Physiological and perceptual responses in male Chinese workers performing combined manual materials handling tasks

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Abstract

A study on combined manual materials handling (MMH) tasks, under two different frequencies and four lifting and lowering height combinations, was conducted in Beijing, China. Eight male construction workers performed a box handling task repetitively for an hour either at once or twice per minute. On each day, the task consisted of: lifting a box of ceramic tile weighting 23 kg from a specified height, carrying it for 8.5 m, lowering the box to a specified height, and then walking 8.5 m back. The specific heights included: lifting the box from floor and lowering it onto the floor (F–F); lifting from the floor and lowering to the knuckle height (F–K); lifting from knuckle height and lowering onto the floor (K–F); and lifting from knuckle height and lowering to the knuckle height (K–K). Oxygen uptake, heart rate, and ratings of perceived exertion (RPE) for whole body were measured during the task. Additionally, actual energy expenditure of the box handling for an hour was calculated from the oxygen uptake measured, whereas the predicted energy expenditure was estimated using the valid regression equations available in the literature. Statistical analysis demonstrated that both task frequency and lifting and lowering heights influence oxygen uptake, heart rate, and the RPE. The RPE during the task frequency of twice per minute was higher than that of once per minute. The RPE for the F–F and F–K conditions were both higher than that of the K–K condition. The difference between the actual and predicted energy expenditures was not statistically significant. This implies that the predictive equations used in this study are acceptable in estimating the physiological cost of Chinese construction workers performing similar MMH tasks as in this study.

Relevance to Industry: Combined MMH tasks are very common on construction sites. This study investigated the physiological and subjective responses in Chinese construction workers performing combined MMH tasks. A predictive model in the literature was also examined to determine whether it could be used to describe the energy expenditure of these workers.

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1. Introduction

The labor force of the People’s Republic of China is estimated at over 600 million workers, making it the largest single-nation labor force in the world (Takala, 1999). Driven by the fast growing economy, workers’ safety and health issues in China are becoming more of a challenge than ever before. Xia et al. (2000) reported construction work as one of the leading sectors in occupational fatality among all industries in Shanghai, China. In addition to fatalities, musculoskeletal problems are also very common at construction sites. In a survey conducted in northern Taiwan (Lee et al., 2003), 97% of the interviewees had experienced musculoskeletal symptoms over the previous 12 months. Half of these interviewees had their symptoms treated by medical personnel, with low back pain as the leading body symptom reported. Aches in the upper extremities were also very common for construction workers (Li, 2002; Chen and Chen, 2004), suggesting the urgent need for investigating safety and health issues among these workers.

The MMH tasks are very common on construction sites, and are one of the major contributors for musculoskeletal symptoms for construction workers (Lee et al., 2003). Workers manually handle construction materials, including cement, brick, steel, wood, and others (Li and Lee, 1999). The MMH tasks at construction sites normally have a high degree of variability, both in duration and content (Punnett and Paquet, 1996; Mirka et al., 2000; Lee et al., 2003).
One of the most widely accepted approaches in designing MMH tasks is to design or modify a job so as not to exceed the capabilities of the materials handlers (Snook, 1978, 1985; Ayoub and Mital, 1989; Waters et al., 1993; Ciriello and Snook, 1999; Ciriello et al., 1999). Physiological measures are one of the scientific means to evaluate the physical burdens and capabilities of workers in MMH tasks under various job conditions. In the physiological approach, a job is usually divided into simple individual tasks, and the physiological cost of the job is assumed to be the sum of the energy expenditures of these individual tasks. Many researchers have developed regression equations to predict oxygen consumption using personal, task, and workplace variables based on this assumption. The most comprehensive and flexible predictive equations in the MMH tasks were developed by Garg et al. (1978) and (Dempsey, 1998). One of the major controversies of using these predictive equations was that the additivity assumption was not confirmed and errors associated with this assumption could be significant (Genaidy et al., 1985; Tabou and Dutta, 1989). Tabou and Dutta (1989), for example, indicated that the errors caused by the additivity assumption in combined lifting and carrying tasks ranged from 25.25 to 60.36%. Even with these controversies, predictive equations are practical and valuable in quantifying the energy expenditure in many industrial settings (Dempsey, 1998).

Subjective measures may be used to quantify the physical strain caused by physical activities. The ratings of perceived exertion (RPE) developed by Borg (1970) has been one of the most commonly used subjective measures in assessing the whole body and segmental strain. The RPE is constructed so that the ratings, 6–20, are linearly related to the heart rate expected for that level of exertion. As indicated by Hutchinson and Tenenbaum (2006), a single measure of RPE is insufficient to capture the whole range of perceptual sensations that people experience when exercising or being physically active. There are numerous examples of using the RPE as supplementary measures in addition to some objective measures in studying the MMH tasks (Wu, 1997, 2003; Chung and Wang, 2001; Li et al., 2007) and other physical phenomena and activities (Deeb, 1999; Spielholz, 2006).

Although a small number of MMH studies on Chinese participants have been reported (Lee et al., 1995; Wang et al., 2000; Chung and Wang, 2001; Wu, 2003; Wu and Chen, 2003; Li et al., 2007), these studies were conducted using only student participants, and very little has been addressed on the Chinese construction workers. The predictive equations of Garg et al. (1978) have been widely adopted in the USA in evaluating job designs at workplaces. However, the equations are based on a small student sample in the USA. It was hypothesized that these equations may not be applicable in estimating energy expenditures of Chinese construction workers due to the differences in anthropometric measures of the Chinese workers versus the American students such as age and body weight. Thus, the first objective of this study was to test this hypothesis in the laboratory. The second objective of the study was to evaluate the influences of frequency and lifting and lowering height combinations included: F–F, F–K, K–F, and K–K. The participant was instructed to adapt the squat posture and K–K. The participant performed light physical exercise including movements of adductions and abductions of the extremities, flexions, and rotations of the trunk and neck. After the warm-up period, the participant started to handle the box under the specific experimental condition.

For this study, a task is defined as: the participant lifting the box from a specified height to his elbow height, carry it against his waist for a distance of 8.5 m, lower the box from his elbow height to a specified height, and walking back a distance of 8.5 m empty-handed to the original starting position. On each day, the box handling task lasted for 1 h. Due to the limitation of the space in the laboratory, the participant walked on a triangular path with a perimeter of 8.5 m which was delineated using a yellow tape. The lifting and lowering height combinations included: F–F, F–K, K–F, and K–K. The participant was instructed to adapt the squat posture during both lifting and lowering from the floor.

It should be noted that the walking speeds of the participants were not controlled. However, depending on the experimental session, they were required to complete one or two tasks in each minute and were instructed to maintain a consistent working and walking pace during the experiment. The time to complete the box handling was measured using a stop watch. The average time to complete the task per day was then calculated using the average of six measurements, i.e. duration of completion of three tasks at the beginning and three at the end of the session. The walking speed for each session was estimated by dividing the total walking distance (17 m) by the average time to complete the task. Overall, the participants handled the box under eight experimental conditions (two frequencies × four lift and lowering height combinations). The temperature and relative humidity in the laboratory when performing the MMH tasks were approximately 22 °C and 48%, respectively.

2.3. Physiological and perceptual measurements

During the experiment, the oxygen uptake was measured using a MAX II metabolic cart (AEI Technologies, Inc., Naperville, IL). The cart was calibrated by comparing the machine readings with the actual volume and composition of the oxygen and carbon dioxide in two steel bottles. The calibration procedure was repeated every 12 h of cart usage. The heart rate was measured using a POLAR® vantage XL heart rate monitor (Polar Electro Oy, Kempele, Finland). The means of the participant’s oxygen uptake (in L/min) and heart rate (in beats/min) during the 1-h period were used for statistical

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analysis. At the end of each session, the participant immediately reported his RPE of the whole body strain on a scale ranging from 6 (no exertion at all) to 20 (maximal exertion) (Borg, 1985). The actual energy expenditure (in kcal/min) was calculated from the averaged oxygen uptake data of 1 h task handling. The predicted energy expenditure was calculated using the equations in Table 1.

2.4. Experiment design and data analysis

The study was a two-factor completely randomized design. A total of 64 trials (two frequencies × four lifting and lowering height combinations × eight participants) were conducted. Analysis of variance (ANOVA) was performed on the oxygen uptake, heart rate, and RPE scores. The experimental variables and conditions are summarized in Table 2. A Student–Newman–Keuls test was performed if a variable was statistically significant at \( p < 0.05 \). Pearson’s correlation coefficients between the dependent variables were calculated. Statistical analysis was performed using the SAS® 9.1 software (SAS Institute, Inc., Cary, NC). A two-tailed \( t \)-test was performed to compare the difference between the actual and predicted energy expenditures across all experimental sessions.

3. Results

The ANOVA results of the study are summarized in Table 3. The oxygen uptake responses were influenced by the frequency of task performance and lifting and lowering height combinations (both main effects significant at \( p < 0.0001 \)) and their two-way interaction \( (p < 0.05) \). Oxygen uptake during sessions performed at the frequency of twice per minute \( (105.0 \pm 0.15 \text{ L/min}) \) was higher than that of once per minute \( (70.0 \pm 0.14 \text{ L/min}) \). The sessions with F–F had a higher oxygen uptake \( (108.0 \pm 0.12 \text{ L/min}) \) than all other combinations \( (p < 0.05) \). The sessions with a height combination of F–K had a higher oxygen uptake \( (92.0 \pm 0.17 \text{ L/min}) \) than those of the combinations, K–F \( (78.0 \pm 0.12 \text{ L/min}) \) and K–K \( (73.0 \pm 0.16 \text{ L/min}) \) \( (p < 0.05) \). However, the difference in oxygen uptake between the sessions with combinations of K–F and K–K was not statistically significant. The oxygen uptakes under different experimental conditions are shown in Fig. 1.

The effects of both task frequency and lifting and lowering height combinations on heart rate were significant (both at \( p < 0.0001 \)). However, their two-way interaction was not statistically significant. The heart rate for sessions performed at the frequency of twice per minute \( (111.3 \pm 8.5 \text{ beats/min}) \) was higher than that of once per minute \( (97.0 \pm 10.1 \text{ beats/min}, p < 0.05) \). The sessions with F–F combination had a higher heart rate \( (115.0 \pm 10.5 \text{ beats/min}) \) than all other combinations \( (p < 0.05) \). Performance during combinations of F–K had a higher heart rate \( (103.5 \pm 9.4 \text{ beats/min}) \) than that of the K–K \( (95.9 \pm 9.4 \text{ beats/min}, p < 0.05) \) but similar to that of K–F \( (102.1 \pm 7.6 \text{ beats/min}, p > 0.05) \). Similar to oxygen uptake responses, the heart rate for the sessions with K–F combination was not significantly different from that of the K–K combination. Fig. 2 shows the heart rate responses under different experimental conditions.

The RPE was influenced by both task frequency \( (p < 0.0001) \) and lifting and lowering combinations \( (p < 0.05) \). The two-way interaction of frequency and height combination was not statistically significant. The RPE during the task frequency of twice per minute \( (12.1 \pm 0.9) \) was higher than that of once per minute \( (10.8 \pm 1.0) \). The RPE for sessions with both combinations of F–F \( (11.9 \pm 0.9) \) and F–K \( (11.8 \pm 0.8) \) were higher than that of the K–K combination \( (10.9 \pm 1.2, p < 0.05) \). However, the RPE of the combination K–F \( (11.2 \pm 1.1) \) was not significantly different from any other combinations. Fig. 3 shows the RPE scores under different experimental conditions.

The actual and predicted energy expenditures for the 64 trials are shown in Fig. 4. The actual energy expenditure \( (4.3 \pm 1.3 \text{ kcal/min}) \) across all experimental conditions was slightly higher than that of the predicted values \( (4.2 \pm 1.1 \text{ kcal/min}) \). However, the two-tailed \( t \)-test results showed no statistical significance between the actual and predicted values. A mean absolute deviation (MAD) was calculated to measure the averaged absolute differences of the measured and predicted oxygen consumption based on the 64 trials. The MAD values under the eight experimental conditions are shown in Table 4. Pearson’s correlation coefficients for the dependent variables are shown in Table 5.

4. Discussion

The main findings of this study are that construction workers expended greater physiological and perceptual responses during

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box handling at twice per minute than at once per minute. Greater responses were also observed during sessions with lifting and lowering from the floor level than those at the knuckle height.

Furthermore, a strong correlation was demonstrated between actual and predicted energy expenditures, suggesting the applicability of using the predictive equations of Garg et al. (1978) on these Chinese construction workers. Body weight is one of the most important factors affecting the energy expenditure in the equations of Garg et al. (1978). The subjects in this study were approximately 6 kg thinner than that of their counterpart in Garg et al. (1978). This difference might not be huge enough to generate a significant result. In addition to the body weight, age and tenure at job might also affect the energy expenditure performing the combine MMH tasks. The subjects in this study were approximately 5 years older and had 37.5 month on-the-job experiences than the subjects in Garg et al. (1978). The reason why these factors did not affect energy expenditure was not clear. In addition, the additivity assumption errors in this study seemed to be negligible. Such a result was not consistent with those reported in the literature (Genaidy et al., 1985; Taboun and Dutta, 1989). The reason for such a discrepancy might be attributed to the lack of control of walking speed in this study and different experimental settings among the different studies.

In this study, the maximal aerobic capacity of workers was not evaluated. However, the intensity of the workload can be evaluated through the heart rate reserve percentage. Our participants' age-predicted maximal heart rate was 195 beats/min (220-age of 25 years). Average resting heart rate obtained was 82 beats/min, whereas the average maximal working heart rate for the task obtained during the performance of highest task frequency was 115 beats/min (see Fig. 2). Calculating the heart rate reserve percentage, therefore clearly demonstrated that the cardiac cost for the participant workload did not exceed 29%.

It is important to note that the sessions with lifting and lowering at the floor level involved a squat posture but not during sessions at the knuckle height. This finding implies that sessions involving the squat posture demand more oxygen uptake (Fig. 1) and heart rate responses (Fig. 2) for F–F compared to sessions where participants adapted non-squat postures to accomplish the required task. To this effect, the influence of work-related variables such as posture and frequency on physiological responses during lifting and lowering from various heights was well documented (Waters et al., 1993; Chen, 2000).

In terms of Chinese population, a few studies have demonstrated the influence of work-related variables on psycho-physiological responses (Wu, 1997; Wang et al., 2000; Chung and Wang, 2001; Wu and Chen, 2003; Li et al., 2007). For example, during lifting from F–K and at the frequency of once per min, Wang et al. (2000) demonstrated their heart rate responses were greater to that of this study. However, participants in Wang et al. (2000) were college students, therefore may not have been adapted to MMH activities. On the contrary, the participants in this study were experienced construction workers who were familiar with the workloads, thus the physiological training effect. Interestingly, Wu (1997) reported that for Chinese ‘inexperienced’ male manual handlers, the heart rate responses obtained for their psychophysically accepted loads were 91% of the corresponding values for experienced workers. These conflict findings might also be due to the fact that the heart rate (and other physiological measurements) in this study were representative of the whole task performed for an hour versus measurements carried after 10–15 min of the lifting task (Wu, 1997; Wang et al., 2000) only. In addition to the effect of task variables, the discrepancy among the heart rates can also be attributed to the specific workload, i.e. evaluating a psychophysically chosen load (Wu, 1997; Wang et al., 2000; Li et al., 2007) versus the fixed load of 23 kg in this study.

In this study, both frequency and lifting and lowering heights affected the RPE significantly ($p < 0.05$). A strong correlation between RPE scores and physiological responses was observed (Table 5), suggesting the strength of relationship between perceived exertion of the whole body and the physiological responses. This was consistent with the findings in literature (Hagen et al., 1993; Chung and Wang, 2001). The RPE results, ranging from 9 (or ‘very light’) to 15 (or ‘hard’), indicated that
different subjects could work at different RPE levels. This was also consistent with the findings in the literature (Garg and Saxena, 1982). The mode of RPE was 12, which corresponded to somewhere between “light” and “somewhat hard.” Among the 64 trials, 63 of them had a RPE value less than or equal to 13 (“somewhat hard”).

Since the participants have to repetitively exert considerable effort to lift or lower the box from the floor during the box handling, it is evident from the RPE scores (Fig. 3) that the sessions with the combination of F–F was the most stressful combination whereas K–K was the least among all the combinations tested. This finding is in agreement with previous investigations (Wang et al., 2000; Chung and Wang, 2001; Wu and Chen, 2003; Li et al., 2007). Furthermore, the participants reported a lower RPE scores at once per minute with the F–F combination than that at twice per minute with a K–K combination, implying that the task frequency was a more dominant factor affecting the RPE score than the lifting and lowering combinations.

Using both direct and indirect measures, Capodaglio et al. (1997) compared the energy expenditure of six Italian workers conducting MMH tasks in the field. These authors used a portable telemetric metabolic device for direct measurement of energy expenditures, where indirect measures were estimated using the regression equations developed by Garg et al. (1978). From their findings, Capodaglio et al. (1997) reported that the two measures were strongly correlated ($r = 0.96$), and is consistent with the high correlations observed in this study ($r = 0.85$). The results of our study indicate that the equations in Table 1 are acceptable in predicting the energy expenditure of the participants with the mean absolute deviation values shown in Table 4. In other words, the model developed by Garg et al. (1978) may be adopted to estimate the energy expenditure for Chinese construction workers conducting various manual materials handling tasks that were similar to those in this study.

There were limitations to this study as well. Firstly, the walking speeds of participants were estimated using the mean value of six tasks. However, variations in the walking speed might exist among the tasks performed within each session that might affect the estimated energy expenditure. Secondly, the participants were required to lift and lower the box from the floor using a squat posture, however, it was difficult for the participants to maintain the posture consistently throughout the session. Therefore, some of the postures adapted may have been somewhat between squat and free style. To this effect, Chen (2000) demonstrated that Chinese men use stoop technique in frequent lifting tasks, thereby minimizing the metabolic cost. Finally, results of the study were based on a small sample size, however, the strong correlation between actual and predicted values suggest that energy expenditures of tasks can be predicted non-invasively using the valid regression equations.

<table>
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<tr>
<th>Table 4</th>
<th>Mean absolute deviation (in kcal/min) under different frequency and lifting and lowering conditions</th>
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<tr>
<td></td>
<td>F-F</td>
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<tr>
<td>Once per minute</td>
<td>0.31</td>
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<tr>
<td>Twice per minute</td>
<td>0.71</td>
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5. Conclusion

Both task variables, frequency and height combinations significantly affected the workers’ physiological and subjective responses on whole body strain, with the frequency of task handling was a more dominant factor compared to the different combination of the lifting and lowering heights. The predictive equations developed by Garg et al. (1978) still provide a good estimate of the energy expenditures for the Chinese construction workers under the specified experimental conditions tested in this study. Future studies with conditions and tasks not listed in Tables 1 and 2 should also be explored to understand the physiological stress imposed on the Chinese working populations.

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