Physiological Demands of Concrete Slab Placing and Finishing Work

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Abstract: Construction craft work is physically demanding. As a result, many craft workers become excessively fatigued, which may lead to decreased productivity and motivation, inattentiveness, poor judgment, poor quality work, job dissatisfaction, accidents, and injuries. This paper investigates the feasibility of measuring in situ physical demands of concrete slab placing and finishing work and how this physical demand may be used to characterize both work intensity and whether the demands are physically fatiguing to the workers. Physiological measures of energy expenditure, including oxygen consumption and heart rate data, were collected for an eight-member concrete slab placing and finishing crew performing actual construction work. The results reveal that most of the crew members who were performing manual work experienced heavy physical demands and more potential for physical fatigue compared with those operating construction machinery and equipment. These workers routinely exceed one or more published guidelines for acceptable levels of energy expenditure, oxygen consumption, and heart rate. The methods described in this paper have wide application in identifying excessively demanding construction tasks so the work can be modified and productivity improved.

INTRODUCTION

Despite advances in technology, construction craft work remains a physically strenuous occupation. In the *Jobs Rated Almanac* ranking of 250 jobs for physical demands, construction trades account for 18 of the worst 50 jobs in the United States (Krantz 1992). Except for earthmoving equipment and cranes, the highly capital-intensive automation and robotic equipment that has become widespread in many manufacturing industries has not gained acceptance in construction. The culture of the construction industry has evolved such that contractors rely heavily on hand labor with small, relatively inexpensive, multipurpose tools.

Physically demanding work leads to physical fatigue. Physical fatigue is hard to define, because it is multifaceted. Brouha (1967) stated that ''some call it [fatigue] a negative appetite for activity—and usually for the activity that caused the fatigue.'' Bonjer (1971) suggested that ''the longer a body has to work, the lower its power to convert chemical energy into mechanical energy.'' Fatigue may have its roots in physical and mental causes. These causes include noise, vibration, boredom, stress, and the buildup of metabolic by-products in the muscle and blood stream. In general, physical fatigue leads to decreased productivity and motivation, inattentiveness, poor judgment, poor quality work, job dissatisfaction, accidents, and injuries (Brouha 1967; Janaro 1982).

Many investigators, dating back to Frederick W. Taylor (the father of Scientific Management) in the early 1900s, have argued that, because fatigue affects performance, performance can be improved either by eliminating the causes of fatigue or by at least finding ways in which to combat the effects of fatigue. Doing this for construction work tasks may involve changing the work methods, including investment in more automated tools and equipment; providing appropriate work-rest cycles; or even adjusting expectations of what workers can reasonably be expected to accomplish. These and many other examples of administrative and engineering interventions to reduce physical demands and fatigue would provide endless opportunities to improve construction work today.

Clearly, physically demanding and physically fatiguing tasks have to be identified first before any performance improvement efforts may start. Therefore, the objective of this paper is to investigate the feasibility of measuring in situ physical demands of construction work and how this physical demand may be used to characterize work intensity and whether the demands are physically fatiguing to the workers. For the purposes of this paper, physical fatigue is assumed to result when the energy demands placed on the worker (estimated by measuring oxygen consumption) exceed his or her ability to produce energy, according to widely published and accepted physiological standards.

This paper does not seek to generalize its findings to all construction tasks or to the general construction craftworker population. A field study was conducted on an eight-member concrete placing and finishing crew, which was selected at random. The eight-member crew was engaged in real-life work situations. For each worker, oxygen consumption and heart rate values were measured and used to characterize the physical demands of work based on work physiology standards.

BACKGROUND: WORK PHYSIOLOGY

Measurement of the physical demands of work and assessment of physical fatigue and the limitations it may have on worker productivity have attracted and occupied work and exercise physiologists and industrial engineers for many years. The decrease in performance due to fatigue is widely accepted, but no agreement has been reached in trying to quantify this decrease or in setting acceptable limits for it. Different researchers have approached the measurement of physical demands and assessment of physical fatigue in a multitude of ways. The most common methods of measuring physical demand are those of measuring the oxygen consumption or oxygen uptake, VO_2 (usually measured in liters of oxygen per minute), during work or exercise, and/or recording the heart rate, HR (measured in beats per minute) associated with the performance of an activity. VO_2 estimates from HR or from direct measurements have also been used to indirectly estimate the energy cost of performing various human activities, which in turn is used to assess the potential for physical fatigue.

Oxygen's Role in Metabolism

The energy required by the human musculoskeletal system to perform physical work comes from a complex series of

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chemical reactions within muscle cells. Oxygen plays a vital role in these reactions. Metabolic reactions that use oxygen are called aerobic reactions. Aerobic metabolism is desirable from a physiological point of view because of the relatively high amount of energy produced and because the by-products produced (primarily carbon dioxide and water) are relatively harmless. However, the amount of oxygen that is available to and can be used by the muscles is limited, and this limit varies greatly among individuals. The maximum oxygen utilization an individual can achieve is termed VO_{2max}. Many techniques exist for the determination of VO_{2max}, ranging from actual measurement (which involves exercising at submaximal or maximum levels) to prediction techniques.

Metabolic reactions that do not use oxygen are termed anaerobic reactions. When a shortage or underutilization of oxygen supplies to muscle groups occurs, the muscle fibers progressively lose their ability to produce tension and, at the same time, anaerobic reactions may be triggered. If anaerobic chemical reactions dominate, by-products of these reactions can quickly cause a state of fatigue, and the ability to perform physical activity decreases quickly. Fatigue in this case is mediated due to the formation of lactic acid and its build-up in the muscle and blood stream, which also inactivates many enzymes that are needed for the energy metabolism process; hence, recovery time through rest to get rid of lactic acid accumulation becomes necessary (McArdle et al. 1996). In essence, oxygen supply to and utilization by various muscle groups is a determining factor in whether and how quickly a person will become fatigued.

Assessment of Physical Demands Using Oxygen Consumption

By measuring the amount of oxygen consumed before, during, and after performance of work or exercise activities, the total energy expended by a human can be estimated, because the anaerobic energy yield is quite small under such conditions (McArdle et al. 1996). This technique is referred to as indirect calorimetry.

For every liter of oxygen consumed, on average 4.83 kilocalories (kcal) of energy are produced. The exact amount varies slightly depending on a physiological attribute termed the ''respiratory quotient.'' Thus, measured VO_2 may be converted to energy expenditure.

The most practical method for measuring VO_2 is known as open-circuit spirometry. In the open-circuit spirometer, the subject inhales ambient air with known concentrations of oxygen, carbon dioxide, and nitrogen. Because oxygen is used and carbon dioxide is produced during energy-yielding reactions, the exhaled air contains less oxygen and more carbon dioxide than the inhaled air. The difference in composition between the inspired and expired air volumes reflects the body's release of energy through aerobic metabolic reactions (McArdle et al. 1996). Many open-circuit spirometry techniques exist, including portable spirometers, bag techniques (the most famous of which is the Douglas bag), and, most recently, computerized instrumentation.

Assessment of Physical Demands Using Heart Rate

The second approach to assessing physical work demand is the measurement of heart rate. It has been suggested by many engineering psychologists that HR is a sensitive measure of mental as well as physical load. In addition, it has been found that HR is quite sensitive to changes in muscular force and body posture (Astrand and Rodahl 1986).

Similar to VO_2, the HR is not without limits, and each individual can achieve a maximum HR of some value. It has been widely accepted that the maximum heart rate (HR_{max} in $\text{beat}\cdot\text{min}^{-1}$) attainable by an individual can be obtained by subtracting the individual's age from 220 (McArdle et al. 1996). Measurement of HR is performed using heart rate monitors, which are widely available in different sizes and portability.

Evaluating Energy Cost of Tasks

The energy cost of a task as a measure of physical demand is only one side of the story, the so-called assessment phase in the literature. The other important side is known as the evaluation phase. The objective of the evaluation phase is to determine whether the physical demand of a certain task is excessive and whether the worker performing the task may suffer from physical fatigue. Absolute energy cost values, oxygen uptake values, and/or heart rate values are all used to perform these evaluations.

Use of Absolute Energy Expenditure as Workload Criteria

The average young adult male, 5 feet 8 inches (173 cm) tall, weighing 160 pounds (72.6 kg), in good physical condition, can develop power (energy/time) at the rate of about 5 kilocalories (kcal) per minute for several hours (Astrand and Rodahl 1986). The kilocalorie is the unit of energy known familiarly to dieters as the Calorie, and is equal to about 4 BTUs, 1.162 watt-hours, or 4,186 joules. A widely used rule of thumb is that activities requiring less than 5 $\text{kcal}\cdot\text{min}^{-1}$ can be performed continually for a work shift without overly taxing the worker. An activity requiring more than 5 $\text{kcal}\cdot\text{min}^{-1}$ can be performed for a limited time before the worker needs a rest to recoup energy from stores within the body (Oglesby et al. 1989).

The rest duration required for a worker varies greatly with the intensity and duration of the work cycle itself, as well as with individual differences. According to Brouha (1967), a worker should be allowed to rest until all physiological functions, such as heart rate, blood pressure, oxygen uptake, rate of perspiration, body temperature, and chemical composition of the blood and urine, return to pre-work levels. As stated by Brouha (1967), ''When mechanical work stops, physiological work continues above the resting rate until recovery is complete.''

Use of Oxygen uptake (VO_2) as Workload Criteria

Early attempts to establish workloads in order to avoid undue fatigue to workers while performing physically demanding tasks were based on the absolute metabolic cost (Muller 1953; Murrell 1965; Astrand and Rodahl 1986). More recent efforts are based on the relative intensity of the metabolic cost, in which actual VO_2 is expressed as a fraction of the maximal (actual or predicted) oxygen uptake capacity, VO_{2max} (Astrand and Rodahl 1986). Bonjer (1971) and many others suggested that the longer the work period, the lower the percentage of VO_{2max} that can be sustained without undue fatigue.

Although the value of VO_{2max} is a major determining factor for objective and/or subjective feelings of fatigue, it is not the only one. Other factors, including neuromuscular functions disturbance, water balance, drop in blood glucose concentrations, and depletion of glycogen depots in working muscles, may all give rise to physical fatigue.

Heart Rate as Workload Criteria

Brouha (1967) has suggested that an average HR of 110 $\text{beat}\cdot\text{min}^{-1}$ over an eight-hour shift should not be exceeded for industrial workers. Other researches have introduced different criteria by distinguishing between HR at rest and HR

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TABLE 1. Severity of Prolonged Physical Work and Cardiovascular Response

Work severity (1)	Oxygen uptake [(VO_2) liters·min^{-1}] (2)	Heart rate response (beats·min^{-1}) (3)
Light work	up to 0.5 liter/min	up to 90 beats/min
Moderate work	0.5–1.0 liter/min	90–110 beats/min
Heavy work	1.0–1.5 liter/min	110–130 beats/min
Very heavy work	1.5–2.0 liter/min	130–150 beats/min
Extremely heavy work	over 2.0 liter/min	150–170 beats/min

Note: Adapted from Astrand and Rodahl (1986).

under physical work. The individual's general fitness level, duration of work, and level of work stress may all affect HR.

Muller (1950) suggested that when the HR remains constant at a prolonged uniform level of work, this HR may be considered as the permanent work HR. Research has shown that if an individual's HR at rest is known, the value of HR for permanent work lies approximately 40 beats above that (Kuhlmann 1985). Muller (1962) also emphasized the importance of recording the time required for recovery or ''normalization'' of the HR after a work activity has been finished. According to Muller, ''the sum of heart beats during the recovery time (sum of recovery heart rate) is proportional to the degree to which the permanent performance limit has been exceeded.''

Existing Evaluation Techniques

Existing evaluation techniques include classification of work intensity based on published guidelines for oxygen uptake and heart rate (see Table 1) and evaluation of physical fatigue potential based on absolute energy expenditure values. The most reliable and advocated evaluation technique is to express the energy cost of a task relative to a worker's capacity, i.e., the workload or, alternatively, the percentage of the maximum aerobic capacity at which a worker is working, and comparing that to allowable workloads.

PREVIOUS RESEARCH

Unfortunately, little data are available to assess the overall physiological demands or energy expenditure of construction work. Accurate assessment of construction activities is particularly difficult because of the variety of individual operations involved (Astrand and Rodahl 1986). The few available studies of energy requirements for construction tasks are summarized in Tables 2 and 3. The dashed line shown in Table 2 separates the activities that require energy expenditures of 5 kcal·min^{-1} or more for males and energy expenditures of 3.5 kcal·min^{-1} or more for females, from those requiring less.

Most of the values in Tables 2 and 3 were collected in the 1950s and 1960s. In those times, the construction work force was composed primarily of young healthy males. The values for females in Table 2 were estimated assuming that values for females are 70% of those for males. No data for older workers have been reported.

The equipment available in the 1950s for measuring energy expenditure was cumbersome during vigorous activities, such that the equipment itself may have limited or interfered with normal work activity. Moreover, all determinations of VO_2 relied on complex methods of gas analysis, and some questions exist as to the accuracy of air-flow measurements during heavy work or exercise (McArdle et al. 1996). For these reasons, many early studies used only one or two subjects, were confined to laboratory settings, and typically involved hundreds of separate gas analyses for a single experiment, requiring frequent multiple calibrations to verify results.

TABLE 2. Total Energy Expenditure for Various Tasks Performed by Young Adults

Activity (1)	Energy Expenditure (kcal·min^{-1}) Males (2)	Females (3)
Sleeping	1.1	0.9
Resting on job	1.5	1.1
Sitting	1.7	1.1
Standing	1.7	1.4
Doing office work	1.8	1.6
Driving car	2.8	2.1
Walking, level, casual	3	2.2
Walking briskly, carrying 22 pounds	4	3.4
Driving a truck, local	3.6	2.5
Bricklaying	2.5–4	1.8–2.8
Doing carpentry	4	2.9
Sawing with power saw	4.8	3.4
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Pushing wheelbarrow, loaded	5.5	3.9
Doing average construction work	6	4.2
Chopping wood	6.2–7.5	4.4–5.3
Shoveling sand	6.8–7.5	4.8–5.4
Doing heavy manual work (stonemason)	7.5	6.3
Sledge hammering	6.8–9	4.8–6.3
Digging, heavy activity	8.4–8.9	5.9–6.2
Continuous sawing and hammering	8.1	6.8
Extremely heavy exertions	15–20	12–14

Note: Values Based on Young Adult Males and Females in Good Physical Condition. Source: Oglesby et al. (1989).

TABLE 3. Energy Expenditure of Men Working in Building Industry

Activity (1)	Range (kcal·min^{-1}) (2)	Average (kcal·min^{-1}) (3)
Carrying wooden batons and loading on lorry	5.5–6.9	6.2
Digging with pick and shovel and road-making	4.8–10.1	7.1
Loading lorry with cricks		7.0
Loading stone on truck and driving		5.5
Mixing cement by machine		4.7
Pushing wheelbarrow with loads from 57–150 kg	5.0–7.1	6.0
Shoveling—8-kg load		
Lifting 0.5 m 12 throws/min	5.4–7.2	
Lifting 1.0 m 10 throws/min	6.0–8.4	7.2
Lifting 1–2 m 10 throws/min	6.0–10.5	8.3
Using pneumatic drill		5.0
Using small mechanical diggers	3.7–7.3	5.2
Bricklaying and stone-masonry		
Carrying bricks and cement		3.6
Making brick wall		4.0
Stonemason, cutting paving stones		2.9
Cutting large stones		4.4
Joinery		
Measuring wood		2.5
Machine sawing		2.5
Joining floor boards		4.6
Chiseling		5.7
Sawing soft wood		6.3
Sawing hard wood		7.5
Planing soft wood		8.1
Planing hard wood		9.1
Plastering	3.1–7.0	5.1
Decorating		
Painting, inside	1.9–2.4	2.2
Painting, outside (including preparation)	4.1–5.2	5.0
Scraping paint and sandpapering	3.8–3.7	4.1
Wallpapering	2.5–3.7	3.1

Note: From Durnin and Passmore (1967).

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TABLE 4. Subject Information and Observed Construction Activities

Subject (1)	Trade (2)	Age (years) (3)	Height (cm) (4)	Weight (kg) (5)	Gender (6)	Construction work experience (years) (7)	Smoker (8)	Health problems (9)	Description of work observed (10)
1	Cement finisher (foreman)	34	182.9	83.9	Male	10	No	None	Used two 270 lb, 45″ gas engine walk-behind trowels with float and trowel blades to finish 400 sq. ft. area
2	Cement finisher	29	185.4	88.5	Male	10	No	None	Hand screeding using a 2x4 for a 200 sq. ft. sidewalk slab
3	Laborer	30	180.3	78.5	Male	6	Yes	None	Transported concrete distance of 40 ft from concrete truck to sidewalk placing crew on gas powered ‘‘concrete buggy’’
4	Laborer	29	182.9	84.8	Male	13	No	None	Clean-up: brooming, lifting, and transporting wood, welded wire fabric, paper, etc., to dump truck; distance traveled ranged between 40 and 110 ft.
5	Operating engineer	40	170.2	95.3	Male	20	No	None	Earthmoving; part of preparation work for concrete floor slab placement; used front-end loader and ‘‘Bobcat’’ tractor
6	Laborer	23	172.7	79.4	Male	8	No	None	‘‘Come-along’’ during placement of 100 sq. ft. concrete floor slab
7	Carpenter (foreman)	35	182.9	74.8	Male	10	Yes	None	Preparation work for concrete placement, mostly involved measurements, and hammering expansion joints along walls (120 ft)
8	Cement finisher	26	175.3	83.9	Male	10	Yes	Yes (heat strokes)	Hand troweling (mostly on knees) 350 sq. ft. concrete floor slab

Problems Using Published Energy Expenditure Values and Published Guidelines

Construction workers (and humans in general) differ in age, gender, weight, height, lean and fat weight, cardiovascular and general physical condition, and psychic factors such as skill, attitude, motivation, aspirations, experience, style of work, goals, and stress (Astrand and Rodahl 1986; McArdle et al. 1996). In addition, work attributes such as production rates, means and methods of construction, and environmental factors such as temperature, humidity, and noise also vary tremendously, affecting the energy demands of the work (Kuhlmann 1986; Fraser 1989). With such variability in both workers and work, assuming that one worker will expend the same energy as another worker while performing the same construction activity is unjustified. These variations among individuals and the work itself make the energy expenditure data in Tables 2 and 3 a very rough estimate of the physical demand of the listed tasks and the physical demand evaluation guidelines in Table 1 and the 5 $kcal \cdot min^{-1}$ limit a rough guide at best.

METHODS

Measuring Equipment

The equipment available today is vastly superior to that used in the 1950s and 1960s. Recent advances in computer, microprocessor, and gas analysis technology enable researchers to efficiently measure metabolic and physiologic response to work and exercise in a manner that is nonintrusive to the work itself.

The AeroSport KB1-C ambulatory metabolic analysis system (AeroSport, Inc., Ann Arbor, MI) was used for indirect calorimetry assessment of energy expenditure in this study. This device measures VO_2 (in addition to many other physiologic attributes) during work or exercise. This device is approximately $3 \times 6 \times 2$ in. ($7.5 \times 15 \times 5$ cm) in size and is worn in a chest-vest containing electronic instrumentation, battery, oxygen and carbon dioxide sensors, and telemetry connections to a microprocessor that permits infrared transmissions of up to 3 miles (5 km) to a receiver and computer. The metabolic system weighs approximately 1.13 kg (2.5 lb) and is easily transported during physical activity.

Another appealing feature of the AeroSport KB1-C system is that it allows collection of HR data via its telemetry technology from a separate heart rate monitor system known as the Polar Vantage XL. The HR is measured using a chest band fitted with a sensor/transmitter which measures the HR and transmits it to a microprocessor in the AeroSport KB1-C unit.

Experimental Protocol

Oxygen uptake and heart rate measurements for an eight-member concrete placing and finishing crew were collected while actual construction work was being performed. Table 4 shows the worker's height, weight, age, experience, and general health data. Measurements were taken under normal work conditions. Work activities observed were videotaped to enable synchronization with VO_2 and HR data (see Fig. 1). For each subject, VO_2 and HR data were collected at 20 s intervals for a period ranging from 30–60 min. For each worker, data was collected long enough to ensure that steady state VO_2 and HR

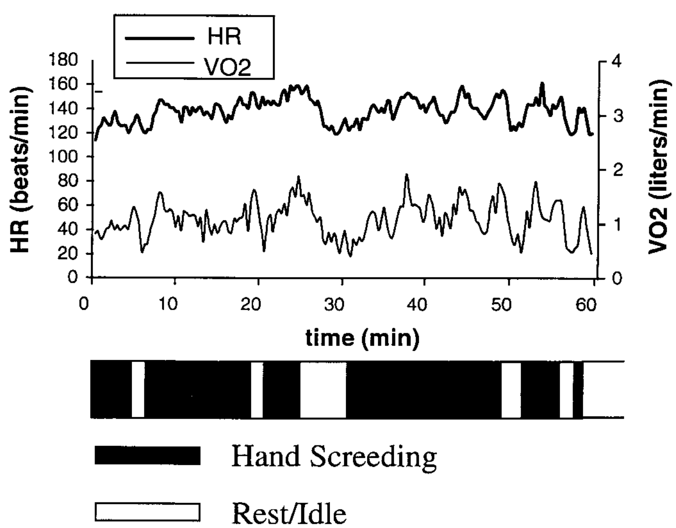

FIG. 1. VO_2 and HR Data versus Time and Work Activities—Subject 2

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TABLE 5. Results and Comparison to Contemporary Physiological Guidelines

Subject (1)	Test duration (min) (2)	VO_2 (litre · min^{-1}) Mean ± SD (3)	Peak VO_2 observed (litre · min^{-1}) (4)	HR (beats · min^{-1}) Mean ± SD (5)	Peak HR observed (beats · min) (6)	Estimated energy expenditure (kcal · min^{-1}) (7)	Classification of work based on Table 1 and mean VO_2 (8)	Classification of work based on Table 1 and mean HR (9)	Classification of work based on the 5 kcal · min^{-1} limit (10)	Worker perception of work (11)
1	60	0.59 ± 0.16	1.24	86 ± 7	111	2.78	Moderate work	Light work	Not fatiguing	Tough, I sometimes fall asleep while driving home
2	60	1.08 + 0.31	1.91	139 ± 10	162	5.34	Heavy work	Very heavy work	Fatiguing	Tiring, especially when you go back home
3	30	0.89 ± 0.12	1.23	113 ± 5	129	4.28	Moderate work	Heavy work	Not fatiguing	Kills you
4	58	1.48 ± 0.35	2.2	131 ± 11	156	7.15	Heavy work	Very heavy work	Fatiguing	Hardest job, and you go home wanting only to sleep
5	28	0.46 ± 0.23	1.41	106 ± 6	126	2.18	Light work	Moderate work	Not fatiguing	It's very tough and depends on day; some are worse than others
6	23	1.24 ± 0.34	2.28	108 ± 16	150	6.12	Heavy work	Moderate work	Fatiguing	Very tiring
7	30	1.25 ± 0.3	2.07	118 ± 8	138	5.79	Heavy work	Heavy work	Fatiguing	Tough
8	33	1.27 ± 0.29	1.89	155 ± 10	171	6.19	Heavy work	Extremely heavy work	Fatiguing	Very hard, but it is what we do for a living

had been reached and that several typical work or work-rest cycles had been completed.

Note on VO_{2max}

To evaluate a particular worker's energy expenditure, as well as evaluating his/her performance compared with others', is to express the energy expenditure relative to the worker's physiological capacity. This physiological capacity is based on the maximum aerobic capacity, which may be determined through actual testing procedures or through prediction techniques. Unfortunately, actual techniques are rather impractical and may even be dangerous for unfit construction workers, and prediction techniques are unreliable. Therefore, it was not possible to obtain VO_{2max} data for the eight workers in this study.

RESULTS AND DISCUSSION

The activities observed for the eight-member concrete slab placing and finishing crew are summarized in Table 4. Fig. 1 shows the VO_2 and HR data collected for subject 2 with respect to the time of observations and work activities. It can be seen that in periods of work, an increase in the HR is followed by an increase in VO_2, whereas during rest, a decrease in the HR is followed by a decrease in VO_2. This display of strong correlation was the same for all subjects. The average and standard deviation for collected VO_2 and HR data, as well as the worker's perception of work, are shown in Table 5. The results in Table 5 indicate that the workers who were using machines (walk-behind trowel, concrete buggy, front-end loader, and Bobcat tractor) had, on average, lower energy expenditures than the workers who worked manually.

Classification of the physical demand based on Table 1 and evaluation of physical fatigue potential for each worker based on the 5 kcal · min^{-1} limit are also shown in Table 5. These results indicate the inconsistent nature of these guidelines. For example, subject 3 was performing ''heavy work'' according to his HR, but was performing ''moderate work'' according to his VO_2, and was working at a rate that is not fatiguing when considering the 5 kcal · min^{-1} limit. Another example is that subject 8 was performing ''heavy work'' according to his VO_2, but was considered to be performing ''extremely heavy work'' according to his HR. As indicated before, the limitations of these guidelines are due to the wide variations among individuals.

In any case, it is clear that these construction workers routinely exceed generally accepted thresholds for sustained energy expenditure, VO_2, and HR. It should come as no surprise that these workers are exhausted at the end of the day and may not be fully recovered at the beginning of the next work shift. Few workers can sustain this level of performance. Many burn out and seek alternative, less demanding, work. If alternative work cannot be found, the worker faces the dilemma of continuing at a job that causes excess fatigue, or perhaps dropping out of the workforce. In their analysis of labor force withdrawal patterns among U.S. men, Hayward et al. (1989) found that white-collar professionals and managers have relatively low rates of retirement and that their careers extend into relatively old ages. This is in contrast to the pattern for physically demanding jobs such as construction crafts who had intermediate to high early retirement rates.

Skilled labor shortages continue to be a major problem for the construction industry. We cannot afford to burn out, injure, or drive away craft workers; yet the situation is likely to get worse before it gets better. As the workforce changes to include higher percentages of women and older workers, excessive physical demands will become more of a problem. The concerns for this new workforce stem from the fact that workers of either gender gradually lose strength as they age. For example, the strength of an average 65 year old person is only 75–80% of the peak strength that occurs about age 20 (Astrand and Rodahl 1986). Older workers also have reduced postural flexibility, making them more susceptible to back injuries (Helander 1981), and lower aerobic and anaerobic power (Astrand and Rodahl 1986). In addition, compared with males, females are shorter, lighter, and have lower strength and lower anaerobic power, forcing females to work at a higher percentage (compared with males at similar production rates) of their maximum capacities and making them more vulnerable to fatigue and overexertion injuries (Helander 1981; Astrand and Rodahl 1986).

CONCLUSIONS

This paper investigates the feasibility of measuring in situ physical demands of concrete slab placing and finishing work. As demonstrated, it is now technically feasible to measure the physical work load for individual construction craft workers performing their normal work in the field. In addition, existing techniques for evaluating measured physical demand have been investigated to characterize work intensity and determine whether the demands are physically fatiguing to the workers. The findings reveal that some craftworkers routinely exceed generally accepted thresholds for three physiological indicators of work load—oxygen consumption, heart rate, and energy expenditure—and can become physically fatigued. This may lead to decreased productivity and motivation, inattentiveness,

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poor judgment, poor quality work, job dissatisfaction, accidents, and injuries.

Examples have been presented indicating that use of any one physiological measurement does not present the entire story. Wide differences exist among individual worker's response to strenuous work. Future research should investigate not only the absolute energy expenditure, oxygen uptake, or heart rate for individual workers, but how these values relate to the individuals' maximum values for each measure. Maximum values are difficult, if not dangerous, to measure, but would lead to a better prediction of physical fatigue.

Other factors, such as neuro-muscular functions disturbance, water balance, drop in blood glucose concentrations, and depletion of glycogen depots in working muscles, are also good predictors of physical fatigue or its perception by workers. Studying these factors requires specialized laboratory procedures and highly trained technicians. On one hand, the results and findings from such controlled laboratory studies would have high internal validity and would be quite beneficial from a physiological standpoint. On the other hand, because real construction environments and tasks would be quite difficult to simulate in the lab, the results and findings of such studies would lose ecological (external) validity, thus rendering their use strictly academic. Moreover, such studies would involve invasive techniques such as drawing blood samples, which, as our experience suggests, would not be welcomed by a vast majority of construction workers.

Additional research is needed to assess the physical demands of other types of work and to investigate how physical demands will affect the changing workforce. This will assist labor and management in identifying opportunities to reduce physical demands and physical fatigue and introducing changes in work procedures and methods to accommodate the abilities of all workers, while improving productivity.

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