibration in Power Tools: Accomplishment of Standards and Users Perception	Vergara et al.	2008
18	Evaluation of Ergonomic Interventions for Bucking Bars in Aircraft Manufacturing	Hull	2007
19	Ergonomic Field Assessment of Bucking Bars During Riveting Tasks	Jorgensen & Viswanathan	2005
20	Effects of Vibration, feed force and exposure duration on operators performing drilling tasks	Muzammil et al.	2010

All the significant factors found from the listed previous studies were reviewed, analyzed and summarized. As a result, a conceptual framework is developed by considering the independent variables and dependent variables related to manual handling tasks, hand-arm vibration sources, and effects on the workers' physiological response respectively.

The Proposed Conceptual Framework

Manual handling tasks using hand-held vibrating tools result in hand-arm vibration exposure (Milosevic & McConville, 2012). The factors involved are force (Nor Azali, 2016; Maedaa et al., 2019), posture (Hull, 2007; Seri et al., 2014), and repetition (Shamsul et al., 2016; Anselm et al., 2014). Interval time (Mirta & Siti Zawiah, 2013) and the types of tools used (Jorgensen et al., 2008; Seri et al., 2013; Vergara et al., 2008) also found influenced the risk level of hand-arm vibration. The exposure level can be assessed objectively using vibration level frequency (Chiad et al., 2015; Muzammil et al., 2010) and the duration of exposure to hand-arm vibration (Clemm et al., 2019; Su & Hoe, 2008). All these factors are presented in the conceptual framework as shown in Figure 1.

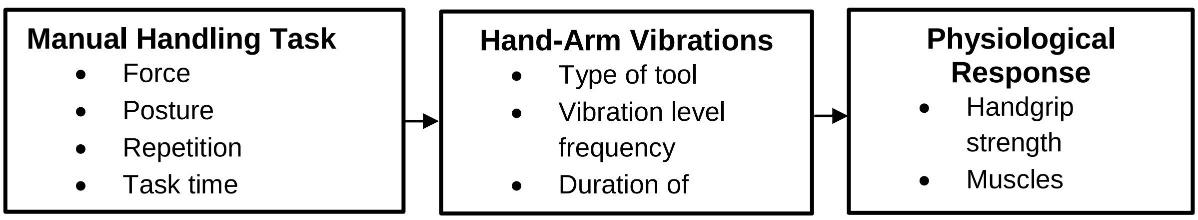

Figure 1: Hand-Arm Vibration Conceptual Framework

The proposed conceptual framework is formulated with three significant elements; manual handling task risk factors (force, posture, repetition, and task time), sources of hand-arm vibration (type of tools, vibration level frequency, duration of exposure), and the physiological response which comes from the result of handgrip strength and muscle activities.

Manual handling task risk factors are categorized as the independent variables which involved force, posture, repetition, and task time. Seri et al., (2013) found that prolonged operating of hand-held vibrating tools reduced the handgrip strength and lead to hand-arm vibration syndrome. It is because a high forceful exertion is applied to operate or grip the tool. The continuity of repetition during manual handling tasks causes the operators to operate the tool in repetitive motions. A study by Campbell et al., (2017) found that workers operating handheld tools repetitively are exposed to the risk of hand-arm vibration syndrome. Consequently, the operator is prone to extreme awkward posture (Coenen et al., 2014) and leads to work-related musculoskeletal disorders (WMSDs) (Charles et al., 2018; Shamsul et al., 2016). Previous studies also suggested that task time (Debela et al., 2019; Mirta & Siti Zawiah, 2013) and the duration of exposure (Bylund, 2004; Forouharmajd et al., 2017) also influences the risk level of hand-arm vibration.

The source of hand-arm vibration is another independent variable in this study. Three element sources of hand-arm vibration to be considered in this study which is the type of tools used (Babu et al., 2017; Qamruddin et al., 2019), vibration level frequency (Jorgensen et al., 2008), and the duration of exposure (Bylund, 2004; Forouharmajd et al., 2017). As the intensity and duration of exposure to vibrating tools increase, the risks of developing hand-arm vibration syndrome will also increase (Mirta & Siti Zawiah, 2013). The dependent variable of this study is the physiological response and task completion times.

The physiological responses due to hand-arm vibration are related to handgrip strength (Mohamad et al., 2018; Maedaa et al., 2019), and muscle activities (Jorgensen & Viswanathan, 2005; Mirta & Siti Zawiah, 2011; Pankaj & Singh, 2016) of the workers involved. The relationship of all factors in the proposed conceptual framework will be further investigated and verified through the experimental task. The outcomes of this study are expected to provide a significant reference to the industry players about the risk of hand-arm vibration and help to mitigate the issues.

Conclusion

All the relevant factors associated with hand-arm vibration had been reviewed, identified and a significant conceptual framework for hand-arm vibration had been proposed. The risk of hand-arm vibrations comes mainly from manual handling task activities. The factors involved are force, posture, and repetition and task time. The factors such as the type of tool used, the frequency of vibration level, and the duration of vibration exposure also influenced the level of hand-arm vibration risk. All these factors are categorized as independent variables. Meanwhile, the dependent variable is the physiological response resulted from the handgrip strength and the muscle activities. The relationship between all these factors will be further investigated and verified through the experimental task study. The results will provide knowledge to manage the risks of hand-arm vibration and help to improve the safety and health of the workers in the workplace. It also can be used as a reference to the aircraft manufacturing industry specifically and other industries generally in manpower planning, hand tool selection, preventive measure and mitigation plan for any tasks performing using hand-held tools.

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References

1) Amaro, A. M., Paulino, M. F., Neto, M. A., & Roseiro, L. (2019). Hand-arm vibration assessment and changes in the thermal map of the skin in tennis athletes during the service. International Journal of Environmental Research and Public Health, 16(24). https://doi.org/10.3390/ijerph16245117

2) Anselm Ting Su, Setsuo Maeda, Jin Fukumoto, Nobuyuki Miyai, Marzuki Isahak, Atsushi Yoshioka, Ryuichi Nakajima, Awang Bulgiba, Kazuhisa Miyashita (2014). A Cross-Sectional Study on Hand-arm Vibration Syndrome among a Group of Tree Fellers in a Tropical Environment. Industrial Health, 52(4), 367–376. https://doi.org/10.2486/indhealth.2013-0137

3) Babu T, R., Karthik N, D., & D, V. (2017). Hand-Arm Vibration Analysis of Demlition Hammers. Journal of Ergonomics, 07(06). https://doi.org/10.4172/2165-7556.1000218

4) Barregard, L., Ehrenström, L., & Marcus, K. (2003). Hand-arm vibration syndrome in Swedish car mechanics. Occupational and Environmental Medicine, 60(4), 287–294. https://doi.org/10.1136/oem.60.4.287

5) Bylund, S. H. (2004). Hand Arm Vibration and Working Women Consequences and Affecting Factors (Issue 931).

6) Campbell, R., Janko, M. R., & Hacker, R. I. et al. (2017). Hand-arm vibration syndrome: A rarely seen diagnosis. Journal of Vascular Surgery Cases and Innovative Techniques, 3(2), 60–62. https://doi.org/10.1016/j.jvscit.2017.01.002

7) Charles, L. E., Ma, C. C., Burchfiel, C. M., & Dong, R. G. (2018). Vibration and Ergonomic Exposures Associated With Musculoskeletal Disorders of the Shoulder and Neck. Safety and Health at Work, 9(2), 125–132. https://doi.org/10.1016/j.shaw.2017.10.003

8) Chiad, J. S., Bdawi, B. A., & Abbed, A. J. (2015). Study the Effect of the Foundation Surface on the Vibration Data at the Worker Arm Using Drilling Machine. 3(1), 539–548.

9) Clemm, T., Faerden, K., Ulvestad, B., Lars-Kristian, L., & Karl-Christian, N. et al. (2019). Dose-response relationship between hand-arm vibration exposure and vibrotactile thresholds among road workers. https://doi.org/10.1136/ oemed-2019-105926

10) Coenen, P., Formanoy, M., Douwes, M., Bosch, T., & De Kraker, H. et al. (2014). Validity and inter-observer reliability of subjective hand-arm vibration assessments. Applied Ergonomics, 45(4), 1257–1262. https://doi.org/10.1016/j.apergo.2014.03.003

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11) C. Heaver, K. S. Goonetilleke, H. Ferguson, S. Shiralkar (2011). Hand-arm vibration syndrome: a common occupational hazard in industrialized countries. Journal of Hand Surgery, 26(5). 354-363. https://doi.org/10.1177%2F1753193410396636

12) Debela, M. B., Taferi, G. R., & Assefa, M. (2019). Occupational Exposure to Hand-arm Vibration and Associated Factors among Metehara Sugar Industry Workers : East-Shoa, Ethiopia Journal of Environmental Hazards. Journal of Environmental Hazards, 2(1), 1–8.

13) Donati, P., Schust, M., Janusz, S., Stark, J., Gil Iglesia, E., Pujol Senovilla, L., Fisher, S., Flaspoler, E., Reiner, D., & Op deer Beeck, R. et al. (2008). Workplace Exposure to Vibration in Europe: An Expert Review.

14) DOSH. (2003). Guidelines on Occupational Vibration. https://www.dosh.gov.my/index.php/legislation/guidelines/ergonomic/603-01-guidelines-on-occupational-vibration-2003/file

15) DOSM. (2020). Labour Force Survey(LFS) Time-Series Statistics by State, 1982 - 2019. https://www.dosm.gov.my/v1/index.php?r=column/ctimeseries&menu_id=bnk3bk0wTTkxOXVHaVg3SUFDMlBUUT09

16) Forouharmajd, F., Yadegari, M., Ahmadvand, M., & Pourabdian, S. (2017). Hand-arm vibration affects performance, tactile acuity, and temperature of the hand. Journal of Medical Signals and Sensors, 7(4), 252–260. https://doi.org/10.4103/jmss.JMSS_70_16

17) Holt. (2007). A Guide to Hand-arm Vibration 2nd Edition (Professor David J. Edwards (ed.); 2nd ed.). Off-highway Plant and Equipment Research Centre.

18) HSE. (2019). Hand Arm Vibration at Work - A Brief Guide (1st ed.). TSO (The Stationery Office). https://www.hse.gov.uk/vibration/hav/regulations.htm

19) Hull, S. S. (2007). Evaluation of ergonomic interventions for bucking bars in aircraft manufacturing.December. http://soar.wichita.edu/dspace/handle/10057/1489

20) J. Jorgensen, M., S.Khan, K., & Polsani, A. et al. (2008). Use of Tungsten to Reduce Vibration Exposure in Aircraft Manufacturing. 52(15), 1045–1048. https://doi.org/10.1177/154193120805201510

21) J. Jorgensen, M., & Viswanathan, M. et al. (2005). Ergonomic field assessment of bucking bars during riveting tasks. Proceedings of the Human Factors and Ergonomics Society, 1354–1358. https://doi.org/10.1177/154193120504901419

22) John G.Chernga, Mahmut Eksioglub, Kemal Kızılaslanc. (2009), Vibration reduction of pneumatic percussive rivet tools: Mechanical and ergonomic re-design approaches. Applied Ergonomics, 40(2), 256-266. https://doi.org/10.1016/j.apergo.2008.04.011

23) Joshi, A., Guttenberg, R., Leu, M. C., & Murray, S. L. (2006). Modeling of hand-arm Vibration.

24) Mansfield, N. J. (2005). Human Response to Vibration (International).

25) Milosevic, M., & McConville, K. M. V. (2012). Evaluation of protective gloves and working techniques for reducing hand-arm vibration exposure in the workplace. Journal of Occupational Health, 54(3), 250–253. https://doi.org/10.1539/joh.11-0176-BR

26) Mirta, W., & Siti Zawiah, M. D. (2011). The effect of hand-held vibrating tools on muscle activity and grip strength. Australian Journal of Basic and Applied Sciences, 5(11), 198–211.

27) Mirta, W., & Siti Zawiah, M. D. (2013). The Effect of Vibration on Muscle Activity and Grip Strength Using an Electric Drill. Advanced Engineering Forum, 10(September 2015), 318–323. https://doi.org/10.4028/www.scientific.net/aef.10.318

28) Mohamad Hanafi, A., Nor Azali, A., & Musli Nizam, Y. et al. (2018). Prediction on Hand Arm Vibration Exposure Cause-Effect among Grass-Cutting Workers in Malaysia.

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29) Mori, K. Ichiro, & Abe, Y. (2018). A review on mechanical joining of aluminum and high strength steel sheets by plastic deformation. International Journal of Lightweight Materials and Manufacture, 1(1), 1–11. https://doi.org/10.1016/j.ijlmm.2018.02.002

30) Muzammil, M., Singh, R., Ahmad, S., & Hasan, F. (2010). Effects of vibration push force, exposure duration and working posture on operators performing a grinding task. Occupational Ergonomics, 9(1), 13–26. https://doi.org/10.3233/OER-2010-0178

31) Nilsson, T., Wahlström, J., & Burström, L. et al. (2017). Hand-arm vibration and the risk of vascular and neurological diseases-A systematic review and meta-analysis. PLoS ONE, 12(7). https://doi.org/10.1371/journal.pone.0180795

32) Nor Azali, A. (2016). Prediction of model Hand Arm Vibration Exposure Among Hand-held Grass-Cutters in Malaysia.

33) Orelaja, O. A., Wang, X., Ibrahim, D. S., & Sharif, U. (2019). Evaluation of Health Risk Level of Hand-Arm and Whole-Body Vibrations on the Technical Operators and Equipment in a Tobacco-Producing Company in Nigeria. Journal of Healthcare Engineering, 2019. https://doi.org/10.1155/2019/5723830

34) Pankaj, S., & Singh, M. . (2016). Effect of Hand Arm Vibration Exposure in Manufacturing Industry (No. 7). 7(3), 112–128.

35) Qamruddin, A. A., Nik Husain, N. R., Sidek, M. Y., Hanafi, M. H., Ripin, Z. M., & Ali, N. (2019). Prevalence of hand-arm vibration syndrome among tyre shop workers in Kelantan, Malaysia. Journal of Occupational Health, 61(6), 498–507. https://doi.org/10.1002/1348-9585.12078

36) S. Maedaa, M. D., Taylorb, L. C., & Andersonc, J. M. et al. (2019). Determination of hand-transmitted vibration risk on the human.

37) S. Sivakumar, & S. Balaji, E. al. (2015). Damage Tolerance Analysis of Aircraft Fuselage Riveted Joint Panel. International Journal of Engineering Research And, V4(05), 862–867. https://doi.org/10.17577/ijertv4is050886

38) Seri, R. K., Nurulhuda, A., & Rohana, A. et al. (2013). Vibration of Power Hand Tool and Discomfort Experience among Malaysian Industrial Workers. Advanced Engineering Forum, 10(September 2013), 313–317. https://doi.org/10.4028/www.scientific.net/aef.10.313

39) Seri Rahayu, K., Norhidayah, H., Halim, I., & Hui Hui, C. (2014). Effect of working posture and handgrip for carpal tunnel syndrome among Aerospace workers. International Journal of Mechanical and Mechatronics Engineering, 14(1), 30–35.

40) Shamsul Bahri, M. T., Maizura Yusoff, N., Rahman, A. A., Dayana Hazwani, M. S. N., & Balkhyour, M. A. et al. (2016). The prevalence of hand-arm vibration syndrome among automobile assembly workers. Malaysian Journal of Public Health Medicine, 16, 128–136.

41) Shen, S. C., & House, R. A. (2017). Hand-arm Vibration Syndrome. Canadian Family Physician, 63(3), 206–210.

42) Su, A. T., & Hoe, V. C. . (2008). Reliability of a Malay-translated questionnaire for use in a hand-arm vibration syndrome study in Malaysia. Singapore Medical Journal, 49(12), 1038–1045.

43) Su, A. T., Hoe, V. C. W., Masilamani, R., & Mahmud, A. B. A. (2011). Hand-arm vibration syndrome among a group of construction workers in Malaysia. Occupational and Environmental Medicine, 68(1), 58–63. https://doi.org/10.1136/oem.2009.052373

44) Vergara, M., Sancho, J. L., Rodríguez, P., & Pérez-González, A. (2008). Hand-transmitted vibration in power tools: Accomplishment of standards and users' perception. International Journal of Industrial Ergonomics, 38(9–10), 652–660. https://doi.org/10.1016/j.ergon.2007.10.014