International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 5, Issue 1, pp: (80-88), Month: April - September 2017, Available at: www.researchpublish.com

A Biomechanical Analysis of Vacuum Cleaning Task Using Risk Assessment Tools

[1]Dr. Abdulbaset Frefer, [2]Sahapol Hoon knew, [3]Rabia Almamlook

[1]Mechanical and Industrial Engineering Department, University of Tripoli, Tripoli, Libya
[2,3] Department of Industrial, Manufacturing Engineering and Engineer Management, Western Michigan University, Kalamazoo, MI, 49008-5314

Abstract: **The purpose of this study was to provide an overview of the most important risks of two types of industrial vacuum cleaners on five related muscles and to provide an overview of the most important issues to highlight the main trends and issues regarding the working conditions, hazard exposure and health outcomes, to identify gaps in knowledge and information available, and to formulate recommendations for future studies. Electromyography (EMG) analysis techniques are widely used in ergonomics and biomechanical studies for analyzing the demand of a job, comparing different tasks, and ergonomics design. Electromyography (EMG) was recorded to measure the electrical activity of different muscles including trapezius, medial deltoid, biceps brachii, brachioradialis and torso located in the neck, shoulder, upper arm, forearm and lower back respectively. Four subjects ranging from 23 and 28 years of age were analyzed. Surface electromyography of different muscles was measured and numerous signal processing methods were applied. ANOVA was used to assess the effects of the dependent variables as well as their interactions. Results of this study demonstrated that there was interaction between vacuum type and trunk flexion angle. Also, there was no significant difference in average compression between vacuum type and trunk flexion angle ($p<00.1$). The study concluded that trunk flexion angle was more sensitive to create stresses on torso muscles compared to trapezius muscles with either the backpack or upright vacuum cleaners. The backpack vacuum cleaner has an effect of torso angles on five related muscles compared to the upright vacuum cleaner regarding cleaning rates. Using backpack vacuum cleaner results in less body stress and risk compared to the upright vacuum cleaner.**

Keywords: **Muscle activity, Ergonomics, Electromyography, Vacuum Cleaning, Non-Neutral Torso Postures.**

1. INTRODUCTION

In the manufacturing setting there are two types of vacuum cleaners that are universally used including a backpack vacuum cleaner (BPVC) and an upright vacuum cleaner (UVC). Approximations of timed cleaning tasks from an industrial job report suggest that industrial BPVCs may be more efficient in cleaning the same area than UVCs (International Sanitary Supply Association, 1994). A housekeeper in hotels and commercial cleaning workers that perform the task of vacuum cleaning are at risk of work-related upper-limb musculoskeletal injury and musculoskeletal disorders. Workers who perform the task of vacuum cleaning are at risk of work-related upper-limb musculoskeletal injury, regardless of the vacuum they use (Maras, et al., 2000, Waldemar, et al., 2012, Tayyari, et al., 2003).

Many of the cleaning tasks involve heavy manual work and are physically demanding. Cleaning is a highly physically demanding job with a high frequency of awkward postures and working environments as contributing risk factors (Kumar et al., 2005). Thus, cleaning workers have a high risk of developing MSDs of the back, neck, shoulders, elbows, hands and lower limbs as a result of their work characteristics. Shoulder and back pains were affected by inappropriate torso postures, for example, in cleaning in terms of the health and safety representatives (Bell, 2008, Bell, et al., 2012).

Among these factors are poor working postures; e.g. poor ergonomic work and workplace, poor design of cleaning tools, and the task including work organization, such as long working hours, low salaries and uncomfortable working times.

Hence, this was partly due to the repetitive bending involved in the mopping task like cleaning under tables and chairs, as well as the actual mopping movement. Therefore, preventive actions are needed to reduce overloading of shoulder muscles and to prevent work-related upper extremity disorders. Furthermore, various types of vacuum cleaning machines are widely available in the market, so that one might unintentionally use an inappropriate type of them to perform a regular vacuuming task and then negatively affects her or his muscles.

Previous studies showed the effect of inappropriate use of vacuum cleaners. Loopik et al., (1994) reported that difficulties experienced by subjects using three new types of vacuum cleaners were mostly of a cognitive nature. Some problems could be resolved by trial and error, but the common requirement of subjects is to read the operating manuals. The key design criticisms were; too short, too thin, unintentional operation of the mechanical suction power regulation, difficulty changing the brush control and adjusting the power suction. Southard, et al., (2007) explained that a slight torso flexion could help reduce some muscle activity when a heavy backpack carried vacuum cleaning is a risk to the musculoskeletal health of cleaning workers, with some variation between the tool ratings, reflecting the specificity and sensitivity of each tool. (Bell, 2008)

2.1. Subjects:

2. METHOD AND PROCEDURES

Randomly chosen, four healthy, male participants were all graduate students at Western Michigan University. Their ages ranged from 23 – 28 years old with an average of 24.78. Their heights are between 163 – 182 cm with an average of

174 cm and weights fall between 68 – 89 kg, with an average of 79.8 kg. All the subjects were specified to be right-hand dominant and also did not experience any previous injuries on upper limbs or musculoskeletal disorders in the past months. They had asked not to do heavy activities primarily associated with repetitive right upper arm and forearm before the experiment. Figures 1 and 2 are illustrations of subject performing the task equipped with the upright vacuum and the back-pack vacuum cleaners at trunk flexion 20$^{o.}$

Figure 1. Illustration of a subject performing the task equipped with the backpack vacuum cleaner at trunk flexion angle 20°

Figure 2. Illustration of a subject performing the task equipped with the upright vacuum cleaner at trunk flexion angle 20°

2.2 Apparatus:

The upright and back pack vacuum cleaners were selected for this experiment with some restrictions. Back pack vacuum has weight approximately 10 lbs, while the upright traditional vacuum cleaner from Bissell has a weight of about 12 lbs. Upright vacuum cleaner was the first vacuum type factor level (Model 95P1, Bissell, MI, USA) and a 10-lb backpack vacuum cleaner from GV (Model GV-BP8QT, GV, China) was chosen for another factor level in the experiment. The hip belt attaching the backpack vacuum was not used for all subjects.

2.3 Experimental procedure:

Upon arrival, personal and anthropometry measurements, including age, weight, heights, occupation and upper limb injury background of each subject were collected. Then, four electrodes were placed on four interest muscles, only on right upper trapezius, medial deltoid, biceps, brachii and brachioradialis respectively. In the meantime, each subject was asked to rotate and move the right arm to see whether or not EMG (Electromyography) signals yielded some fluctuation on the EMG software screen; in other words, all EMG electrodes were placed in the right position and in contact with those muscles under study. Prior to the first test session conducted for each subject, the maximum voluntary contraction MVC of each muscle under study must be measured to normalize EMG data. MVC of upper trapezius, medial deltoid, biceps, brachii and brachioradialis were tested by shoulder shrug (Gowan, et al., 1987) and 90^o lateral arm raise against a static manual resistance, respectively. (Boettcher, et al., 2008) Besides, MVC of biceps, brachii and brachioradialis were then simultaneously tested by flexing forearm about the elbow against a manual resistance (Burkhart, et al., 2013). A subject needed to perform the tests twice for consecutive ten seconds twice with ten-second rest in between. Then, a goniometer was used to measure and control a specified trunk flexion angle by an assigned experiment throughout each session as the experimental layout of two-factor factorial design. After each subject was placed in an intended posture and then photographed on the right-hand side, he was instructed to perform a vacuuming task by the right upper limbs continuously at a constant frequency cycle continuously for 30 seconds.

Table (1) Borg scale for perceived exertion on the scale of 1-10

RATING	DESCRIPTION
0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)

Immediately after each session, the subject was asked to give perceived exertion rating on Borg CR10, (a scale used to quantify fatigue and pain during physical activity ranging from 1 -10) (Borg, 1970), as shown in Table (1) was developed by Borg (1970) to increases linearly with the exercise intensity. The Borg scale has been widely used to study the perception of exertion in laboratory, clinical, and occupational setting (Krawczyk, 1996). Each subject was allowed to have about three-minute rest before performing the next task to avoid excessively accumulative fatigue. Additionally, estimates of %MVCs on torso muscles as well as compression and shear forces were simulated based on estimate of external loads. Backpack strap angle was measured based on photographs to obtain the horizontal force associated with the backpack gravity load on both shoulders. Minimum push forces, as well as the gravity force, acting on the right hand began to exceed the friction between the vacuum roll brush and the rug roughly measured by a force spring meter.

2.4 Design of Experiment:

Two Independent variables in this study were chosen; the first independent variable was vacuum type with two levels of upright and backpack, and the second independent variable was trunk flexion angle with three levels; 20^o, 40^o and 60^o as shown in Table 2. Each subject was exposed to all combinations of harness and forward flexion angle. Each combination of independent variables was performed two times. There was a restriction on complete randomization in that the participants wore one harness system and completed all trunk flexion angles and then changed to the other system and completed all of the flexion angles. The trunk flexion angles were completely randomized within each harness type level and the presentation order of harness type was counterbalanced across subjects. In addition, the first step in the EMG normalization process was to establish the MVC EMG value for each muscle in each forward trunk flexion angle according to the procedure described in (Jiang et al., 2005).

Table 2. Two-way ANOVA experimental layout with full order randomization and blocking

Run	Subject	Vacuum Type	Trunk Flexion angle (degs)	RunOrder	Subject	Vacuum Type	Trunk Flexion angle (degs)
1	1	Upright	20	13	3	Upright	40
2	1	Backpack	60	14	3	Backpack	60
3	1	Upright	60	15	3	Backpack	20
4	1	Backpack	40	16	3	Upright	60
5	1	Upright	40	17	3	Upright	20
6	1	Backpack	20	18	3	Backpack	40
7	2	Upright	40	19	4	Backpack	20
8	2	Backpack	20	20	4	Upright	40
9	2	Backpack	60	21	4	Upright	20
10	2	Upright	60	22	4	Backpack	40
11	2	Backpack	40	23	4	Backpack	60
12	2	Upright	20	24	4	Upright	60

Surface Electromyography (EMG) was used to evaluate the intensity of muscle contraction by collecting electrical activities records of muscles understudy for a task (Delsys 16 Channel Model, Bagnoli EMG desktop system, MA, USA). It was able to detect the electricity generated by muscle cells wherever muscular cells were contracting or at rest. In this experiment, four EMG electrodes were specially attached on different muscles including upper trapezius (A), medial deltoid (B), biceps brachii (C) and brachioradialis (D) muscles only on the right upper limb as shown in the Figure 3, to collect the muscles activity in electrical signals over each 30-second test session at 2,000Hz. Generally, muscular tissues at rest are inactive or produce trivial electricity; in contrast, once the muscles are voluntarily contracting in order to perform a specified task or resistance movement associated with them, electricity signals obviously increase in amplitude. In other words, the higher internal force required in a muscle for a task, the higher amplitude of the related muscles could be observed. This brings about the fact that the higher amplitude of EMG represents more stress on a muscle. As the task in the experiment was performed continuously without any rest, EMG original data was simplified, converted and extracted in RMS EMG values (16 Hz) (Farfán, et al., 2010).

Figure 3. Illustration of EMG electrodes attached to A-Trapezius, B- Medial Deltoid, C- Biceps Brachii, and D-Brachioradialis

2.5 Statistical Data Analysis:

Data collected consisted of nominal, ordinal and interval data by Anderson Darling's test, Levene's test ($\alpha = 0.05$) (Montgomery, 2012). The Minitab Statistical Software for windows version 17 was used when applying the statistical (parametric and non-parametric) techniques. For the EMG data, ANOVA was a primary statistical tool used to assess the effects of the independent variables as well as their interactions. For the effects that were found to be significant, the Tukey-Kramer procedure was subsequently performed to further determine the significant effects across the levels. In those instances, where there were both a significant interaction and a significant main effect, simple effects analysis was performed to verify that the main effect was significant across all levels of the other independent variable. If the main effect did not hold across all levels of the independent variable, then only the interaction effect was considered.

3. RESULTS AND DISCUSSION

All normalized EMG data (% of max) were calculated and based on these MVCs, ANOVA statistical technique was then used to analyze the effects of independent variables at $\alpha = 0.05$. The results of the analysis of the normalized EMG showed an interesting interaction between vacuum type and trunk flexion angle (F=1.63, p=0.229) (Southhard, et al., 2007). Only trunk forward flexion angle significantly affected the %MVC on the right trapezius (F = 4.47, p = 0.030) as shown in Figure 4 and Table 3, but this interaction was not significant. The results of these effects analysis reveal that the effects of %MVC on the right trapezius are found only in their interaction with flexion angle

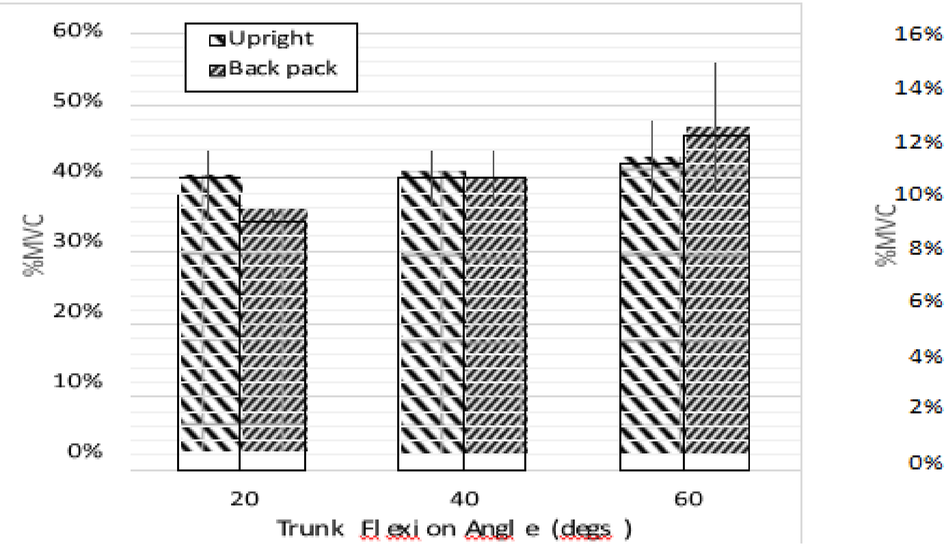

Figure 4. %MVC of Trapezius muscle as a function of vacuum type and trunk angle

Table (3). ANOVA result for %MVC on the trapezius muscle

Source	Df	Adj SS	Adj MS	F-value	P-value
Vacuum Type	1	0.000027	0.000027	0.01	0.916
Trunk Angle	2	0.0214169	0.010709	4.47	0.030
Subject (Blocking)	3	0.2144789	0.071596	29.91	0.000
Vacuum Type*Trunk Angle	2	0.007812	0.003906	1.63	0.229
Error	15	0.035912	0.002394		

In Figures 5-7 and Tables 4-5), performing such a vacuuming task with two different vacuum types and three trunk flexion angles did not represent significant difference on biceps, brachii and brachioradialis muscles.

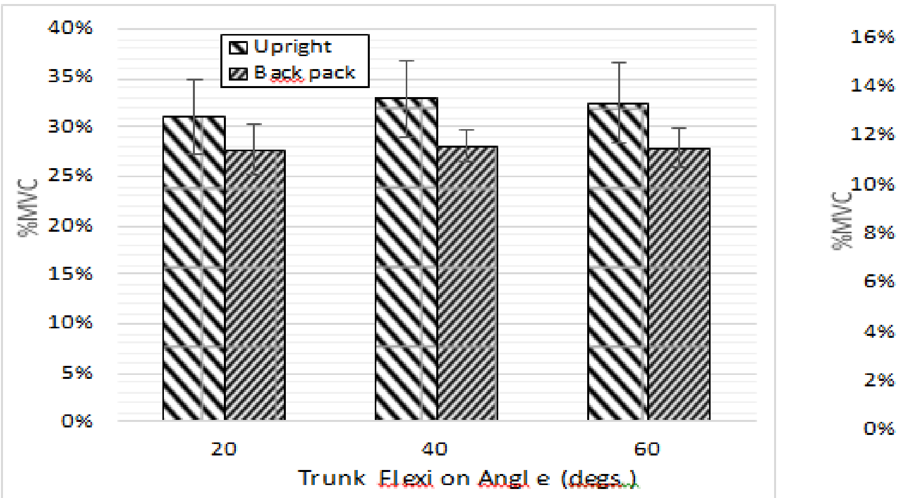

Figure 5. %MVC of medial Deltoid muscle as a function of vacuum type and trunk angle

Table 4. ANOVA result for %MVC on the deltoid muscle

Source	Df	Adj SS	Adj MS	F-value	P-value
Vacuum Type	1	0.005959	0.005959	3.05	0.101
Trunk Angle	2	0.000611	0.000305	0.16	0.857
Subject (Blocking)	3	0.032425	0.010808	5.53	0.009
Vacuum Type*Trunk Angle	2	0.000161	0.000081	0.04	0.960.040
Error	15	0.029306	0.001954		
Total	23	0.068463			

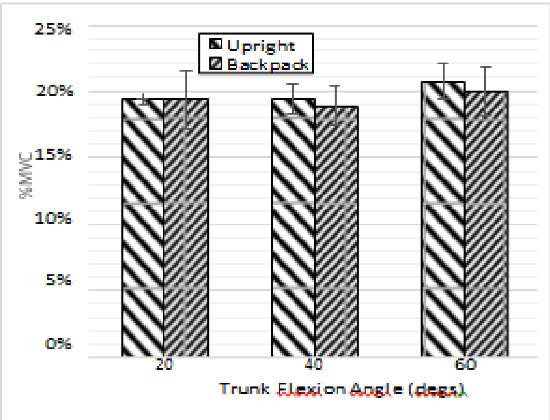

Figure 6. %MVC of Biceps Brachii muscle as a function of vacuum type and trunk angle

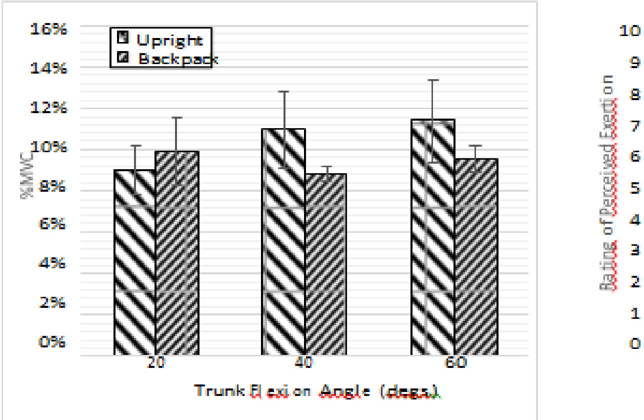

Figure 7. %MVC of Brachioradialis muscle as a function of vacuum type and trunk angle

Table 5. ANOVA result for %MVC on the biceps brachii muscle

Source	Df	Adj SS	Adj MS	F-value	P-value
Vacuum Type	1	0.000318	0.000318	0.47	0.505
Trunk Angle	2	0.000559	0.000280	0.41	0.3741
Subject (Blocking)	3	0.007085	0.002362	3.47	0.043
Vacuum Type*Trunk Angle	2	0.000122	0.0000861	0.09	0.915
Error	15	0.0102136	0.000681		

In Figure 8 and Table 6, the analysis result of %MVC represent an interaction between trunk flexion angle and vacuum cleaner type (p = 0.235). Nevertheless, Tukey method results yield the fact that only trunk flexion angles were significant as was reported by (Southhard, et al., 2007) for all pairs; 20^o versus 40^o, 20^o versus 60^o and 40^o versus 60^o while the vacuum cleaner type did not show any significant effect.

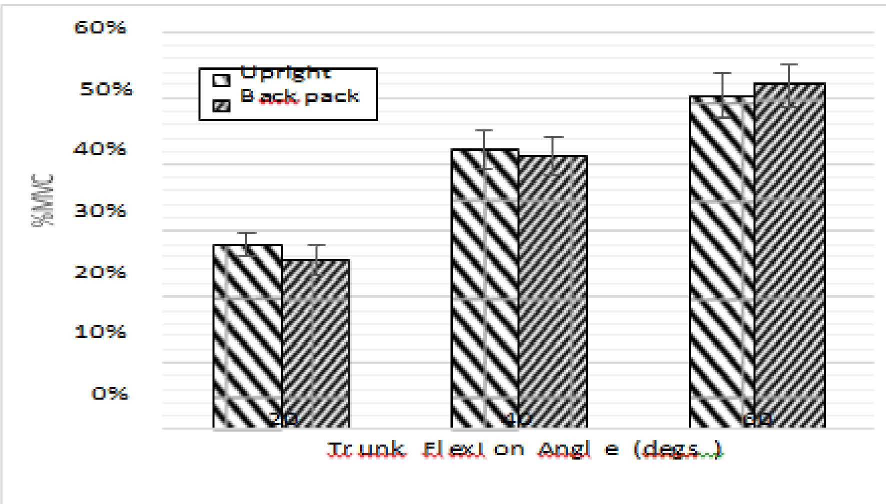

Figure 8. %MVC of Torso muscle as a function of vacuum type and trunk angle

Table 6. ANOVA result for %MVC on the brachioradialis muscle

Source	Df	Adj SS	Adj MS	F-value	P-value
Vacuum Type	1	0.001510	0.001510	2.38	0.144
Trunk Angle	2	0.000079	0.000040	0.06	0.940
Subject (Blocking)	3	0.005298	0.001766	02.78	0.077
Vacuum Type*Trunk Angle	2	0.002027	0.0010174	01.60	0.235
Error	15	0.009512	0.000634		
Total	23	0.018427			

Based on MVC% data analysis, a significant increase in muscular stress on trapezius was found at the 60^o trunk flexion angle while this factor started generating a considerable effect on torso at 40^o and 60^o trunk flexion angles. Generally speaking, trunk flexion angle was more sensitive to create stress on torso muscle compared to trapezius muscle no matter what the vacuum type is equipped with either the backpack or upright vacuum cleaner. Furthermore, vacuum cleaner type had a minor effect on medial deltoid muscle

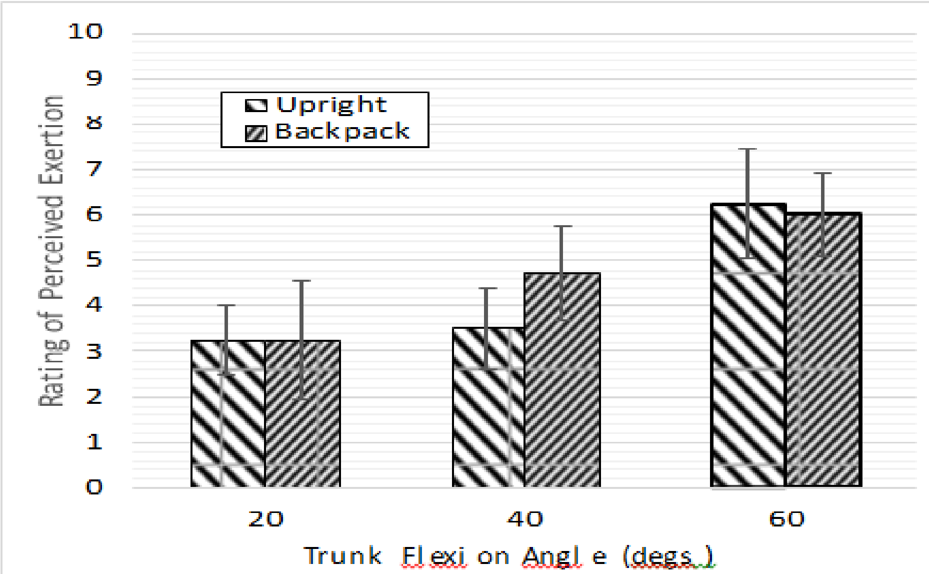

Figure 9. Borg CR10 rates as a function of vacuum type and trunk angle

Figure 9 showed that only trunk flexion angles significantly increased the discomfort when the subjects were asked about the scale while vacuum cleaner type did not. Most subjects reported that discomfort would be noticeably increased whenever they were asked from 20^o to 60^o of trunk flexion angle while they did not feel any significant difference of discomfort between 20^o versus 40^o and 40 versus 60.

4. CONCLUSIONS

The results of this study showed that trunk angle was a significant independent variable in muscle stresses on trapezius muscle and torso muscles on electromyography experiment. Vacuum type in the experiment was statistically an insignificant factor that needed further study on deltoid muscle. The results of this simple effects analysis reveals that the effects of %MVC on the right trapezius are found only in their interaction with flexion angle. The trunk flexion angle brought about a statistical difference of discomfort between 20^o and 60^o trunk angles but did yield discomfort between the vacuum types.

The strength percent of population capability for four joints; namely, torso, hip, knee and ankle have no significant noticeable between the backpack and upright and trunk angles again demonstrated a considerable difference amongst 20^o, 40^o and 60^o. There is no big difference of % population capability between UVC and BPVC for torso, hip, knee and ankle joints.

However, % of population capability is noticeably decreased when the trunk angles are varied between 20^{o} and 60^{o} across all the joints. Using backpack vacuum cleaners results in less body stress than with uprights. The study concluded that the backpack vacuum cleaner was more efficient compared to the upright vacuum cleaner in terms of cleaning rates during a vacuum cleaning task. Backpack vacuum cleaner also was less risks compared to the upright vacuum cleaner.

5. RECOMMENDATIONS

- Workers should use backpack vacuum cleaner because it is less body stress and less potential risk compared to the upright vacuum cleaner in terms of cleaning.
- To optimize the design of vacuum cleaner, the weight of vacuum cleaners should be reduced, especially for the backpack type as it directly generate compression force.
- Although, some simulations of a set of different postures of upper limbs where done, more detailed simulations are needed.
- The handle weight should be also reduced to optimize the design, although this category might not yield a significant effect as the upright and backpack vacuum CGs are generally in the brush next the floor and the weight of the suction hose and tube for a backpack.
- The rolling friction of vacuum wheels and handle joint should be minimized to reduce the pushing force an operator put on to overcome the friction.
- Using backpack vacuum cleaners reduce repetitive motions associated with uprights that can result in long term adverse medical effects.
- By using backpack vacuum cleaners, workers were able to vacuum more than twice the area with similar levels of energy expenditure and perceived effort.
- Using backpack vacuum cleaners minimize the fatigue that is often associated with upright vacuum cleaner use.

ACKNOWLEDGMENTS

This work was supported by the WMU. We wish to thank TA for her assistance in data collection.

REFERENCES

[1] International Sanitary Supply Association, (1994).

[2] Marras, W.S., Allread, W.G., Burr, D.L. and Fathallah, F.A., "Prospective validation of a low-back disorder risk model and assessment of ergonomic intervention associated with manual materials handling tasks", Ergonomics, 43.11 (2000): 1866-1886.

[3] Waldemar, K. and Marras, W., eds., The occupational ergonomics book, CRC Press, New York, USA, 2012.

[4] Tayyari, F. and Smith, J., "Occupational ergonomics: principle and applications", Kluwer Academic Pub., Massachusets, (2003).

[5] Kumar, R., Chaikumarn, M., and Lundberg, J., "Participatory ergonomic and an evaluation of a low-cost improvement effect on cleaner' working posture", International. Journal of Occupational Safety and Ergonomics, 11.2 (2005): 203-210.

[6] Bell, A.F., "An ergonomic analysis of vacuum cleaning tasks using observation risk assessment tools", MSc Thesis, University of Wollongong, (2008).

[7] Bell, A.F. and Steele, J.R., "Risk of musculoskeletal injury among cleaner during vacuuming", Ergonomics, 55.2 (2012): 237-247.

[8] Loopik, W.E., Kanis, H., and Marinissen, A.H., "The operation of new vacuum cleaners", A users' trial, in contemporary ergonomics, Robertson, S.A., ed., Taylor and Francis, London, (1994): 34–39.

[9] Southard, S.A. and Mirka, G.A., "An evaluation of backpack harness systems in non-neutral torso postures", Applied Ergonomics, 38.5 (2007): 541-547.

[10] Gowan, I.D., Jobe, F.W., Tibone, J.E., Perry, J., and Moynes, D., "A comparative electromyographic analysis of the shoulder during pitching- professional versus amateur pitchers", American Journal of Sports Medicine, 15 (1987): 586–590.

[11] Boettcher, C.E., Ginn, K.A., and Cathers, I., "Standard max. isometric voluntary contraction tests for normalizing shoulder muscle EMG", Journal of Orthopaedic Research, 26.12 (2008): 1591-1597.

[12] Burkhart, T.A., and Andrews, D.M.., "Kinematic, kinetic and muscle activation on patterns of the upper extremity during simulated forward falls", Journal of Electromyograhy and Kinesiology, 23.3 (2013): 688-695.

[13] Borg, G., "Perceived exertion as an indicator of somatic stress, Scandinavian Human kinetic", Journal of Rehabilitation Medicine, 2-3 (1970): 92-98.

[14] Krawczyk, S., "Psychophysical method and the evaluation of manual material handling and upper extremity intensive work", Occupational Ergonomics: Theory and Practice, In Bhattacharya, A., and McGlothlin, J., eds., Marcel Dekker, Inc, New York, USA, (1996): 137-164.

[15] Hintermeister, R.A., Lange, G.W., Schultheis, J.M., Bey, M.J., and Hawkins, R.J., "Electromyographic activity and applied load during shoulder rehabilitation exercises using elastic resistance", The American Journal of Sports Medicine, 26.2 (1998): 210-220.

[16] Kumar, R., Hägg, G., and Öhrling, T., "Muscular activity during staircase cleaning while using an easily adjustable and a non-adjustable mop stick", Proceedings at The Nordic Ergonomic Society Conference, Ergonomic Society Conference, Reykjavik, Iceland, August 11-13 (2008).

[17] 3D-Static strength prediction program, (Ver. 6.0.6) User's Manual, Center for Ergonomics, The University of Michigan, Ann Arbor, Michigan, (2014).

[18] Jiang, Z., Shin, G., Freeman, J., Reid, S., and Mirka, G.A., "A study of lifting tasks performed on laterally slanted ground surfaces", Ergonomics, 48.7 (2005): 782-795.

[19] Farfán, F.D., Politti, J.C., and Felice, C.J., "Evaluation of EMG processing techniques using information theory", Biomedical Engineer Online, 9.72 (2010): 72-80.

[20] Montgomery, D.C., Design and analysis of experiments, 8th ed., John Wiley & Sons, (2012).