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Assessment of cardiovascular load among hotel room cleaners

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A R T I C L E I N F O

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A B S T R A C T

Hotel room cleaners are a vulnerable population at risk for cardiovascular disease. To evaluate their workload heart rate (HR), % heart rate reserve (%HRR), blood pressure (BP), metabolic equivalent (MET), and energy expenditure (EE) were measured over two workdays and two off-workdays. The mean age was 45.5 (SD 8.2) years with a mean 10.4 (SD 7.8) years of work experience. Mean average and peak HR, %HRR, MET, and EE were significantly higher during a workday than an off-workday for the entire work shift, first and last hour of work. Mean average HR and %HRR saw the largest increase between the lunch and post-lunch interim. One-fourth of subjects exceeded the recommended 30% HRR threshold for 8-hour shifts. Some workers experienced a substantial increase in HR and DBP over a workday indicating physiologic fatigue and thus may be at increased risk for cardiovascular disease and premature death due to excessive physical work demands.

1. Introduction

Over 1.9 million people work in US hotels, 24% as hotel room cleaners comprising the largest occupational group within the hotel industry (U.S. Bureau of Labor Statistics. (n. d.), 2019). Hotel housekeepers are primarily women of color and/or immigrant status; in a study of five Las Vegas hotels, 76% of hotel housekeepers were Latinas (Krause et al., 2005). Cardiovascular disease (CVD) is the number one cause of death globally, representing 31% of all deaths (WHO, 2017). Cleaners are a vulnerable population as they have a high prevalence of obesity (Jørgensen et al., 2011) and uncontrolled hypertension (Krause and Arias, 2015), and are exposed to increasing physical workloads (Krause et al., 2005), high relative aerobic workloads (Unge et al., 2007), job stress (Rugulies et al., 2008; Feaster and Krause, 2018), low wages (May 2021 National Occupational Employment, 2021), and low socio-economic position, all associated with elevated blood pressure (BP), CVD, and mortality (Jørgensen et al., 2011; Krause and Arias, 2015; Feaster and Krause, 2018; Coenen et al., 2018a; Hall et al., 2019; Cillekens et al., ; Li et al., 2013; Zock, 2005; Sjögren et al., 2003; Colhoun et al., 1998; Raum et al., 2007; Kivimäki et al., 2012).

Hotel room cleaning tasks require prolonged standing, walking, bending, and overall high intensity occupational physical activity (OPA) that may not only contribute to high levels of musculoskeletal disorders and severe pain (Krause et al., 2005; Unge et al., 2007; Coenen et al., 2017, 2018b) but also to detrimental cardiovascular effects. Specifically, OPA including prolonged standing or high levels of energy expenditure (EE) are associated with accelerated progression of atherosclerosis and increased risks for CVD and all-cause mortality (Coenen et al., 2018a; Hall et al., 2019; Cillekens et al., ; Li et al., 2013; Raum et al., 2007; Holtermann et al., 2010; Holtermann et al., 2009; Krause et al., 2007; Smith et al., 2018; Krause et al., 2000).

The overall intensity of OPA can be assessed by either absolute or relative measures of energy expenditure (EE). Absolute EE is typically estimated as metabolic equivalents (MET), kilocalories or Joule, the latter two taking bodyweight into account. Relative measures of EE also take the individual's cardiorespiratory fitness or aerobic capacity into account to better assess the biologically effective workload for the cardiovascular system. Relative aerobic strain, also known as relative aerobic workload (RAW), is such a relative EE measure and can be estimated either directly via ventilatory gas exchange as oxygen consumption relative to cardiorespiratory fitness (%VO_2max) or indirectly as percent heart rate reserve (%HRR), calculated from resting heart rate (HR) and working HR, relative to age-predicted maximum HR (Tanaka et al., 2001). While both absolute and relative intensity measures of OPA

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have been linked with various CVD outcomes, relative measures showed more consistent and stronger associations (Krause et al., 2007, 2015, 2017; Korshøj et al., 2015a; Wu and Wang, 2002). Specifically, high RAW was shown to increase risks for elevated resting and ambulatory BP (Korshøj et al., 2016, 2019), progression of atherosclerosis (Krause et al., 2015), CVD incidence (Krause et al., 2017), and cardiovascular and all-cause mortality (Krause et al., 2017).

The underlying pathophysiological mechanisms can be summarized as follows (Korshøj et al., 2019): All muscular work activities concurrently raise HR and BP that determine cardiovascular work load (estimated as rate pressure product) and that are independent and strong risk factors for CVD (Palatini, 2007; Cooney et al., 2010; Korshøj et al., 2015b). Elevated HR and BP during OPA may therefore be the two main mechanisms explaining why high OPA increases risk for CVD (Krause et al., 2000; Holtermann et al., 2018). HR varies by age, cardiorespiratory fitness, health status, body temperature, working posture, environmental heat, and type, duration and intensity of OPA. Resting HR increases with age, while maximum HR and aerobic capacity decrease with age (McArdle et al., 2007; Meyers et al., 1991). Therefore, identical physical work task demands strain the cardiovascular system in older workers to a higher degree than in younger workers (Ilmarinen, 2001).

The reported relationships are biologically plausible and in agreement with established basic pathophysiological mechanisms. Standing work postures and both static and dynamic muscle work during OPA require increases in cardiac output (blood flow) to provide sufficient oxygenated arterial blood to working muscles and to compensate for reductions in available blood plasma volume due to postural changes (including venous pooling during standing) and gradual hemoconcentration increasing with exercise intensity and associated fluid loss due to sweating and increased breathing rates. Increases in cardiac output are generated mainly via increases in HR but are also accompanied by increases in mean arterial BP (Robergs and Roberts, 1997). During exercise, systolic (SBP) and mean arterial blood pressures (MAP) increase while diastolic blood pressure (DBP) remains close to or slightly less than resting values indicating that during increased cardiac output the ejection of blood from the left ventricle exceeds the compliant properties of the vasculature and any exercise-induced vasodilation partially counteracting the increases in vascular resistance due to external compression of blood vessels by the contracting muscles. Static work postures, lifting and carrying objects or holding tools thus further increase peripheral vascular resistance overwhelming any exercise-induced vasodilation and leading to additional BP elevations (Robergs and Roberts, 1997). Again, these mechanisms are further amplified in workers with preexisting arteriosclerotic changes leading to stiffer arteries, partial stenosis, and suboptimal turbulent blood flow, further increasing BP during exercise. In fact, there is strong epidemiological evidence that pre-existing atherosclerosis or ischemic heart disease amplify detrimental health effects of OPA (Krause et al., 2000, 2015). For these reasons, BP elevations may be another important mechanism explaining the association between high OPA and CVD, that is supported by a linear dose-response association between BP and CVD observed even among normotensive subjects (Olsen et al., 2016). Also, some studies indicate occupational lifting increases resting BP (Fransson et al., 2004; Petersen et al., 2012) due to the repeated acute rises in BP when lifting (MacDougall et al., 1985).

Prolonged exposures to elevated HR and BP confer excessive mechanical strains on the arterial wall, possibly causing endothelial injury, smooth muscle cell proliferation, and inflammatory reactions leading to atherosclerosis and CVD (Suo et al., 2008; Glagov et al., 1988). With increasing age and the associated cumulative mechanical stresses, the arteries gradually lose compliance and thereby the ability to dilate sufficiently, further increasing peripheral resistance and BP, augmented by the effects of an early return of pulse wave reflection (Klabunde, 2011; Wen et al., 2015; O'Rourke and Hashimoto, 2007). While leisure time physical activity may reduce BP for up to 22 h following exercise, occupational physical activities can substantially elevate BP during work, at home, and during sleep (Clays et al., 2012).

Past physiologic studies and recommendations by the International Labour Organization (ILO) of the World Health Organization (WHO) suggest that the average RAW during an 8-h working day should not exceed 30% of maximum cardiorespiratory fitness (Wu and Wang, 2002), but in a study of Danish cleaners, 51% exceeded these recommended levels (Korshøj et al., 2015a). Compared to men, female workers may be at higher risk of excessive OPA exposures because working-age women have lower values of VO_2max and oxygen-transporting serum hemoglobin leading to higher RAW when meeting identical physical job demands. Women also tend to work in physically demanding jobs through higher ages (Aittomaki et al., 2005; Tong et al., 2010; Sanborn and Jankowski, 1994; Diaz-Canestro and Montero, 2019). From an ergonomic perspective it is important to determine which specific cleaning tasks generate the highest cardiovascular load exposures so that workplace interventions aiming to reduce RAW among cleaners can be targeted to those tasks.

While elevated CVD risks have been reported for cleaners (Krause and Arias, 2015; Sjögren et al., 2003), to our knowledge, there are no ergonomic studies assessing the cardiovascular load during hotel room cleaning. The objective of this study was to assess the physiological cardiovascular demands of different hotel room cleaning tasks and the overall daily work shift and compare them with off work and resting values. The main hypothesis of the study is that typical physical job demands such as bed making during hotel room cleaning cause cardiovascular strain that may increase the CVD risk among hotel room cleaners.

2. Methods

2.1. Study population and recruitment of subjects

Recruitment of worksites and study participants was done in collaboration with *Local 2850 of UniteHere! in the San Francisco Bay area*. Researchers presented the project to cleaners at a local union meeting, and the union recruited two unionized Bay Area hotels chosen for having standard rooms without a kitchenette. Study inclusion criteria required management's permission for cleaners to participate during paid working time and to pause work while the BP monitor measured ambulatory BP. Eligible participants had to be female, 18–65 years old, currently working as a hotel room cleaner with one year of experience as a hotel room cleaner, and speaking English, Spanish, Cantonese, and/or Mandarin.

The exclusion criteria were: an active or recently filed (within 1 year) workers compensation claim, a history of cardiovascular and/or pulmonary disease, treated hypertension or elevated BP (>140/90), diabetes mellitus, heart palpitations, chest pain or shortness of breath in the past month, pregnancy, or allergy to adhesive plasters.

Hotel room cleaners at the participating hotels were given written information about the study; those interested in participating met researchers at the UC Ergonomics Laboratory for eligibility screening and informed consent. Participation was voluntary and incentives of $20 per hour were provided for time outside of normal work hours.

2.2. Study design

This was a cross-sectional study conducted in both laboratory and field settings.

A 2-h long appointment at the University of California Ergonomics Lab, included study explanation, informed consent, survey administration, and baseline measurements of resting standing, sitting, and supine HR, SBP, and DBP using SpaceLabs 90217 Ultralite 24-h Ambulatory Blood Pressure Monitor, a validated monitoring device (Baumgart and Kamp, 1998; Sarafidis et al., 2016). Body weight, height and waist circumference (at the shortest distance between the lowest rib and the iliac crest) were measured using a scale, tape measure, and soft measuring tape. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). An online survey administered with an iPad using the Qualtrics software interface assessed education, employment status, workload, job control, job satisfaction household activities and exercise, smoking, and medical history. The supplement were available in English, Spanish, and translated into Mandarin or Cantonese for participants who preferred the respective language.

Field data collection included 24-h ambulatory HR and BP at work and at home including four consecutive days of two 8-h workdays at the hotel and two off-workdays using the Actiheart 4 monitoring device (Camntech, Cambridge, UK), a validated monitor for measuring HR variability and EE estimation, and SpaceLabs BP monitors, respectively (Brage et al., 2005; Crouter et al., 2008). During the first workday, participants were observed at their hotel cleaning two standard rooms with two queen beds and time markers were recorded for each specific task. Participants were trained don and doffing monitors and to interrupt their work while the monitor measured their BP. Throughout all 4 days, subjects completed a daily diary and time-logged activities including sleep, work, leisure, exercise and household activities, and any time off monitors.

Human subjects approval was granted through University of California San Francisco (UCSF) Institutional Review Board (IRB).

2.3. Assessment of cardiovascular load indicators

In addition to ambulatory HR, metabolic equivalents (MET), a measurement of oxygen consumption relative to resting state often used as an indicator of activity level, and EE, a measurement of metabolic rate which at high levels has been seen to be associated with acceleration of atherosclerosis, were estimated with the Actiheart device using standard equations (Krause et al., 2007; Crouter et al., 2008).

RAW was estimated as %HRR as it is often used in the field as an indicator for workload intensity similar to the measurement of one's maximum aerobic capacity (VO_2 max). %HRR is often preferred for dynamic work where measuring oxygen intake is less feasible. %HRR is calculated as follows: $\frac{HR_{current} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100$, with maximum HR estimated as 208-0.7 x age (Tanaka et al., 2001) and the resting HR operationalized as the average of the 10 lowest measured HR during 4 field days (Brage et al., 2004). Pulse pressure (PP) was calculated as SBP minus DBP which is a measurement of the contracting force generated by the heart and is used as an indicator of arterial stiffness (Franklin et al., 1997). Myocardial workload was estimated by the rate pressure product (RPP), calculated as HR times SBP, a measure used as an indicator of cardiovascular oxygen demand (Gobel et al., 1978). HR and SBP were measured every minute and every half hour, respectively. RPP was calculated for every time point with both measures.

Each workday was split into the following time periods based on time points logged on the daily diary: before work shift (from wake time to the start of work shift), first hour of work, second hour of work, pre-lunch interim (third hour of work to start of lunch), lunch, post-lunch interim (end of lunch to second to last hour of work), second to last hour of work, last hour of work, entire work shift (from start to end of work shift excluding lunch), after-work (from end of work shift until start of sleep time), and sleep. The respective averages of the time points during each subject's day of work were then used to define equivalent comparison time points during each subject's respective off-workdays.

2.4. Statistical analysis

Mean and standard deviations of all cardiovascular load variables were tabulated by time period and paired t-tests were performed to determine statistical significance of differences between average workday and off-workday values. MATLAB (MATLAB, 2017b; The MathWorks, Inc.) and STATA statistical software version 15 (StataCorp. 2017) were used.

3. Results

Seventeen eligible hotel workers attended the evaluation in the ergonomics lab; two were excluded due to a high BP or working side jobs during both designated off-workdays. For another subject, one workday was excluded due to low HR values that did not align with their other days' measurements.

Characteristics of the final study population are shown in Table 1. One reported high cholesterol, all others reported no medical conditions. Primary language was Chinese (n = 8) or Spanish (n = 7).

Table 2 summarizes workplace factors. Participants had worked on average 10 years as a hotel room cleaner. All participants cleaned approximately two rooms per hour. Almost all participants (93%) expressed that their job requires them to work very fast and a majority felt fatigued or sleepy on job, and mentally or physically exhausted after work.

Table 3 compares average cardiovascular loads during workdays and off-workdays by specific time periods. All physiological indicators of cardiovascular load were higher during working time periods of a workday compared to a non-workday, except DBP before and during the first hour of work and PP for the entire shift and the last work hour. Before the work shift, lower HR and %HRR were accompanied by higher PP, METs and EE during workdays. During the entire shift, %HRR on workdays was 28.1% versus 15.5% on off-workdays. After shift, HR, %HRR, and RPP remained substantially higher during workdays. During sleep time, no substantial differences were observed. During workdays, interindividual differences for the entire work shift period showed wide ranges for average HR (75–105 bpm), %HRR (14–42%), SBP (94–153 mmHg), DBP (64–99 mmHg), PP (30–57 mmHg), RPP (7132–13958), MET (2–4) and EE (43–154 J/min/kg) (Supplemental Table S2).

Supplemental Table S1 compares mean peak cardiovascular loads during workdays and off-workdays by specific time periods. Before the work shift, peak HR, %HRR, METs, and EE were higher during workdays. During the entire shift, peak HR, %HRR, MET, and EE were higher on workdays while SBP and RPP were higher on non-workdays but higher on workdays during the first and last shift hours. The peak %HRR during the entire shift period of a workday was 55.5% (compared to 45.6% on off-workdays) and ranged from 41.3% to 52.5% across sub-

Table 1
Baseline Survey. Demographic and health characteristics of the study population (n = 15).

	mean (SD), range or n (%)
Age (years)	45.5 (8.2), 24-55
< 40	3 (20%)
≥ 40 &<50	6 (40%)
≥ 50	6 (40%)
Education	
Some Highschool or less	7 (47%)
Highschool Graduate or above	8 (53%)
General Health	
Very Good or Excellent	8 (53%)
Good	3 (20%)
Fair or Poor	4 (27%)
Body Mass Index (kg/m^2)	26.9 (3.7), 22-33
<25	5 (33%)
≥25 - <30 (Overweight)	6 (40%)
≥30 (Obese)	4 (27%)
Smoking Status	
Never Smoked	13 (87%)
Active or Previous Smoker	0 (0%)
Passive Secondhand Smoker	2 (13%)
Any Alcohol Drinking	
Yes	3 (20%)
No	12 (80%)
Regular Activities at Home or Exercise	
Yes	12 (80%)
No	3 (20%)

Table 2
Workload Survey. Self-reported indicators of physical workload. exhaustion, and work stress (n = 15).

Physical Workload	mean (SD), range or n (%)
Years worked as Hotel Housekeeper	10.4 (7.8), 0.8–27
< 3	2 (13%)
≥3 - < 10	5 (33%)
≥10	8 (53%)
Beds Made on a Typical Day	22.7 (3.6), 15-28
Job Requires Working Very Fast	
Disagree	1 (7%)
Agree	9 (60%)
Strongly Agree	5 (33%)
Work Strain Indicators	
Feeling Sleepy or Fatigued On the Job	
Never	0 (0%)
Some of the time	13 (87%)
Often/Always	2 (13%)
Physically Exhausted After Work	
Never	1 (7%)
Some of the time	7 (47%)
Often/Always	7 (47%)
Mentally Exhausted After Work	
Never	5 (33%)
Some of the time	6 (40%)
Often/Always	4 (27%)
Job Satisfaction	
Very satisfied	2 (13%)
Somewhat satisfied	10 (67%)
Not too satisfied or not at all satisfied	3 (20%)
Sick Leave Days Previous Year	
0 Days	3 (20%)
1–3 Days	6 (40%)
4–7 Days	6 (40%)

periods. During workdays, interindividual differences for the entire work shift showed wide ranges for peak HR (101–146 bpm), %HRR (37–78%), SBP (104–166 mmHg), DBP (68–110 mmHg), RPP (8104–17643), MET (3–8) and EE (154–381 J/min/kg) (Supplemental Table S3).

Fig. 1 shows average HR and %HRR throughout the course of a workday and off-workday. During workdays, average HR and %HRR trended upwards until the lunch period where there was a decrease, followed by the largest increases during the post-lunch interim period by 10.4 bpm for HR and %HRR by 9.0%, in contrast to a slight decline during off-workdays. During off-workdays, HR and %HRR were stable below 81 bpm and 18%, respectively, across the entire work shift.

Fig. 2 shows peak HR, HRR, RPP, and SBP throughout the course of a workday and off-workday. During workdays, the largest increases in peak HR, %HRR, and RPP occurred after lunch (15.3 bpm, 13.3%, and 1989, respectively); the largest increases in peak SBP (8.3 mmHg) and DBP (6.0 mmHg, Supplemental Table S1) occurred between the last hour of work and the after-work period, while all other parameters remained stable. During off-workdays, all peak values were lower throughout the entire shift period (except for SBP), rose less after lunch, and rose the most in the after-work time period, compared to workdays. In contrast to all other measures during off-workdays, SBP, DBP, and RPP rose steeply after waking (Supplemental Table S1).

Table 4 shows mean changes (with interindividual ranges) in average and peak HR and %HRR from before to after work, first hour of work to last hour of work, and first hour of work to post-lunch interim time periods during workdays. Increases in average and peak HR and %HRR occurred during all three time periods. Largest increases were observed between the first hour of work and post-lunch interim: average and peak HR and %HRR increased by > 11 bpm and approximately 10% units, respectively, with individual average and peak HR increases up to 40 and 48 units, respectively.

Fig. 3 shows the average and peak %HRR by job task. Observed tasks included bathroom cleaning, bed-making, wiping and dusting, vacuuming, and completion of the room after all tasks had been finished. The overall mean average and peak %HRR across all tasks were 39.1% and 46.4%, respectively. Wiping and dusting had the highest average %HRR (40.8%), and bed-making had the highest peak %HRR (50.2%) followed by wiping and dusting (47.0%).

Fig. 4 shows average %HRR by workday periods, separately for up to 15 participants. All individuals showed increases in average %HRR throughout their workday. The average %HRR for the entire 8-h work shift – excluding the lunch break – ranged from 14 to 42%, with a fourth of participants exceeding the 30% HRR 8-h threshold.

4. Discussion

This field study evaluated several absolute and relative (to measures of individual fitness) cardiovascular physiological demand outcomes across different time periods and cleaning tasks, and also compared overall and day-time-specific cardiovascular loads during workdays with off-workdays. Increases in HR and HRR were seen throughout the entire work shift as well as increases in SBP and DBP during the after-work shift period indicating insufficient recovery. Workdays yielded consistently higher cardiovascular loads than off-workdays. ILO-

Table 3
Comparison of average cardiovascular loads during workdays and off-workdays. Means with standard deviations for average heart rate (HR), percent heart rate reserve (%HRR), ambulatory systolic (SBP) and diastolic (DBP) blood pressure, pulse pressure (PP), rate pressure product (RPP), metabolic equivalents (MET), and energy expenditure (EE). All n-values are 15 unless otherwise noted with † for n = 9 and ‡ for n = 14.

		HR (beat/min)	HRR (%)	SBP (mmHg)	DBP (mmHg)	PP (mmHg)	RPP	MET	EE (J/min/kg)
Before Shift	Workday	78.0 ± 11.5	15.2 ± 8.1	123.7 ± 13.6	79.4 ± 5.4	44.4 ± 10.1	9602 ± 2104	1.9 ± 0.4	54.4 ± 25.2
	Off-Workday	80.0 ± 9.4	17.0 ± 7.1	122.2 ± 14.1	80.4 ± 7.0	41.8 ± 10.6	9281 ± 1648	1.7 ± 0.4	42.8 ± 24.3
	p-value	0.73	0.74	0.30†	0.79†	0.18†	0.20†	0.01	0.01
Entire Shift	Workday	92.8 ± 8.3	28.1 ± 6.8	119.9 ± 16.2	77.1 ± 9.1	42.8 ± 8.6	10691 ± 1997	2.6 ± 0.5	99.8 ± 26.5
	Off-Workday	78.4 ± 10.9	15.5 ± 7.5	118.6 ± 17.1	75.2 ± 8.6	43.4 ± 10.6	8986 ± 2092	1.7 ± 0.4	44.8 ± 24.9
	p-value	0.00	0.00	0.21	0.04	0.68	0.00	0.00	0.00
First Hour of Shift	Workday	86.7 ± 12.2	22.8 ± 9.4	121.4 ± 18.3	76.8 ± 13.4	44.7 ± 8.4	10148 ± 2199	2.4 ± 0.6	85.6 ± 36.9
	Off-Workday	79.0 ± 10.9	16.0 ± 8.0	117.6 ± 17.3	77.1 ± 9.2	40.5 ± 11.0	9022 ± 1968	1.7 ± 0.5	43.1 ± 29.2
	p-value	0.00	0.00	0.08‡	0.57‡	0.01‡	0.00‡	0.00	0.00
Last Hour of Shift	Workday	89.4 ± 10.6	25.2 ± 9.1	121.6 ± 17.3	77.9 ± 9.8	43.7 ± 9.5	10664 ± 2355	2.4 ± 0.6	88.2 ± 31.7
	Off-Workday	75.7 ± 13.0	13.1 ± 9.7	118.1 ± 18.6	73.4 ± 11.3	44.7 ± 11.2	8804 ± 2421	1.7 ± 0.4	43.8 ± 27.4
	p-value	0.00	0.00	0.10	0.02	0.70	0.00	0.00	0.00
After Shift	Workday	79.1 ± 7.2	16.2 ± 5.5	119.0 ± 15.9	76.4 ± 9.0	42.6 ± 7.6	9301 ± 1825	1.6 ± 0.2	37.5 ± 14.2
	Off-Workday	75.5 ± 10.5	13.0 ± 7.7	118.0 ± 16.5	75.8 ± 9.3	42.2 ± 9.8	8810 ± 2143	1.6 ± 0.3	35.5 ± 20.6
	p-value	0.07	0.06	0.28	0.32	0.40	0.05	0.36	0.37
Sleep	Workday	62.1 ± 5.0	1.5 ± 2.2	103.7 ± 12.1	64.4 ± 7.5	39.3 ± 6.8	6483 ± 1172	1.1 ± 0.0	4.3 ± 2.6
	Off-Workday	62.1 ± 5.6	1.5 ± 3.1	104.4 ± 13.9	64.7 ± 8.0	39.7 ± 7.4	6558 ± 1478	1.1 ± 0.1	5.2 ± 3.8
	p-value	0.49	0.47	0.70	0.67	0.65	0.69	0.91	0.88

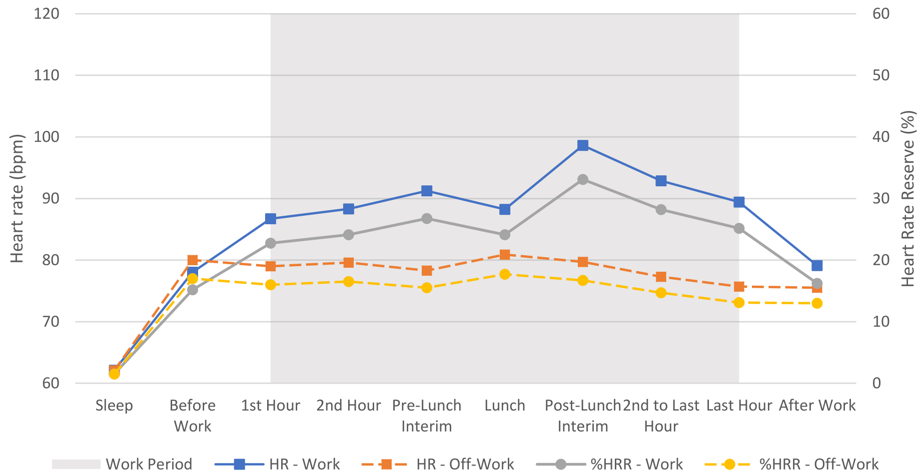

Fig. 1. Average cardiovascular load progression during workdays and off-workdays. Average heart rate (HR) and percent heart rate reserve (%HRR) throughout specific time periods. The entire work shift period is represented by the gray area of shading (n = 14–15).

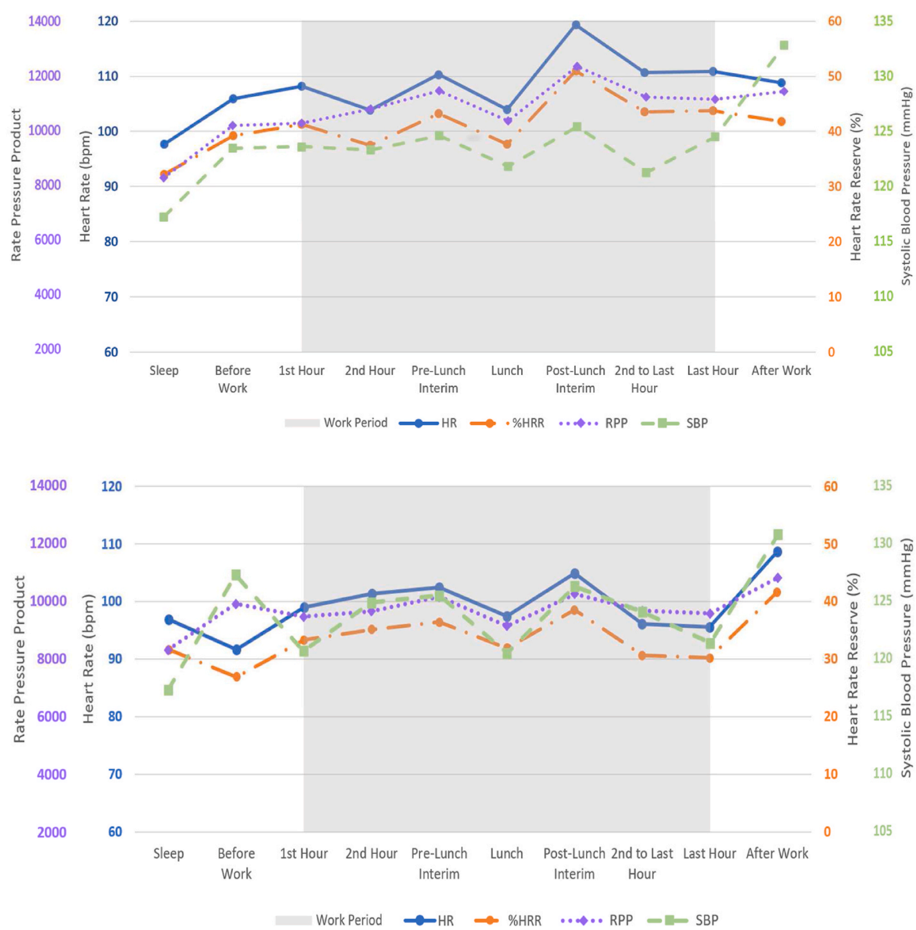

Fig. 2. Peak cardiovascular load progression during workdays (top graph) and off-workdays (bottom graph). Peak heart rate (HR), % heart rate reserve (% HRR), rate pressure product (RPP), and systolic blood pressure (SBP). The entire work shift period is represented by the gray area of shading (n = 9–15).

recommended maximum levels of RAW (30% VO_{2max} for an 8-h shift, estimated by %HRR (Wu and Wang, 2002)) were exceeded by a quarter of workers (Wu and Wang, 2002; Bonjer, 1971). Each main job task required over 36% HRR and bedmaking required the highest peak workload (50% HRR). These results indicate cardiovascular over-exertion among hotel housekeepers who cleaned a standard hotel room. Such workloads pose a substantially increased risk for CVD such as heart attacks and strokes. For example, each 10% unit increase in average RAW has been associated with an 18% increase in acute myocardial infarction in previous research (Krause et al., 2015).

4.1. Overall work intensity, recovery, and expected health impact

To assess hotel room cleaners' work demands, we presented the average HR of these workers, a value of 92.8 bpm which categorizes hotel room cleaning as one of moderate intensity (Astrand et al., 2003).

Table 4
Average and peak changes in heart rate (HR) and percent heart rate reserve (%HRR) during three selected time periods during a workday: before to after work, first hour to last hour of work, and first hour of work to post-lunch interim work period. Mean change with standard deviations (in parenthesis) and interindividual ranges (n = 15).

	Δ Before to after work		Δ First hour to last hour of work		Δ First hour of work to post-lunch interim	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Average						
HR (bpm)	+1.10 (8.2)	−15 to +18	+2.69 (16.8)	−21 to +44	+11.92 (11.1)	−4 to +40
%HRR	+1.01 (7.2)	−13 to +16	+2.40 (14.8)	−18 to +39	+10.34 (9.9)	−4 to +35
Peak						
HR (bpm)	+2.91 (14.8)	−22 to +30	+2.39 (17.9)	−29 to +46	+11.13 (13.4)	−7 to +48
%HRR	+2.60 (12.9)	−17 to +27	+2.92 (17.7)	−29 to +46	+9.61 (11.8)	−6 to +42

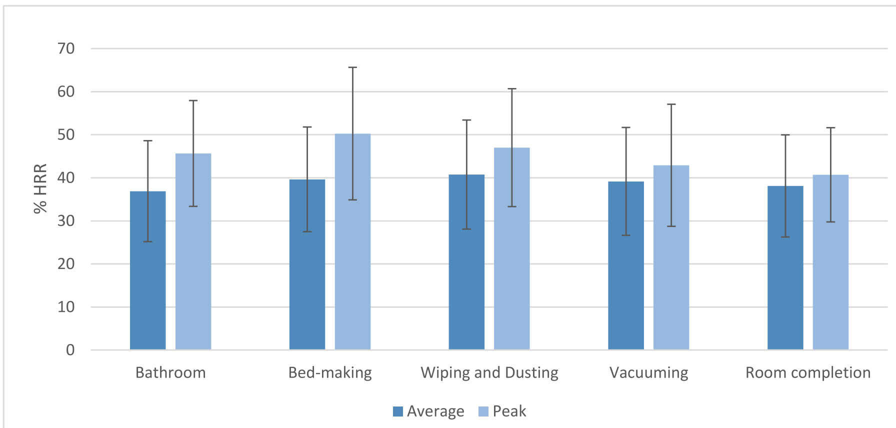

Fig. 3. Average and Peak % Heart Rate Reserve by Task. Average and peak percent heart rate reserve (%HRR) during cleaning tasks performed in an assigned standard room – bathroom cleaning, bed-making (2 queen beds), wiping and dusting, vacuuming, and completion of room tasks. Bars represent %HRR and whiskers standard errors. The order of tasks as presented in the figure (left to right) is the typical order in which tasks were performed (n = 8 to 10).

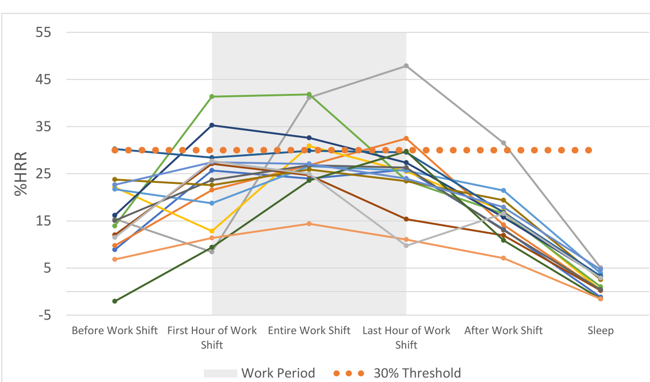

Fig. 4. Workday Average %HRR by Subject and Time Period. Average percent heart rate reserve (%HRR) by subject and time period. The 30% HRR threshold is represented by the dotted line (n = 15).

The average %HRR across individuals was close to 30% but individuals varied widely and a quarter of women exceeded this recommended upper limit. (Fig. 4, Supplemental Table S2&S3). Using a formula to estimate maximum HR by age rather than determining it by cardiorespiratory fitness test may have underestimated %HRR (Silva et al., 2007). Despite this underestimation, four individuals (26.7%) worked above the recommended 30% HRR threshold, and 55% of the other workers (N = 6) worked at 25–30% HRR, just below that threshold (Fig. 4). (Astrand et al., 2003; Tipton et al., 2013) This may put hotel room cleaners at increased risk for CVD and mortality. In fact, in previous studies each 10% unit increase in RAW was associated with increased risks of acute myocardial infarction (18%), coronary heart disease mortality (28%), and all-cause mortality (18%), after adjustment for BMI, LTPA, income, and other potential confounders (Krause et al., 2015, 2017). Moreover, the observed monotone dose-response relationship applies to workers below and above the recommended 30% HRR. The recommendation of a 30% RAW maximum was based on physiological indicators of fatigue such as HR and serum lactate levels among healthy young adults in the 1960s (Wu and Wang, 2002) and did not take these recent epidemiologically confirmed CVD and mortality risks into account that increase with increasing workloads already below the recommended limit. Moreover, these risks are higher among workers with pre-existing CVD, which are more prevalent among older worker populations, who also have less aerobic capacity because cardiorespiratory fitness (%VO_{2max}) declines by 1% each year after the age of 25 (Krause et al., 2007, 2015). Our study population was on average 45.5 years old, and experiences a much higher %HRR relative workload than younger workers exposed to the same external workload. For these reasons, the observed levels of %HRR need to be considered detrimental to the cardiovascular health in this occupational group.

Starting from the beginning of the work shift on a workday, there is an increase in average HR and %HRR as one moves to a later time period (Fig. 1). There is a disruption in this trend during the lunch break period with complete recovery to first hour of work levels but followed by an even higher increase during post-lunch interim. While an increase from lunch to the post-lunch interim was also observed during off-workdays, it was about 10% units less and may reflect EE for digestion and home kitchen work (Fig. 2a and b). The extensive rise above prior lunch values during work and higher levels during the afternoon compared with the morning hours indicate that the lunch period did not provide adequate recovery time, despite the fact that workers did return to first-hour (but not pre-shift) values at the end of their lunch break. This increase in cardiovascular load during and after the work shift despite the fact that hotel room cleaners perform mostly the same tasks throughout their work shift is an indicator of insufficient recovery time between demanding job tasks and could be contributing to subjects being seen near or above the recommended 8-h maximum of 30% HRR. These elevations in cardiovascular load may in part be due to a concurrent increase in the afternoon pace of work to meet daily productivity requirements. Although hotel room cleaners are paid by the hour, they are expected to clean a certain number of rooms per shift. In previous surveys of Las Vegas hotel room cleaners, 88% reported to "have constant time pressure due to a heavy workload" and 66% of hotel room cleaners reported that they skipped or shortened their breaks or worked longer hours to complete their assigned rooms during their last work week (Krause et al., 2005). As the day progresses, there may be pressure to work harder to deal with excessive room quota or unforeseen delays in cleaning very dirty, VIP or check out rooms that require extra attention. Following the Las Vegas study, hotel room cleaners successfully negotiated labor contracts that reduced the overall number of rooms to clean per shift by 7% and provided additional room credits for extra demanding rooms such as check-out rooms (Lee and Krause, 2002). Some Las Vegas hotel managers also reported that they started requiring room cleaners to leave hotel room floors midday to take their lunch break. A combination of such measures could help prevent the post lunch spike and afternoon elevations in cardiovascular demands.

Although most variables experienced their largest increase during the post-lunch interim period, SBP and DBP showed their largest rise between the last hour of work and the after-work time period (8.3 and 6.0 mmHg, respectively). This could be attributed to commuting and the various tasks that hotel room cleaners, who are majority female and shoulder many domestic responsibilities such as picking up children from school, shopping, cooking and cleaning. All of these activities had been noted in the daily diaries of several study subjects, with most of them occurring after work and aligning with the rise in SBP observed. A few subjects also noted exercise following their work shift, but the lack of any accompanying rise in average HR makes exercise an unlikely explanation behind the overall observed rise in BP.

4.2. Comparison of workdays with off-workdays

HR and %HRR showed higher peak values before the work shift during workdays. This could be attributed to the stress of and need to rush to work, especially in our subject population of women who often bear the burden of domestic duties such as preparing breakfast, transporting children to school, and household chores (Bratberg et al., 2002; Cerrato and Cifre, 2018). As expected, average and peak HR, %HRR, MET, and EE were all higher during workdays compared to off-workdays, for the first work hour, entire work shift, and last work hour. Average DBP was also higher for the entire work shift and the last hour of work. Many studies evaluating physiological workload and strain only report daily average values precluding direct comparisons with our more detailed task assessments. Many cleaning tasks require full body posture changes, repetitive upper extremity movements, and tool handling requiring simultaneous agonist and antagonist muscle activities. Performing the same external workload with smaller upper extremity muscles requires 30% more energy expenditure compared to using larger lower extremity muscles (Astrand and Saltin, 1961). Having comparable time periods during off-workdays available was helpful in the identification of inadequacies of break and recovery times during workdays. Although all but one study participant did not perform any other paid work, hotel room cleaners often report having to hold additional jobs in order to earn an adequate income (KNOX, 2011; Appelbaum et al., 2006), and we excluded two volunteers during recruitment screening who worked another job on their off-workdays. Such additional jobs further reduce recovery time and constitute additional cardiovascular loads that need to be considered when assessing CVD risks for this worker population.

4.3. Job task-specific analyses

Our observations showed that participants followed a standard order of accomplishing their tasks with no break time in between them except occasional one to 2-min standing breaks during ambulatory BP measurement (room cleaners are not allowed to sit down on guest room furniture or toilets). Bed-making required highest average and peak energy expenditures and accounted for 24.2% of cleaning work. This prolonged high exposure makes bed-making a prime target for administrative and ergonomic interventions. Using a mattress lift tool in conjunction with fitted sheets achieved a reduction in the number of lifts and physical exertion involved in bed-making (Harris-Adamson et al., 2019). Efforts to reduce cardiovascular load should consider these tools and a reduction of work quota that consider not only number but also type of rooms and number and type of beds.

Typically, the wiping and dusting task was performed just after the bedmaking task which may have contributed to the high average %HRR. Additionally, the high demand on the upper extremities, which greatly contribute to rises in EE as well as oxygen utilization, and pace of work may contribute to the high average %HRR during this task (Astrand and Saltin, 1961). Given that a fourth of participants exceeded the 30% HRR 8-h threshold, strategies to reduce the physical workload during bed making and wiping/dusting or provision of more work and recovery time for these tasks may help prevent workers from overloading their cardiovascular system.

Since the %HRR was lower overall during the entire shift compared to task specific values, less strenuous activities such as supply gathering, walking to different rooms, or taking the elevator to different floors may be assisting with recovery. However, recovery between rooms can easily be diminished if the tasks between rooms are strenuous themselves. For example, the type of floor and cart pushed between rooms co-determine workloads during those activities. A motorized cart, would reduce workloads more than a mechanical cart that is heavy, has small or unmaintained wheels, or is pushed on plush carpet (Intilli, 1999). Thus, this recovery time is one to be safeguarded or improved (e.g., by provision of motorized carts or carts retrofitted with bigger wheels and better grip design; or by reintroduction of the job of "houseman" supporting cleaners with delivery and disposal of cribs, linen, trash and other heavy materials; or by providing benches near linen rooms and service elevators to allow rest from mostly standing and walking during cleaning.

4.4. Comparison of general health status, CVD risk factors, and disease risks with other populations

General health of study participants was much better compared to previous epidemiological hotel worker studies (29% vs 60% reported poor health) (Krause et al., 2010). Yet, Chronic CVD with activity-related symptoms such as chest pain or shortness of breath take decades to develop, and women develop CVD about a decade later than men and mostly after menopause (Lerner and Kannel, 1986); women in our study were relatively young between 24 and 55 years old. Exposure to other CVD risk factors was low, no participant ever smoked, few were exposed to second-hand smoke (13%), consumed any alcohol (20%), were obese (27%) or physically inactive during leisure (20%). Average seniority on the job was 10 years indicating that our study population comprised a relatively healthy survivor population. All participants came from unionized hotels that typically have lower room cleaning quotas, higher salary, and better benefits (including a comprehensive health care plan) compared to non-unionized hotels. Nevertheless, 93% stated their job required them to work very fast and 60% reported not having enough time to complete their job similar to earlier studies of unionized hotel workers. This combination of high physical job demands with high levels of time pressure and other psychosocial job stressors has been associated with smoking intensity (Rugulies et al., 2008), poor general health (Krause et al., 2010), hypertension (Feaster et al., 2019), severe bodily pain (Krause et al., 2005), work-related musculoskeletal disorders (da Costa and Vieira, 2010), associated work disability (Krause et al., 2001) and an 34% increase in coronary heart disease (CHD) risk (Kivimäki et al., 2012; Kivimäki and Kawachi, 2015).

Room cleaners did not sit at all during cleaning, they are not allowed to sit on guestroom furniture or toilets. Although not separately assessed in this study, the mostly upright work posture during cleaning work may contribute to cardiovascular loads because of the extra cardiovascular work needed to pump venous blood against increased gravitational forces and hydrostatic pressures back to the lungs. Prolonged standing can cause pain in lower back (Coenen et al., 2018b), hip (Pope et al., 2003), and lower extremities (Reid et al., 2010), and pain triggers the sympathetic nervous system leading to elevations in HR and BP (Rathmell et al., 2018). Prolonged standing has also been associated with CVD, including varicose veins and their complications and risk for hospitalizations (Tüchsen et al., 2005; Tabatabaeifar et al., 2015), progression of atherosclerosis (Krause et al., 2000), and incidence of CHD (Smith et al., 2018), transitory ischemic attack and stroke (Hall et al., 2019). Upright work postures, high intensity of physical work, and psychosocial job stressors as well as severe pain share a common biological pathway to cardiovascular load and disease: increases in HR and/or BP that are known strong independent predictors of CVD. The simultaneous exposure of cleaners to those occupational hazards will substantially increase their CVD risk but also indicates a substantial potential for primary prevention of CVD in this high-risk population through ergonomic and organizational interventions at work.

4.5. Significance of findings for primary prevention of CVD

In summary, hotel room cleaners have work demands that increase cardiovascular load and place them at increased risk for CVD. Physical job demands should be reduced in order to decrease cardiovascular load for these workers. This is even more imperative when considering the additional risk factors that have been documented in previous studies of hotel room cleaners, including: advanced age, overweight, underdiagnosed, undertreated, and non-controlled hypertension (Krause and Arias, 2015) and high prevalence of psychosocial job stressors such as job strain and effort-reward-imbalance (Rugulies et al., 2008; Krause et al., 2010; Effort-reward Imbalance and One, 2020). Psychosocial job stressors have been shown to interact with high intensity occupational physical workload in a synergistic super-additive manner (Ferrario et al., 2019). Hotel workers who are simultaneously exposed to both types of risk factors may also be at a super-additional increased risk for CVD.

Theoretically, workload strain could be alleviated by either increasing workers' capacities or decreasing job demands. A randomized controlled trial with Danish cleaners evaluated the effects of a high intensity aerobic exercise program during paid work time on aerobic capacity, BP, and other CVD risk factors and showed small increases in cardiovascular fitness. However, the intervention was not recommended as a safe strategy as it also caused substantial SBP increases, especially among those with low cardiorespiratory fitness (Korshøj et al., 2015a). Even a small change of 1 mmHg SBP has been associated with heart failure events of 20.3 and 13.3 per 100,000 person-years in African Americans and whites, respectively (Hardy et al., 2015). Physical exercise of high intensity (above 60–70%HRR) is needed to increase cardiorespiratory fitness but may not be suitable for vulnerable populations that already have to cope with exhaustion due to rather high physical workloads. The majority of hotel room cleaners works very close to or over the recommended maximum RAW. It is therefore imperative to prioritize workplace interventions that reduce cardiovascular loads. The only responsible safe way to achieve that goal is to reduce the physical and psychosocial job demands by providing better tools and more time to clean rooms, or more time throughout the work shift to recover from the high demands of existing workloads.

Specifically, ergonomic interventions with the potential to reduce cardiovascular loads may include the following: (1) Fitted sheets, wedge handles to reduce heavy mattress lifting (Harris-Adamson et al., 2019) or no longer require sheets and duvets to be tucked under the mattresses; (2) Motorized carts or carts with bigger wheels that are easier to push on carpeted surfaces (Intilli, 1999) and with better vertical grips accommodating different body heights (3) More ergonomic cleaning tools (i.e. adjustable handles); to reduce awkward posturing and force required when cleaning (Kumar and Kumar, 2008); (4) Reduction of room quota and number of beds to clean and extra credits for check-out, VIP, or very dirty rooms as negotiated in labor contracts in San Francisco and Las Vegas (Lee and Krause, 2002); (5) Sufficient rest breaks and seats to rest or allow room cleaners to sit down on guestroom furniture to reduce physical exertion and to allow for HR and BP to drop to resting levels.

4.6. Study strengths and limitations

The entire study sample was comprised of females from ethnic minorities, a typical gender and ethnicity distribution in the hotel industry (Krause et al., 2005). However, our sample likely over-represents healthy workers because we excluded new workers, workers above age 65, and those with certain cardio-metabolic health conditions or work-related injury or illness. New employees not able to endure high workloads and speeds, older workers with lower cardiorespiratory fitness, or workers with chronic health conditions or experiencing acute illnesses or work injuries may leave this physically demanding job or not enter it in the first place. The surviving healthy workers being studied tend to bias study results towards zero health effects (Eisen and Robins, 2006). The exclusion of subjects who had additional jobs also may have led to an underestimation of cardiovascular load. Given that low wage workers may have multiple jobs, future studies should include or even oversample workers holding several jobs for a more comprehensive evaluation of workload strain among cleaners. The 30% HRR threshold applies to an 8-h shift but is lower for individuals with longer work hours or additional jobs (Wu and Wang, 2002).

Our estimation of aerobic capacity ($\%VO_{2max}$) as %HRR used age-based maximum heart estimates and ambulatory HR monitoring instead of oxygen consumption during exercise tests and actual work. Wearing a mask, tank, and measurement devices during dynamic cleaning work would have been impractical. However, using %HRR as a proxy for $\%VO_{2max}$ produces comparable results given the direct proportionality with percent oxygen reserve that provide a more accurate and only slightly lower estimate of maximal aerobic work capacity compared to VO_2max (Wu and Wang, 2002).

The use of objective measures of energy expenditure, RAW as %HRR, and cardiac work load as RPP instead of self-reported measures of workload or exertion is a major strength of this study although self-reported workload measures are also valid instruments and perceived exertion as measured by the Borg 20 scale correlates strongly with HR during work (STAMFORD, 1976). To our knowledge, this is the first in-depth evaluation of cardiovascular load among hotel room cleaners both during and after work including resting periods outside of the work shift during workdays as well as off-workdays. This enabled us to assess spill-over effects from work into rest and the adequacy of recovery periods. Further, task-specific analyses identified high risk tasks such as bed-making as promising targets for ergonomic interventions.

In contrast to %HRR, the assessment of METs with the Actiheart device may have produced some conservative bias in our workload assessments. While the Actiheart software algorithm utilizing both accelerometer and HR data to estimate EE as METs has shown overall good agreement with directly measured average oxygen consumption for 18 different leisure and household activities, those algorithms have not been validated for any higher intensity occupational physical activities and they have been shown to substantially underestimate common cleaning activities such as sweeping/moping and vacuuming by 16% and 42%, respectively, while algorithms based on HR produced less biased EE estimates for these activities (Crouter et al., 2008).

Comprehensive accurate assessments of occupational cardiovascular loads should in general not rely on absolute EE measures such as METs but include relative measures such as %VO2max or % HRR that take objectively measured individual cardiorespiratory fitness into account as well as unmeasured effects of typically co-occurring factors such as mental or thermal stressors. In addition, a comprehensive exposure assessment needs to combine emerging wearable sensor technologies with traditional observer-based ergonomic methods, detailed interviews, and administrative or production data to assess effective external loads (such as lifting, carrying, and manual handling of objects and tools as well as environmental heat or noise). Constructing complete job histories with relevant job exposure matrixes that include cumulative repeat exposures assessments are needed to accurately determine the risk of chronic CVD and mortality in epidemiological studies that can also assess and adjust for other behavioral and environmental cardiovascular risk factors.

5. Conclusions

The continuous combined measurements of HR, BP and MET of hotel room cleaners during and off-work showed that hotel room cleaners consistently perform moderately heavy work and often exceed maximum workload levels as recommended by WHO-ILO based on work physiology, especially while making beds. Some workers experienced a substantial increase in HR and DBP over the course of their workday indicating physiologic fatigue. They may be at increased risk for CVD and premature death due to excessive physical work demands.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apergo.2022.103886.

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