Analyses on Human Fatigue and Posture Risk of Demolishing Task

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Keywords: Demolishing Task, Human Fatigue, Posture Risk, Maximum Endurance Time (MET).

Abstract: Safety plays a key role in ensuring the efficiency of demolition operation. Exploring the fatigue development of demolition operators in the operation process at the view of safe man-machine and risk control is not only conducive to improving the safety and humanization of operation design, but also in favor of ensuring the physical and mental health of operators. This research aimed to explore the law of development and influencing factors of demolishing task that are contribute to prevent WMSDs and design assignment for demolishing task. A simulated demolishing task was designed and 10 male college students were recruited as participants. Then the pushing and griping strength before and after demolishing and MET, were measured, and the RPE for four limbs and waist after demolishing were collected to explore the influence of the size of demolition equipment, demolishing height on fatigue for demolishing task. In addition OWAS was employed to analyze poor working postures and evaluate the risk on demolishing task. The results show that the decrease degree of pushing strength was significantly greater than that of griping strength, and the risk of fatigue accumulation was greater. The size of the demolition equipment did not affect the development of human fatigue in the process of demolition operation. Furthermore demolishing height had a great impact on MET, which would affect the accumulation of fatigue. The posture risk shows that the posture risk of 115cm is lower than 65cm, but it also needs to be corrected as soon as possible.

1 INTRODUCTION

Demolition equipment is an indispensable tool to building engineering, road and bridge engineering, disaster rescue and so on, being used to dismantle solid reinforced concrete or obstruction (Li 2019). Demolition equipment is partially automated man-machine operation system, and it needs human assist to accomplish a task (Nordmand 2013). As the clunky of demolition equipment, the complex components of architectural structures and equipment vibration and so on, there are many influence factors contribute to human overload and operating fatigue, such as high degree of applying force, strong vibration, repetitive operation and awkward position (squat or creep). The operating fatigue, which has been accumulated for long, were likely to cause work-related disorders, this not only decreases effectiveness, frequent safety accidents, and brings personal injury accidents, and led to a lot of business and social damage to property (Prati 2010, Xu 2019). Early research confirmed that long-term use of demolition equipment can lead to a greater risk of Work-related musculoskeletal disorders (WMSDs) (Xu 2017, Phairah 2016). At the same time, the decreased response and restricted physical exercise when workers work under the state of fatigue have a directly impact on the concentration level and the accuracy level of operating which are mostly contributed to human's unsafe behaviors (Zhang 2019). Therefore, it is very importance to investigate the fatigue of the workers used demolition equipment for ensuring the work safety.

The inappropriate man-machine and man-work assignment match are major cause of WMSDs (Miller 2007, Wu 2013). The careful reasonable

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Yu, K., Sun, Y., Huang, J., Yi, C. and Tang, F.
Analyses on Human Fatigue and Posture Risk of Demolishing Task.
DOI: 10.5220/0011292200003438
In *Proceedings of the 1st International Conference on Health Big Data and Intelligent Healthcare (ICHIH 2022)*, pages 272-277
ISBN: 978-989-758-596-8

designs of work assignment and workload have significant preventive effect on WMSDs, and that need to be analyzed the influencing mechanism between the physiological function and operating mission (Ma 2009). So exploring the progression of fatigue for demolishing task is the essential method for reducing physiological overhead and preventing WMSDs. The mechanism of operating fatigue is more complicated and involves physiological fatigue and psychological fatigue. The measure of fatigue involves multiple discipline knowledge such as biology, psychology and human factors engineering, and the concrete method includes subjective evaluation, biomechanical analysis, biochemical analysis and operational evaluation (Yi 2018). The combination of several methods to measuring fatigue will help to more comprehensive understanding of the progression of operating fatigue. Studies have shown a good coherence between these approaches (Hu 2018). The present research related development of fatigue for manual demolishing task have concentrated principally on localized muscle fatigue (Xu 2019, Widia 2009, Fattorini 2016, Jacquelyn 2016), force distribution in different positions (Li 2019, Xu 2017, Alabdulkarim 2017), the effects of the human body's characteristics to muscle fatigue (Xu 2017, Su 2013, Bast 2017). However, the above researches mainly used a single approach to recruit operating muscle fatigue, focused on the fatigue of the body parts and particular body postures, and lack of in-depth research on the development tendency of muscle fatigue on demolishing task.

The field observation method is the important assessment tool to research the risk of WMSDs, and can be used to identify the bad factors associated with the workplace in the view of human engineering (Tzu 2013, Wahyudi 2015). In order to adopt more comprehensive analysis on the development of fatigue and assessment of risk in performing a demolishing task, a demolishing task was designed and arranged. The objectives of this study were to i) compared the strength of griping and strength of pushing before and after performing a demolishing task; ii) explore the influence of the size of the demolition equipment and the height of demolishing on operating fatigue, and evaluate the risk of working posture for demolishing task; and iii) provide advices on how to lower the risk of WMSDs for performing a demolishing task.

2 METHODOLOGY

An experiment was conducted in the laboratory to simulate demolishing task. The temperature and humidity were 19.21°C (±1.83) and 62.17% (±14.66), respectively.

2.1 Subjects

Ten male adults volunteered as subjects in the demolishing task experiment without payment. All subjects were right-handlers. All of them did not have a history of WMSDs. They read and signed an informed consent for participating in the study. The age, stature, body weight, body mass index were 19.64(±0.7) yrs, 70.85(±8.15)kg, 172.05(±4.85) cm, and 23.91(±5.92) kg/m^2, respectively. All subjects were requested to refrain from strenuous physical exercise a day before joining the experiment.

2.2 Apparatus

An apparatus to measure the push strength was employed. This apparatus encompassed a height-adjustable fixed mount, a loadcell (FH3D-45), and a panel (see Fig.1). The panel was made from wood and had one centimeter of hole in the middle for determining the position of the bit. Demolition equipment includes the larger (BOSCH, GSH 9VC, 8.9kg) and smaller （BOSCH, GSH 500, 5.6kg） size models. Hand grip strength was measured using a dynamometer (EH101, CAMRY).

Figure 1: Simulated demolishing task.

A Borg CR-10 rating scale was employed to measure perceived physical exertion of the subject at the end of each trial (Gunnar 1990). The Ovako Working Posture analysis System (OWAS) (Karhu 1977) was employed to analyze poor working postures and evaluate the risk.

2.3 Experimental Procedure

Before each trial, the subject was requested to do warm up exercise for five minutes. The isometric pushing and griping strength were measured at 65cm and 115cm altitude, respectively. The pushing and griping strength were MVC_{push} and MVC_{grip} separately. In this measurement, the postures are consistent with the experiment.

For the simulated demolishing task, the subject was instructed to perform a push-forward task simulating the operation of a wall demolition. One stood and grasped the demolition equipment using his both arm and maintained this push until he could not do so any longer (see Fig. 1). The time of performing the task was the maximum endurance time (MET). After demolishing task, the pushing and griping strengths were assessed once again which were marked as F_{push} and F_{grip}. The CR-10 rating of bodily fatigue on the participant's right and left upper limb, waist, right and left lower limb were recorded after each trial. In the trial, OWAS was employed to encode and grade the demolishing postures of black, arm, leg and loading.

2.4 Experiment Design & Data Analysis

Each subject needs to complete four sessions (2 height conditions × 2 device models) of the experiment. Microsoft® Excel was employed for data analysis and figure preparation. The SAS® 9.4 was used for statistical analyses.

3 RESULTS

3.1 Strength & MET Statistics

The ANOVA results indicated that the pushing (p<0.0001) and griping (p<0.0001) strength before and after the demolishing test were significantly different. The decreasing degrees of pushing strength and griping strength were 46.90% and 24.26%, respectively. To account of individual differences, the average drops of pushing strength and griping strength were normalized and marked as FD (FD= (MVC-F)/MVC). The FD of pushing and griping were 0.23(±0.09) and 0.48(±0.17), respectively. The t-test results indicated that the FD of pushing and griping was significantly difference (p<0.001). The ANOVA results shown that only the size of the demolition equipment was significant (p<0.05) to the FD of pushing strength, and the FD of the larger (0.36±0.16) was significantly lower compared with the smaller (0.45±0.16). The size of the demolition equipment was also significant (p<0.01) to MVC_{push}, and the MVC_{push} of the larger (103.15±24.75N) was significantly lower than the smaller (117.10±28.61N). The ANOVA results indicated that demolishing height was significant to MET (p<0.01). The mean (±SD) MET of 115cm (85.29±37.54s) was significantly higher than that of 65cm (64.64±33.51s). However, the size of the demolition equipment was insignificant.

3.2 CR-10 Ratings after the Trial

The CR-10 scores among body segments were statistically significant (p<0.001). Duncan's multiple range test results showed that the CR-10 of right upper limb was significantly higher than other body parts (p<0.05) (see tab.1). The ANOVA results indicated that demolishing height was significant to CR-10 of right upper limb (p<0.05) and waist (p<0.05). And the size of the demolition equipment was insignificant to CR-10 of five body parts.

Table 1: Duncan's multiple range tests for subjective ratings.

Body parts	right upper limb	left upper limb	waist	right lower limb	left lower limb
Mean ±SD	5.88±1.13	3.21±1.33	3.73±1.15	4.25±1.47	2.54±1.48
Duncan's grouping	A	D	C	B	E

Different letters in the Duncan's grouping indicate that they are significantly different at = 0.05.

3.3 Posture Observation

The OWAS are widely used in a variety of tasks and have well adaptive degree with demolishing task. The action rankings of demolishing postures were AC3 (obvious harm) and AC4 (serious harm) (see tab.2). The action ranking of 115cm posture was below 65cm, and the urgency of improvement was

Table 2: The OWAS's results for demolishing postures.

Equipment	Height	Low back	Arm	Leg	Loading	Code of Working Postures	Action ranking of Working Postures
The larger	65cm	4	1	4	1-2	4141、4142	AC4
	115cm	3	1	4	1	3141	AC3
The smaller	65cm	4	1	4	1-2	4141、4142	AC4
	115cm	3	1	4	1-2	3141、3142	AC3

"as soon as possible to improve" and "immediately improve".

4 DISCUSSIONS

Two actions including griping and pushing are needed to complete the task when using the demolition equipment, therefore, the changes of muscle strength in demolishing operation can be obtained by measuring pushing strength and griping strength (Xu 2017, ISO 2001). In the experiment, the decrease of pushing strength （p <0.001）was significantly higher than griping strength. Li et al. also showed that pushing fatigue rate (0.056) higher than griping fatigue rate (0.018) (Li 2019). Therefore, it can be seen that the accumulation of human fatigue caused by the pushing is greater than that caused by the griping in the demolition operation under the experiment conditions.

The size of the demolition equipment did not cause a significant decrease in griping strength but it related to the MET experimental design. Regardless of the loading value, the operator continues to work until he can no longer hold, the muscle strength will be approximately equal at the end of the trial, and this result is also illustrated by the fact that the size of the equipment have no obvious effect on RPE. The size of the demolition equipment has a distinct effect on the value of the FD of pushing, which is mainly dominated by the time factor. After adding the time factor, the value of pushing strength reduction per unit time (FD/MET) can be calculated, which is 0.37 (± 0.19) / min for larger size and 0.37 (± 0.14) / min for smaller size and that was insignificant difference. The ANOVA result shows that the size of the demolition equipment has no significant effect on MET. Therefore, in the demolition task under the experiment conditions, the equipment sizes did not lead to a difference in the development of human fatigue, which may be due to the smaller weight difference (3.3kg) between the two sizes of equipment. However, the size of equipment has a remarkable effect on the value of MVC_{push}, which indicates that the size of the equipment has an impact on the generative capacity of pushing strength. The larger the equipment size is, the heavier the load is, and the worse the generative capacity of pushing strength is.

Although the demolishing height has no significant effect on the decrease of muscle strength, it has a significant effect on the value of MET. At 65cm height, the value of MET is lower than that of 115cm, and the risk of fatigue accumulation is greater compared with 115cm. The OWAS results also validated this view from a perspective of posture risk. The posture code of 65cm is 4141 and 4142, and the risk level is AC4 (serious harm). The posture code of 115cm height is 3141, and the risk level is AC3 (obvious harm). The risk level of 65cm is higher than that of 115cm, which is due to the different bending degree of waist and right limb caused by different heights. The results showed that the bending degree of right lower limb and waist at 65 cm was greater than that at 115 cm, which was consistent with the striking effect of height on RPE of right lower limb and waist. The RPE of right lower limb and waist at 65cm height were 4.68 (± 1.19) and 4.12 (± 1.08) respectively, which were extremely higher than those at 115cm height of 3.82 (± 1.61) and 3.34 (± 1.20).

The right upper limb has the highest subjective rating of perceived exertion (5.88±1.13) in the demolition operation, which is mainly due to the fact that the right upper limb not only needs to grasp the equipment but also needs to continuously apply pushing strength on it. Therefore, the muscle fatigue of the right upper limb is more serious than that of the other limbs, so the degree of fatigue of the right upper limb is an important basis for the subjects to decide whether to stop the experiment. During the demolition operation, the left upper limb is mainly responsible for grasping the auxiliary handle to ensure that the position of the demolition equipment remains unchanged, and the muscle force required to be applied is smaller, and the fatigue feeling is weaker. The fatigue of the right lower limb is second only to that of the right upper limb, according to the feedback from the subjects after the experiment, the right lower limb should not only keep the trunk posture unchanged, but also keep the forward trend by pedaling against the ground in order to continuously exert the thrust, then, the fatigue perception of this part is also sensitive. The left lower limb only needs to maintain the posture of trunk during the task, so the fatigue feeling of it is the weakest. The results show that the waist is slightly twisted to the left and tilted forward during the application of force, and the RPE of it is at a medium level. The degree of lumbar fatigue is mainly influenced by demolishing height ($p<0.05$).

It is worth pointing out that only two demolishing heights are considered in the horizontal demolition operation, and the posture of operator is squatting posture, which is quite different from standing posture, sitting posture and crawling posture. Therefore, the amounts of heights and postures need to be further increased in the follow-up research, so as to explore the development of muscle fatigue in the horizontal demolition operation more comprehensively. The demolition operation belongs to the operation of hand-held electric equipment. In the simulation test process, the demolition equipment is not working, so its force application mode is different from the real operation. Especially when the vibration factor is added to the running equipment, the characteristics of the development of human fatigue need be further studied.

5 CONCLUSIONS

Based on the results and discussions presented above, the conclusions are obtained as below:

In this study, three methods of operation task measurement, OWAS method and subjective fatigue method were used to measure the fatigue indexes and risks of the operators after completing the simulated demolition task under different sizes of equipment and heights. The griping strength, pushing strength, RPE and posture risk were obtained to evaluate the WMSDs risk in the process of demolition task.

In order to better optimize the task and load design of demolition operators, suggestions are put forward as follow. Considering the significant effect of thrust on fatigue accumulation, it is suggested that the design of the demolition equipment should add a corresponding booster to reduce the pushing strength load. Demolishing height has obvious effects on fatigue accumulation and posture risk, so it is necessary to set reasonable demolition height in actual operation. At the same time, protective measures should be taken to reduce the load on the right upper limb and back during the operation to avoid the accumulation of fatigue in these parts which resulting in WMSDs.

The follow-up study can add more sizes of equipment, drilling heights to carry out the research. It is also possible to explore the development of human fatigue and postural risks in longitudinal and confined space operating environment. In order to better evaluate the development of human fatigue during demolishing operation, follow-up research can try to build a fatigue prediction model combined with risk factors.

ACKNOWLEDGEMENTS

This work was financially supported by the National Natural Science Foundation of China (NSFC) (71801089), Natural Science Foundation of Hunan Province, China (2020JJ4263), Guidance Project Foundation of Hengyang City of Science and Technology Bureau, China (2020jh052793), Research-based Learning and Innovative Experimental Program of Hunan Institute of Technology.

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