

## Assessments by HR and %HRR of Occupational Work Exertion for Alternating Periods of Rest and Manual Labor

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**Abstract: Assessments by HR and %HRR of Occupational Work Exertion for Alternating Periods of Rest and Manual Labor: Yasumasa EGUCHI, et al. Department of Health Development, Institute of Industrial Ecological Sciences, University of Occupational and Environmental Health, Japan—**

**Objectives:** Metabolic equivalents (METs) and relative metabolic rate (RMR) as calculated by oxygen uptake ( $\dot{V}O_2$ ) are often used to assess physical exertion. In practice, accurate measurements of  $\dot{V}O_2$  are difficult; heart rate (HR) values represent an alternate index of physical exertion. We investigated whether one can assess physical exertion based on HR in the workplace, even if the physical task in question involves alternating periods of strenuous anaerobic activity and rest. We also examined the potential usefulness of assessments based on percentage of heart rate reserve (%HRR) and percentage of oxygen uptake reserve (%  $\dot{V}O_{2R}$ ). **Methods:** Six healthy men were asked to perform several physical movements. HR and  $\dot{V}O_2$  were recorded in real time. **Results:** HR and  $\dot{V}O_2$  are significantly correlated even under conditions of various repeated intermittent movements including anaerobic exertion. Cumulative fatigue results in inadequate recovery in various parameters indicating sufficient rest times, whereas  $\dot{V}O_2$  values recover immediately. One movement may generate large differences in HR among individuals, but not in  $\dot{V}O_2$ . We found no significant differences between dispersion for %HRR and  $\dot{V}O_{2R}$ . However, as with HR, %HRR values indicated insufficient recovery after strenuous exertion. **Conclusions:**  $\dot{V}O_2$  alone does not adequately reflect the exertion entailed by certain physical activities. HR is more useful than  $\dot{V}O_2$  in evaluating the exertion required by physical labor in individual workers. While we can

use %HRR and %  $\dot{V}O_{2R}$  to compare physical exertion from individual to individual, %HRR is more valuable, since %  $\dot{V}O_{2R}$  can underestimate physical exertion in recovery periods for the same reasons as  $\dot{V}O_2$ . (J Occup Health 2011; 53: 343–349)

**Key words:** Heart rate, HRR, Oxygen uptake, Physical exertion, RMR, Work strain

Correctly evaluating the physical work strain imposed on workers is essential in protecting workers against the occupational health risks of manual labor, heat and inhaled chemicals, among other factors. Physical exertion is commonly assessed by the WBGT index for work performed in hot environments<sup>1–4</sup>. Under the ISO 7243 Heat Stress Standard, physical exertion is assessed by metabolic rate per unit of body surface ( $W/m^2$ ). RMR (Relative Metabolic Rate) is the index most commonly used in Japan<sup>5–8</sup>, based on the recommendations for occupational exposure limits set by the Japan Society for Occupational Health<sup>9,10</sup>. MET (Metabolic Equivalent) is well-known worldwide as an index of physical exertion during exercise, daily activities and work<sup>11–14</sup>. We assessed the physical exertion required by various activities while comparing them to model patterns in the checksheets used to draw associations between various movements and RMRs or METs. However, applying the appropriate information by this approach poses problems due to insufficient or entirely absent information on specifics such as rate of work, frequency of rest periods and the fitness of the subject. Many checksheets provide outdated data, including data on tasks now performed by machine. For all these reasons, worker exertion during various tasks has remained difficult to quantify by industrial physicians and safety supervisors.

In general, the checksheets offer little data from recent research. Even the most up-to-date data is rapidly rendered obsolete by the pace of advances in industrial and environmental technologies. RMR and MET obtained based on oxygen uptake ( $\dot{V}O_2$ ) indicate multiples of a basal

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or resting metabolism imposed by a task; we can also assess physical exertion by heart rate (HR) due to the strong correlation between HR and  $\dot{V}O_2$  for any given individual<sup>15, 16)</sup>. HR offers many advantages in assessing physical exertion:

1. Miniature high quality devices have made it easy to make accurate measurements of HR or pulse and can even identify arrhythmias.
2. Most people can count their pulse with no device at all.
3. HR measurements do not require troublesome tasks like comparisons of RMR or MET required to model patterns with checksheets.
4. HR measurements make it possible to identify short-term changes.

Furthermore,  $\dot{V}O_2$  measurements may underestimate overall physical exertion, since they reflect energy demand only. However,  $\dot{V}O_2$  may be preferred to HR when assessing physical exertion, since HR measurements tend to give larger errors if the labor performed involves intermittent anaerobic tasks interspersed with rest periods, rather than a steady state. Some studies have suggested that assessments based on HR are useful. HR correlates with exertion even for activities not involving steady state work, including activities composed of anaerobic periods interspersed with rest. For these reasons, HR assessments are often used in sports and exercise.

Another index of physical exertion is percentage of heart rate reserve (%HRR)<sup>11, 17–22)</sup>. Assessments by %HRR allow us to estimate relative stress without accounting for differences in individual ability or fitness. We can also estimate physical exertion based on percentage of oxygen uptake reserve ( $\dot{V}O_2R$ )<sup>11, 21)</sup>. Understanding the characteristics of these parameters and their relationships should prove useful for occupational health.

The present study examined whether one can assess physical exertion by HR in workplace settings, even when the labor in question involves intermittent bouts of strenuous anaerobic activity with intervening rest periods. We also explored the potential advantages of assessments based on %HRR.

## Methods

### Subjects

Subjects were recruited from workers, university students and instructors at a comprehensive community sports club. All subjects met the following requirements:

1. Given the physical rigor of the examinations, healthy males from 20 to 60 yr in age having the physical fitness required to perform manual labor.
2. To rule out the stress of commuting, those living within 30 min of our university.
3. Those able to secure days off on the date of the examination.

Ten individuals responded to a call for subjects, and six subjects meeting all requirements were finally accepted. All participants provided written informed consent before the examination. The study protocol was approved by the ethics committee of the University of Occupational and Environmental Health.

### Experimental design

The experiments were performed at our university in an automated climatic chamber set to comfortable environmental parameters (24°C, 50% RH, 760 ± 10 hPa) from May to June 2009. We obtained anthropometric data for each subject (height, weight, body fat percentage and fat free mass), muscle strength (back strength) and maximum oxygen uptake ( $\dot{V}O_{2max}$ ). Percent body fat and fat free mass (FFM) were determined by measurements of body impedance performed with the subject standing on a body fat analyzer (DC-320, Tanita, Tokyo, Japan). Subjects participated in a preliminary multistage graded submaximal exercise test on a bicycle ergometer (818E Monark, Sweden). Oxygen uptake values (ml/kg/min) were determined with an expired air gas analyzer (Westron RL-600, Arcosystem, Chiba, Japan). Values for  $\dot{V}O_2$  were calculated by a formula recommended by the ACSM (American College of Sports Medicine)<sup>23)</sup>. Heart rates were acquired by ECG monitor (Bioview1000 PB1402, NEC, Tokyo, Japan) while ECGs were monitored for cardiovascular risks. Values for HR and  $\dot{V}O_2$  were recorded every 10 s as a converted average, and values on the Borg scale for the Rating of Perceived Exertion (RPE)<sup>24)</sup> were recorded in the last 30 s at each movement stage. All subsequent  $\dot{V}O_2$  values are values per unit of body weight (ml/kg/min).

Values for %HRR and % $\dot{V}O_2R$  were calculated as follows:

$$\%HRR_{each} = (HR_{each} - HR_{rest}) / (HR_{max} - HR_{rest}) \times 100$$

$$\%\dot{V}O_2R_{each} = (\dot{V}O_{2each} - \dot{V}O_{2rest}) / (\dot{V}O_{2max} - \dot{V}O_{2rest}) \times 100$$

Workload experiments were performed several days after the exercise test. Subjects began the workload experiment by resting for 10 min in a supine position, resting for 3 min in a sitting position and then standing motionless for 3 min. After these rest positions, the subjects performed nine workload exercises in the following sequence: three upright rowing exercises, three deadlift exercises and three sessions combining both patterns. Each repetition of a pattern was performed with a successively heavier load: that is, 0 kg (no weight) for the first session of a pattern, 15 kg (barbell) for the second and 20 kg (barbell) for the third. Each session was followed by a 3-minute rest period (Table 1-A). All movements consisted of a repeated motion cycle of 8 s: 2 s for lifting, 2 s for bringing down and 4 s with the weight resting on a support or on the floor, all performed in time to a metronome (Table 1-B). Any data generated when subjects lagged by more than 2 s as indicated by a

**Table 1.** Sequence of movements

A	Table 1. Sequence of movements	
	Time (min)	Movement
	0	Rest (supine)
	10	Rest (sitting)
	13	Rest (upright)
	16	Upper body: upright rowing (0 kg)
	19	Rest (sitting)
	22	Upper body: upright rowing (15 kg)
	25	Rest (sitting)
	28	Upper body: upright rowing (20 kg)
	31	Rest (sitting)
	34	Leg: deadlifts (0kg)
	37	Rest (sitting)
	40	Leg: deadlifts (15 kg)
	43	Rest (sitting)
	46	Leg: deadlifts (20 kg)
	49	Rest (sitting)
	52	Whole body: combination (0 kg)
	55	Rest (sitting)
	58	Whole body: combination (15 kg)
	61	Rest (sitting)
	64	Whole body: combination (20 kg)
	70	Rest (sitting)
	73	End

metronome or reached an RPE of 18 were invalidated based on our understanding of the limits of load and pitch obtained in preliminary experiments.

#### Statistical analysis

In this study, we devised a step for comparing dispersion between HR and  $\dot{V}O_2$  through a group called the Modified Coefficient of Variation (M-CV), instead of Coefficient of Variation (CV).

#### Formula: Modified Coefficient of Variation

M-CV(%) = (SD for the group at the measured point) ÷ (mean for the group on an individual maximum value of trend–mean for the group on an individual minimum value of trend) × 100

We generally use the CV value (SD / Mean × 100) to compare dispersion across a group for different measurements. However, this can result in underestimates if the variation interval is near the range from 50 to 200, as with HR, but not near the range from 0 to 70 as with  $\dot{V}O_2$ , since the SDs are divided by an inflated average. To consider such characteristics, we need to modify the value by dividing it by the variation interval between the mean for maximum and minimum of trend, rather than an average as done for determining the CV value. We defined this as M-CV.

The data were analyzed statistically using StatView ver.

B	Table 1. Sequence of movements	
	Count (s)	Motion Cycle
	1	Lifting up
	2	
	3	Bringing down
	4	
	5	Holding with the weight resting on a support or on the floor
	6	
	7	
	8	

5 (SAS Institute Inc., Cary, NC, USA). Pearson product-moment correlation coefficients were used to analyze the correlation between HR and  $\dot{V}O_2$ . The paired sign test was used to identify significant differences between trend lines for M-CV. Statistical significance was established at  $p < 0.05$ .

## Results

### Subject characteristics

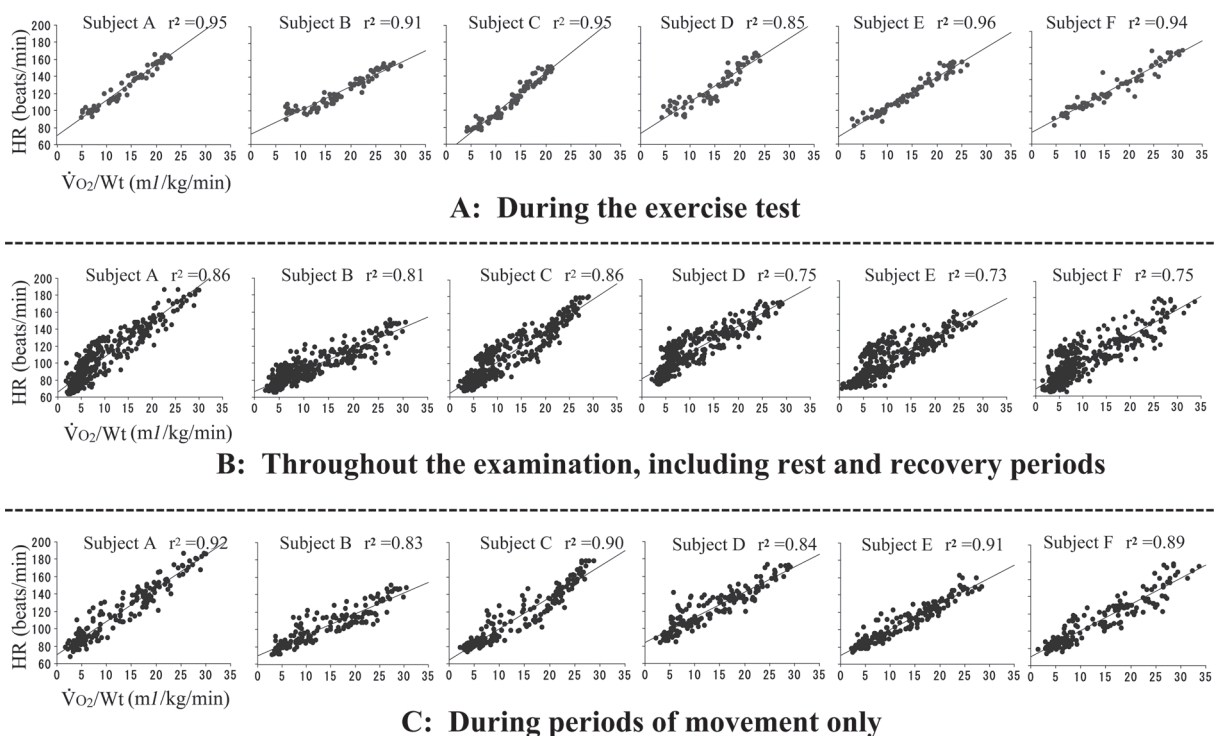
Table 2 gives the profiles of the six subjects. The subjects ranged from 26 to 53 yr in age, 161.8 to 178.5 cm in height, 51.5 to 85.1 kg in weight, 14.7 to 25.8% in body fat percentage and 43.9 to 63.1 kg in FFM. Measured back strength ranged from 90 to 126 kg.  $\dot{V}O_{2max}$ , which served as an index of physical fitness, ranged from 26.9 to 31.9 ml/kg/min.

### Relation between HR and $\dot{V}O_2$ in various tasks

Figure 1-A shows the individual correlation between HR and  $\dot{V}O_2$  in the preliminary submaximal exercise test. As expected, we saw a strong linear correlation between the two values under conditions involving graded aerobic exercise at steady states ( $r^2 = 0.85\text{--}0.96$ ). Figure 1-B shows the individual correlation between HR and  $\dot{V}O_2$  in the workload experiments through the various movements, including rest periods. Heart rate and  $\dot{V}O_2$  were also significantly correlated ( $r^2 = 0.73\text{--}0.86$ ) under conditions of various repeated intermittent movements, including anaerobic exertion. However, HR shows significant dispersion compared with the HR values observed during exercise testing, and the average correlation coefficient for the group was significantly lower ( $r^2 = 0.93 \pm 0.041 \rightarrow 0.79 \pm 0.058$ ;  $p = 0.0030$ ). Meanwhile, the correlation coefficient significantly increased ( $r^2 = 0.79 \pm 0.058 \rightarrow 0.88 \pm 0.038$ ;  $p = 0.0006$ ) after excluding rest and recovery periods and abstracting only movement periods from all of the data (Fig. 1-C). These regression lines are approximately equivalent to the lines obtained for the

**Table 2.** Subjects characteristics

Subject	Age (y.o)	Height (cm)	Weight (kg)	Body fat (%)	Fat-free mass (kg)	Back strength (kg)	$\dot{V}O_{2\max}$ (ml/kg/min)
A	26	164.5	68.0	24.4	51.4	90	26.9
B	53	161.8	51.5	14.8	43.9	94	31.9
C	34	178.5	75.2	24.1	57.1	126	28.2
D	31	163.8	54.6	14.7	46.6	105	28.4
E	44	168.4	85.1	25.8	63.1	100	29.5
F	29	163.5	72.2	22.7	55.8	110	31.7

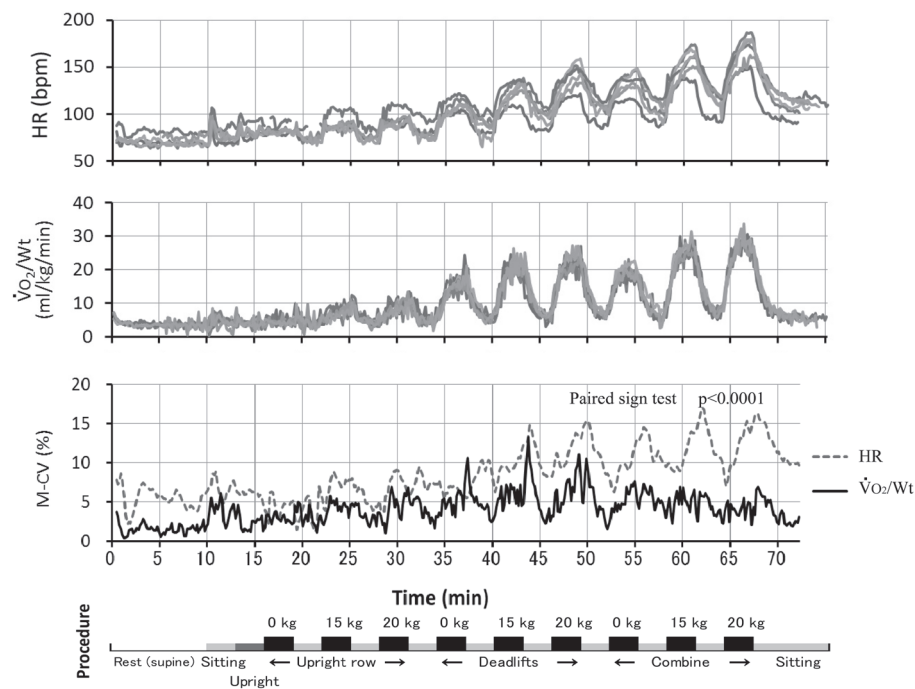
**Fig. 1.** Correlation between HR and  $\dot{V}O_2$  for each individual. A: During the exercise test. B: Throughout the examination, including rest and recovery periods. C: During periods of movement only.

exercise test. However, only two of the six subjects showed significant differences. Significant correlations also emerged after we excluded movement periods, while the correlation coefficient significantly dropped ( $r^2=0.79 \pm 0.058 \rightarrow 0.72 \pm 0.067$ ;  $p=0.0014$ ). We suspect that the data obtained in such periods affected the dispersion in whole values, as shown in Fig.1-C. This means we should consider specific characteristics when assessing physical exertion based on HR values.

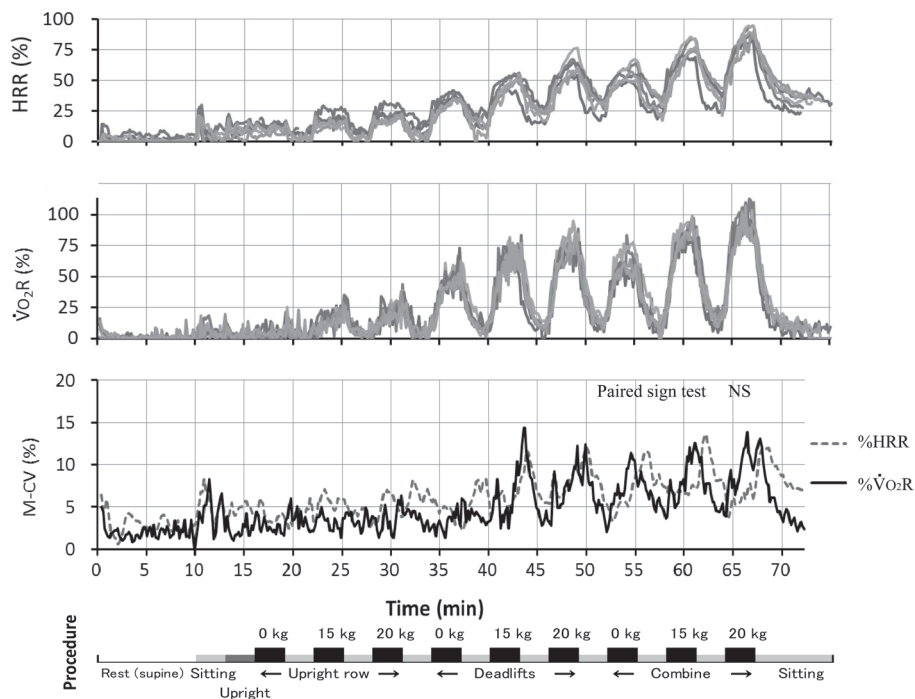
#### Differences in characteristics of HR and $\dot{V}O_2$

The upper areas of Fig. 2 show trends in the values for HR and  $\dot{V}O_2$  among the six subjects. Both HR and  $\dot{V}O_2$  values increased steadily with increased workload.  $\dot{V}O_2$

values returned immediately to the approximate baseline, even after strenuous exertion; in contrast, HRs did not return fully to their rest values. A particular movement may result in large differences in HR from individual to individual but small differences in  $\dot{V}O_2$  among the same individuals. To confirm objective variations, we compared M-CV between the HR and  $\dot{V}O_2$  values. As shown in the lower part of Fig. 2, the trend line for the M-CV of HR tended to be higher than for the M-CV of  $\dot{V}O_2$ , and we see significant differences ( $p<0.0001$  with paired sign test) through each movement and rest. Figure 3 shows the trend line for %HRR and % $\dot{V}O_{2R}$  as ratios to individual maximum reserve capacity. We found no significant differences between the M-CVs for %HRR and % $\dot{V}O_{2R}$ .



**Fig. 2.** Trend lines for HR,  $\dot{V}O_2/Wt$  and M-CV. The upper areas of figure show trends in the values for HR and  $\dot{V}O_2/Wt$  among the six subjects. Each line shows each subject. The lower part of figure shows the trend line for M-CV on HR and  $\dot{V}O_2/Wt$ .



**Fig. 3.** Trend lines for %HRR,  $\% \dot{V}O_2R$  and M-CV. The upper areas of figure show trends in the values for %HRR and  $\% \dot{V}O_2R$  among the six subjects. Each line shows each subject. The lower part of figure shows the trend line for M-CV on %HRR and  $\% \dot{V}O_2R$ .



However, as with HR, %HRR values indicated insufficient recovery after strenuous exertion.

## Discussion

We have long known that a strong correlation exists between HR and  $\dot{V}O_2$  individually under gradual exercise at steady states. No study has indicated whether we can apply this correlation to other patterns of exertion, such as manual tasks performed under intermittent and variable conditions. Numerous studies discuss HR and %HRR as indices of physical exertion<sup>17–22</sup>. Few discuss the relationship between HR,  $\dot{V}O_2$ , %HRR and % $\dot{V}O_{2R}$  and physical exertion. We found that HRs and  $\dot{V}O_2$  are also significantly correlated ( $r^2=0.73–0.86$ ) under conditions of various repeated and intermittent movements, including anaerobic exertion. However, the dispersion was greater for values of HR for individuals. Our study results indicate that these HR values in rest and recovery affect dispersion for overall HR; thus, we must consider these characteristics as a part of assessments for physical exertion. HR values do not return fully to rest values after strenuous exertion, whereas  $\dot{V}O_2$  values recover immediately. This result must be attributable to the fatigue that accumulates with intensive anaerobic exercise and to  $\dot{V}O_2$  alone not adequately reflecting the exertion required by certain physical activities. It may be that accurate assessments of physical exertion may also require assessments during recovery.

We must also consider the differences from individual to individual, since a particular movement may result in significant differences among individuals with respect to HR, but small differences among the same individuals with respect to  $\dot{V}O_2$ . This suggests  $\dot{V}O_2$  alone is insufficient for identifying differences among individuals with respect to the actual exertion required to perform certain physical tasks. Heart rate, in contrast, reflects the actual exertion of each individual when performing such movements. Few occupational health physicians assess the physical exertion experienced by workers in recovery time with checksheets of RMRs and METs. These cases may result in underestimating the actual physical exertion. The results of the present study suggest the importance of assessing not just activity, but also recovery times, as well as the differences from individual to individual. While strenuous exertion leads to cumulative fatigue and prolonged recovery times, identifying the appropriate intervals and length of rest periods is difficult. We attempted to use HR values to estimate the recovery times required. HR can be used to estimate both stress and appropriate recovery times.

On the other hand, it is possible that physical exertion may have been significantly affected by body mass until the barbells reached the weight level of 20 kg. We found insignificant differences in  $\dot{V}O_2$  from individual to individual when these values were divided by body

weight. It may be useful to define exertion vs. cumulative exertion as the difference between elevated HR and  $\dot{V}O_2$  in response to the stress imposed by physical workloads. Our results may explain why RMR and MET are used as an index of physical exertion: RMR and MET are determined by  $\dot{V}O_2$  measurements that do not differ significantly from individual to individual. In any case, manual tasks performed at actual workplaces are exceedingly fluid and varied. Assessing physical exertion precisely by RMR or MET poses several difficulties. HR has become an increasingly significant index for managing occupational health and safety. We can use %HRR to compare levels of physical exertion from individual to individual, whereas HR alone is valid only for one specific individual. Percentage of oxygen uptake reserve is equally effective for comparing physical exertion. Previous studies show a strong correlation between % $\dot{V}O_{2R}$  and %HRR, but these studies exclude recovery and rest times. As shown in the present study, since % $\dot{V}O_{2R}$  likely underestimates physical exertion and recovery times for the same reasons as  $\dot{V}O_2$ , assessments that include %HRR are significantly more valuable. Percentage of heart rate reserve quantifies physical exertion against maximum capacity, which is more useful than HR in assessing workplace physical exertion. Needless to say, we should select the indices that most accurately reflect the tasks performed and that help us identify the nature of the tasks performed.

## Study limitations

We cannot rule out inconsistencies between laboratory experiments and actual conditions given the handful of physical movements used in this study. We asked subjects to perform tasks at a constant and set rhythm. Further study is needed—in particular, expired gas analysis under actual work conditions and in real time—despite the difficulties posed by such studies. We must also determine to what extent HR and %HRR can be affected by mental states, although HR is far more objective than interpretations of RMR or MET based on model patterns, which leave room for subjective assessments and mismatches or differences. This study involved a small number of male subjects. Additional study is needed based on a larger subject group that also includes women.

## Conclusion

Determining RMR or MET as calculated by the oxygen uptake required for various movements is important for collective assessments of physical exertion. However, HR is more useful than  $\dot{V}O_2$  in evaluating the exertion required by physical workloads for individual workers, especially with regard to recovery times. Percentage of heart rate reserve is even more useful than HR in assessing physical exertion and in objectively quantifying levels of physical exertion vs. maximum capacity. Ideally, %HRR should

be taken into account when configuring work environments for individual workers.

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