A study of a simulated pulling task

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Abstract. Muscular fatigue, occurred in all types of manual materials handling (MMH) tasks, contributes to musculoskeletal injures in workplace. Truck pulling, one of the typical MMH tasks, with high risk of muscular fatigue, is commonly used in logistic sectors and other industries. The purpose of this study was to assess the development of muscular fatigue in simulated truck pulling tasks via examining the decrease of the pulling strength. Ten male college students were recruited for the experiment. The subjects pulled a truck handle simulating that of a pallet truck for a time period of 1, 2, 3, 4, and 5 minutes. Their pulling strengths and subjective ratings of muscular fatigue were measured before and after each trial. The results showed that time period affected pulling strength significantly ($p<0.001$). Time period was also highly correlated with the subjective ratings of arm fatigue ($r=0.91$, $p<0.0001$) and waist fatigue ($r=0.66$, $p<0.0001$). Pulling strength was negatively correlated with arm fatigue rating (r=-0.38, p<0.061), but was insignificant to that of waist fatigue rating (p=0.18). Predictive models of muscular fatigue and maximum endurance time were established, their mean absolute deviations were in a range of 0.53-10.49 N. Predictive models proposed may be used to indicate the progress of muscular fatigue in truck pulling tasks.

Keywords: manual material handling, pulling truck, muscular fatigue, maximum endurance time, CR-10

1. INTRODUCTION

Muscular fatigue, occurred frequently in manual materials handling (MMH) tasks due to overwork, overexertion or improper body posture, contributes to musculoskeletal injures in workplace and private life(Li et al., 2015). Pulling truck, one of the typical MMH tasks, with high risk of muscular fatigue, was common in logistic sector and other industries transporting materials under 2000kg. Assessing the muscular strength decrease was vital in job design and environment safety and health (ESH) control in industry (Sesboüé and Guincestre,2006).

Muscular fatigue generated by exertion force could be assessed by the electromyographic (EMG) of the muscular, the decrease of the strength and the maximum endurance time(MET) (Zhang et al., 2014). By testing EMG including HR, VO2 and VE and RER of the subjects, the development of the muscular fatigue could be indicated (Egaña et al., 201 0; Karthick and Ramakrishnan, 2016). Also, the progress of the muscular fatigue could be achieved easily via examining the strength after performing physical work with a time period(Li and Chiu, 2015). Concerning MET, dozens of prediction models had been presented and applied in job design, analysis and control (Ahrache et al., 2006; Ahrache and Imbeau, 2009). LI (2015) and ZHANG (2014) used the predicted model proposed by Ma (Ma et al.,2009) to successfully assess the development of muscular fatigue for pushing task and carrying task, respectively. The current capacity of muscle was defined as (Mag et al., 2009):

$$F(t)=MVCe^{-k\frac{F_{load}}{MVC}t} \quad (1)$$

Where F(t) is the muscular strength at time t, MVC is the maximum voluntary contraction of the muscle (F(0)), F_{load} is the muscle force required to balance the external load, k is fatigue rate.

By logarithmic transformation, Eq.(1) can be transformed into:

$$LN\left(\frac{F(t)}{MVC}\right)=-k\frac{F_{load}}{MVC}t \quad (2)$$

Eq.(2) may be represented as eq.(3) if b is equal to ln(F(t)/MVC). For each subject, k can be determined after performing force-exerting task since all parameters except k can be measured using:

$$k=-b\frac{MVC}{F_{load}} \quad (3)$$

According to Ma (Ma et al.,2009), MET could be defined as:

$$MET=-\frac{\ln(f_{MVC})}{kf_{MVC}}=-\frac{\ln(F_{load}/MVC)}{k(F_{load}/MVC)} \quad (4)$$

The purpose of this study was to assess muscular fatigue development in simulated truck pulling tasks for male subjects with right handedness using the predicted models proposed by Ma (Ma et al.,2009), and to support for providing reasonable work-rest design, reducing musculoskeletal injures and ensuring safety and comfort for workers performing pulling tasks.

2. METHODS

An experiment was conducted to measure the pulling strength after pulling a simulated truck handle for a time period of 1, 2, 3, 4, and 5 minutes. The experiment was done in the laboratory, southern China, winter, with the temperature and humidity of 9.03 ℃(±0.40) and 82.69(±4.49), respectively.

2.1 Human Subjects

Ten male college students, all free of musculoskeletal problems in the arm-hand region of the body and with right dominated hands, participated voluntarily in this study, without any rewards. They were demanded to keep themselves from sports or physical activities leading to muscular fatigue of body segments the day before each trail. Their age, body mass, stature, body mass index (BMI), arm length, leg length, shoulder height and knee height were 21.60(±1.43) yrs, 61.80(±6.91) kg, 164.04(±1.85) cm, 22.96(±2.44) kg/m^2, 62.03(±2.17) cm, 93.77(±1.70) cm, 136.20(±2.91) cm and 46.08(±1.75) cm, respectively.

2.2 Instrument

2.2.1 Simulated Stick of a Pallet Truck

To resemble pallet truck pulling task, a simulated stick pictured in Figure 1, rectangle steel welded with a 3.0 cm diameter cylindrical stainless steel to be a shape “T”, was designed according to pulling tests on a real pallet truck. The stick was mounted to the ceiling with two steel wires at one and two thirds of the end. The length of the wires were adjusted to form an θ(42 º) angle stick with the horizon, an β(18º) angle of wire 1, an γ(21 º) angle of wire 2, and the lower end of the stick was approximately 37cm above the ground as were observed in truck pulling tests. A load of 30kg was hanged on the middle of the stick (see Figure 2). Thus the strength the subjects should resist against the external load is 11.38kgf (111.5N).

2.2.2 Apparatus for Testing Pull Strength

A testing apparatus(see Figure 3), including a chain, an S-shape loadcell (Lutron® Inc., FG-5100) , and a handle with a diameter of 3 cm, was installed and fixed to the wall with a height of 37cm to measure the pull strength. This apparatus was capable of measuring a force up to 980 N. A digital display on the gauge shows the maximum force in each trail.

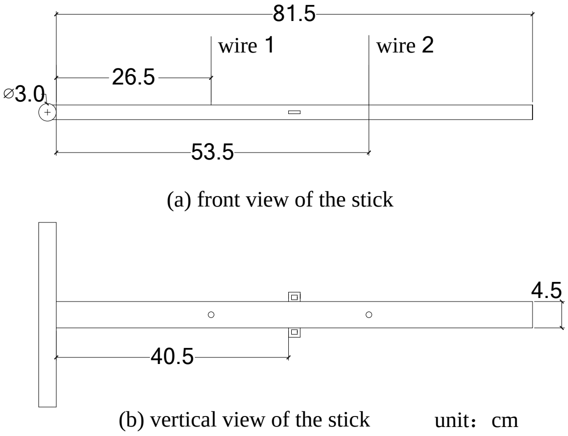

Figure 1: Simulated truck stick

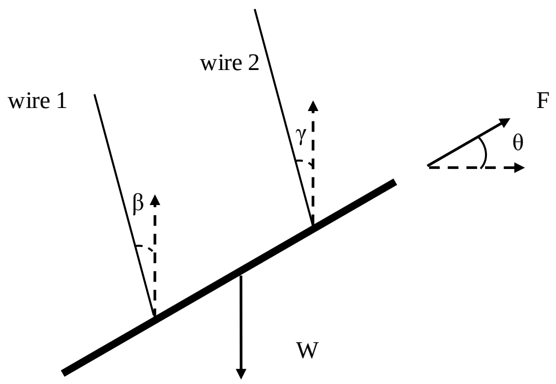

Figure 2: Simulated pulling task

Figure 3: Apparatus for testing pull strength

2.2.3 Borg CR-10

After each time period of simulated truck pulling trial, all participants were demanded to report the subjective fatigue rating of their dominated arm and waist, according to Borg CR-10.

2.3 Process of Experiment

1) Preparation for experiment. To test the maximum force as high as possible, all participants were asked to do a warm-up exercise, following an aerobic fitness video, for 5 minutes.

2) Pull strength testing. Before each trail and after each truck pulling task at a time period of 1, 2, 3, 4, 5 minutes, all participants were asked to pull the testing apparatus with their maximum force within 6s, with the same posture of truck pulling.

3) Pallet truck pulling. All participants pull the handle of the simulated pallet truck for a time period of 1, 2, 3, 4, 5 minutes, resembling the real pallet truck pulling task by keeping the left foot in the front and the two feet apart and the left knee bending slightly. Both pull strength and subjective rating of their arm and waist were measured after each trail.

2.4 Data Analysis

All subjects participated in the experiment based on their ability. A total of 60 pulling strength (F(t))(6 time periods×10 subjects) and 100 CR-10 ratings (2 segments×5 time periods×10 subjects) were recorded. Regression analysis were performed for the data of all subjects using Eq.(1). By the fatigue rate k, calculated by Eq.(3), and the MVC as well as external load F_{load}, muscular fatigue predicted could be established by Eq.(1). By MVC and external load Fload, MET could, then, be put forward. An analysis of variance (ANOVA) was performed to test the effects of time period on pull strengths and subjective ratings. Person's correlation coefficients between pull strength and subjective ratings were calculated. Statistical analysis was performed using the SAS® 9.0.

3. RESULTS

3.1 ANOVA Results

An ANOVA was carried out for pulling strength over time space, the average mean strengths at time 1, 2, 3, 4, 5 min were 90%, 88%, 83%, 80% and 75% of the MVC, respectively(see Table 1). The results indicated that time period affected pulling strengths and subjective ratings significantly (p<0.001). The Duncan's multiple range tests comparing the pulling strength under different time period was conducted. As shown in Table 2, F(0) was significantly higher than F(3), F(4) and F(5), both F(1) and F(2) were significantly higher than F(5). The differences among F(1), F(2), F(3) and F(4) were not statistically significant.

Time period was also highly correlated with the subjective ratings of arm fatigue (r=0.91, p<0.0001) and waist fatigue (r=0.66, p<0.0001). Table 2 showed the results of the Duncan's multiple range tests comparing the CR-10 scores of the arm and waist under different time period, different letters in the Duncan's grouping indicated that they were significantly different at α=0.05(p<0.0001).

Pulling strength was negatively correlated with arm fatigue rating (r=-0.38, p<0.061), but was insignificant to that of waist fatigue rating (p=0.18). BMI was insignificant to pulling strength (p=0.061), subjective fatigue ratings (p=0.50 for arm fatigue and p=0.36 for waist fatigue), and MET (p=0.451).

Table 1 Pulling strength (N) after pulling for a time period t(min)

Time	Pulling strength F(t)	SD	%MVC (%)
0	267.82[a]	39.53	100
1	242.24[a,b]	39.32	90.00
2	235.40[a,b]	30.86	88.00
3	222.80[b,c]	35.94	83.00
4	215.36[b,c]	35.11	80.00
5	199.87[c]	25.85	75.00

[a,b,c] are Duncan's grouping for F(t), same letters indicate that they are not statistically different, α=0.05：*p*<0.001

Table 2 CR-10 scores and Duncan's multiple range test results

Time (min)	CR-10score	DUNCAN grouping	CR-10score	DUNCAN grouping
	arm	arm*	waist	waist*
1	1.50（0.71）	A	1.40（0.84）	A
2	2.10（0.99）	A	2.00（1.15）	AB
3	2.90（0.57）	B	2.80（1.03）	BC
4	3.80（0.63）	C	3.20（1.14）	CD
5	4.40（0.97）	C	4.00（1.15）	CD

Numbers in the parentheses are standard deviation; different letters in the Duncan's grouping indicate that they are significantly different at α=0.05(*p*<0.0001).

3.2 Predictive Models

3.2.1 Muscular Fatigue Predicting

Simple linear regression without intercept for pulling strengths under time period for each subject was conducted to calculate the fatigue rate k. K for all subjects were 0.14(±0.05) (range: 0.076-0.245). The averaged k(0.14), external load(111.5N) and MVC(267.82N) were, then, adopted to predict the pulling strength of the subjects after performing a simulated pulling task for a time period using Eq.(1):

$$F(t)=267.82e^{-0.14\frac{111.5}{267.82}t}=267.82e^{-0.058t} \quad (5)$$

To evaluate the difference between the measured value and predicted value, a mean absolute deviation (MAD) and a percentage of estimation error (MADP) were defined as:

$$MAD=\frac{1}{n}\sum_{i=1}^{n}\left|measured\ value-predicted\ value\right| \quad (6)$$

$$MADP=\left(\frac{1}{n}\sum_{i=1}^{n}\frac{\left|measured\ value-predicted\ value\right|}{measured\ value}\right)\times 100\% \quad (7)$$

Table 3 MAD (N) and MADP (%) for subjects

Time(min)	1	2	3	4	5
MAD	10.49	3.09	2.25	2.99	0.53
MADP(%)	4.33	1.31	1.01	1.39	0.26

Table 3 showed MAD(N) and MADP(%) for all subjects. At time period of 2, 3, 4, 5 minutes, the differences between MADs and MADPs were under 4N and 1.31%, respectively, which suggested the predicted values matches well with the measured values. When t=1min, MADP was

4.33%, little higher than other time period, belonged to be the allowable error.

3.2.2 MET Predicting

The existing MET predicting models for static physical work could be classified into two kinds: one was general model, the other upper limb models including shoulder, elbow, hand and back/hip. Pulling tasks involved efforts from all body segments, especially from arm and body. By Eq.(4), the k value, external load(111.5N) and MVC for each subject were, then, adopted to predict MET for pulling pallet truck. The MET for the subjects is 15.64(±4.03)min.

4. DISCUSSION

A simulated pulling task was carried out by 10 male college subjects in this study. The development of muscular fatigue was explored via measuring the current pulling strength and subjective ratings.

Subjects were required to free from exercise one day before each trail, and other right hand related force-exerting activities on the very day of having trail. Before the test, all the participants were demanded to find a location best for exerting force, allowing for using their body against the stick and the chain. The footprints for every participant were marked on the floor where testing the pulling strength and pulling the simulated pallet truck to make them exert force at the same posture for each time period. To minimize variation due to statues of their body parts, participants, instructed to stand on the exact position according to the mark during the pulling task and test, were asked to keep their body in strain and then tilt their body/trunk, all body parts expect left leg curved remain still, to pull the handle, keeping the iron chain, handle and arm, as well as leg, hip and waist, in a line, respectively. The angle of inclination for subjects' left leg with the horizon were recorded at the beginning and at the end of each trail, 72.95(±2.50), 74.10(±3.84), respectively.

Subjective fatigue ratings for arm and waist were both measured as subjects reported that ache accumulated in left side of the waist over time period when conducting preliminary experiment. Results showed that arm subjective fatigue ratings were significantly related with waist subjective ratings ($r=0.59$, $p<0.0001$), while pulling strength was negatively correlated with arm fatigue rating ($r=-0.38$, $p<0.061$), but was insignificant to that of waist fatigue rating ($p=0.18$). Simulated pulling task in our study mainly involved extension of dominated arm and the flexion of the left waist, leading to muscular extension or flexion. The powerful the pulling strength was, the more ache the arm would be, leading more ache of the left waist. Time period affected pulling strength ($p<0.001$) and subjective ratings significantly ($p<0.0001$), consistent with our hypothesis. MET for subjects, 15.64(±4.03)min, calculated using MA's model obtained by Eq.(3), further experiment was needed to validate since there were kinds of MET models.

The experiment was done with another hypothesis that BMI was a significant factor affecting the development of muscular fatigue since higher BMI implies higher percentage of body fat and/or muscular mass. But results showed that it was insignificant to pulling strength($p=0.061$), subjective ratings($p=0.50$ for arm fatigue, $p=0.36$ for waist fatigue) and MET($p=0.451$), consistent with ZHANG and LI (2014) who found that BMI was insignificant to carrying strength. The insignificance of the BMI might be contribute to fact that the pulling task in the current study mainly involved hand grip, elbow and shoulder extension of the right arm while the BMI was an index for the whole body. The fatigue development of muscular in our pulling task might be, then, influenced by their force exertion history and experience, which was not considered in our experiment.

The height of the stick and the chain weren't adjusted to suit each participant' stature since the stick, with 30kg heavy weight hanging on, was fixed with steel cable mounted to the cell, inconvenient to readjust. The load, 30kg, equivalent to 761 kg (111.5N×sin42°/ 9.8 N/kg /0.01) of mass, assuming the rolling coefficient of friction of the truck on the floor was 0.01, was chosen as the load since electric forklift might be used to transport heavier load.

When subjects pull the simulated truck and test the current force, they were required to stand at a specific position without walking, convenient to measure. The variation of the posture and the speed of walking were not considered in current study. Future research might be designed to explore these factors. Another limitation was that the experiment was conducted in a laboratory of HuNan Institute of Technology, HuNan, China, in winter, with a low temperature 9.03℃ (±0.40) and high humidity 82.69%(±4.49%), as there was no air-condition equipment. However, such a temperature and humidity was common in the winter in central China where little central heating was available. Lower temperature posed significant influence on force exertion, the lower the temperature was, the more inflexible the body was, and the weaker the strength was. So a 5 minutes warm-up exercise was required for all subjects.

5. CONCLUSION

A single arm pulling experiment was conducted in laboratory. The prediction of pulling strength and MET was obtained based on theoretical models proposed by Ma (Ma et al., 2009). Results showed that pulling task lead to significant muscular fatigue in arm and waist, the decrease of pulling strength could be calculated by an exponential equation with a acceptable error, MAD and MADP, and that both the decrease of pulling strength and subjective fatigue ratings could be used to indicate the development of muscular fatigue. MET for pulling task required further experiment or comparing METs using different MET models to validate.

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REFERENCES

Li, K. W., Wang, C. W., & Yu, R. (2015). Modeling of predictive muscular strength for sustained one-handed carrying task. *Work*, 911-919.

B. Sesboüé, J.-Y. Guincestre. Muscular fatigue(2006). *Annales De Réadaptation Et De Médecine Physique*, 49(49):348-354.

Zhang, Z., Li, K. W., Zhang, W., Ma, L., & Chen, Z. (2014). Muscular fatigue and maximum endurance time assessment for male and female industrial workers. *International Journal of Industrial Ergonomics*, 44(2), 292-297.

Egaña, M., Ryan, K., Warmington, S. A., & Green, S. (2010). Effect of body tilt angle on fatigue and emg activities in lower limbs during cycling. *European Journal of Applied Physiology, 108*(4), 649-656.

Karthick, P. A., & Ramakrishnan, S. (2016). Muscle fatigue analysis using surface emg signals and time–frequency based medium-to-low band power ratio. *Electronics Letters*, 52(3), 185-186.

Li, K. W., & Chiu, W. S. (2015). Isometric arm strength and subjective rating of upper limb fatigue in two-handed carrying tasks. *Plos One, 10*(3),1-14.

Ahrache, K. E., Imbeau, D., & Farbos, B. (2006). Percentile values for determining maximum endurance times for static muscular work. *International Journal of Industrial Ergonomics, 36*(2), 99-108.

Ahrache, K. E., & Imbeau, D. (2009). Comparison of rest allowance models for static muscular work. *International Journal of Industrial Ergonomics, 39*(1), 73-80.

Liang, M., Chablat, D., Bennis, F., & Zhang, W. (2009). A new simple dynamic muscle fatigue model and its validation.*International Journal of Industrial Ergonomics*, 39(1), 211-220.