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Cardiovascular and Psychophysical Response to Repetitive Lifting Tasks in Women

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Background: Understanding the cardiovascular and psychophysical demands of repetitive lifting tasks is important in job design strategies. This study determined the cardiovascular (oxygen consumption (VO_2) and heart rate (HR) and psychophysical response to repetitive lifting tasks in women.

Methods: Ten female (age 27 ± 5 yrs) participants transferred 11.4, 15.9, and 20.5 kg weights back and forth from a rung 40.6 cm high to a rung 156.2 cm high. Rungs were 195.6 cm apart horizontally. Three, 10 minute bouts (1 = 11.4 kg; 2 = 15.9 kg; 3 = 20.5 kg) were performed at 6 lifts per minute. Cardiovascular and psychophysical (rating of perceived exertion, RPE) parameters were monitored throughout the bouts. VO_2max and HRmax were determined via a maximal treadmill test.

Results: VO_2, HR, and RPE were significantly different between each work bout ($p < 0.01$), with each outcome variable increasing as load increased. VO_2max and HRmax equaled 46.5 ± 7.5 mL · kg^{-1} · min^{-1} and 191 ± 11 bpm, respectively. Work at 11.4 kg was performed at 38% VO_2max and 63% HRmax; at 15.9 kg at 41% VO_2max and 72% HRmax; and at 20.5 kg at 49% VO_2max and 81% HRmax. RPE at 11.4, 15.9, and 20.5 kgs were: 8.4 ± 1.6, 11.4 ± 1.9, and 15.0 ± 2.2.

Conclusion: During these repetitive lifting tasks, metabolic cost and perceived exertion increased with weight lifted; average work intensity ranged from 63 to 81% of HRmax and 38 to 49% of VO_2max. Results have important implications in relation to job pacing and design, and worksite health promotion strategies aimed at reducing work place injury.

Key Words: Work, Manual lifting, Musculoskeletal disorders

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INTRODUCTION

Despite increasing technology related to work efficiency, lifting tasks involving manual material handling are still common. Occupations such as construction, agriculture, military, fire, etc., often require manual lifting tasks [1-6]. Related musculoskeletal disorders (MSDs) are a significant problem [7-9]. Causes of MSDs are multifactorial [8]; however one factor is the link between physiological and psychological fatigue and injury [10-12].

The aging workforce magnifies the MSD problem [13,14], especially with trends of increased obesity and declining fitness with age, and their association with chronic disease [15,16]. These trends, combined with the impact of sarcopenia [15] highlight the importance of understanding the implications of declining physiological capabilities on work-related lifting tasks [17,18].

Women represent a high proportion (~54%) of the work force. In 2012 it was estimated that 71 percent of women aged 55 and older were working full-time, including jobs with many routine lifting tasks [14,19]. Typically, women have lower peak absolute cardiovascular and muscular performance levels compared to men [20]. Women also have a greater probability of developing a MSD than men [21]. There is a lack of data related to quantifying the cardiovascular and psychophysical stress involved in work related lifting tasks in women, especially in relation to maximal cardiovascular function as measured by the gold-standard maximal oxygen consumption (VO_2max) treadmill test.

The purpose of this study was to determine the cardiovascular and psychophysical responses to repetitive lifting tasks in women, and compare the relative metabolic stress of these lifting tasks to maximal oxygen consumption (VO_2max) and heart rate (HRmax).

MATERIALS AND METHODS

1. Participants

Ten healthy women volunteered (27 ± 5 yrs; 168.7 ± 6.9 cm; 68.2 ± 15.9 kg). Participants performed manual labor jobs in the past year and were experienced recreational weightlifters. This study was approved by the University's Institutional Review Board and participants signed an informed consent.

2. Procedures

After five minutes of seated rest, three randomly ordered repetitive lifting tasks took place using two 11.4 kg, 15.9 kg and 20.5 kg weight plates. Using two hands, participants transferred the individual weight plates back and forth between two racks. Racks were separated horizontally by 195.6 cm and vertically by 115.6 cm, setting the height of the weight at 40.6 cm on rack 1 (i.e., ~knee high) and 156.2 cm on rack 2 (i.e., ~shoulder high).

Starting at rack 1, the participant grasped the weight plate, transferring it to rack 2, sliding it onto the rack and releasing grip; then moving back to rack 1, they grasped the second plate and transferred it onto rack 2 with the other plate; next, they again grasped the weight plate, transferring it back to rack 1, then moving back to rack 2 to transfer the second weight plate to rack 1. The task required six weight transfers each minute for 10 minutes. Total weight transferred during the tasks using 11.4 kg plates = 684.0 kg, using 15.9 kg plates = 954.0 kg, and using 20.5 kg plates = 1230.0 kg.

Pace was monitored by a metronome. Lifting technique was self-selected. Coupling classification remained the same throughout the lift. One-minute rest was allowed between bouts. Temperature was ~20°C.

As described in Sevene et al., this lifting task was designed to mimic a manufacturing production line task [22]. While recognizing that anatomical (e.g., height, limb length) and physiological (e.g., fitness) differences may alter stress of a given lifting task, workers often encounter tasks unrelated to their size, gender or physiological readiness [23-25].

Cardiovascular parameters (O_2 consumption [VO_2 $mL \cdot kg^{-1} \cdot min^{-1}$], RER (respiratory exchange ratio), caloric cost [$kcal \cdot min^{-1}$], heart rate [HR]) were measured during the work bouts using a metabolic cart (Parvomedics, Salt Lake City, Utah, USA), and a heart rate monitor (Polar, Bethpage, New York, USA) [26]. Rating of perceived exertion (RPE) was assessed immediately at the end of each 10 minute work bout using the Borg 6-20 scale [27]. Standardized instructions for using the RPE scale were given [20].

Within one week of their lifting tests, VO_2max and HRmax were determined via a maximal treadmill running test. Standard procedures were used [20]. Testing was performed at the same time of day in both tests. Body composition was determined via skinfold testing using standard procedures [20] and Lange calipers (Beta Technology, Santa Cruz, CA, USA).

3. Statistical analysis

Steady state data from minute 3 to 10 of each lifting task was used for analysis (ANOVA with Tukey's post hoc).

Likewise, RPE was also compared between the three repetitive lifting task conditions. Alpha level was set at $p < 0.05$.

RESULTS

Participant descriptive information is provided in Table 1. Results showed that most variables (VO_2, HR, RER, HR) were significantly different between each work bout ($p = 0.000$) except RPE ($p < 0.01$), with each increasing with the higher weight load (Table 2).

DISCUSSION

This study determined the cardiovascular and psychophysical response to repetitive lifting tasks in women, and compared the relative metabolic stress of these lifting tasks to maximal cardiovascular fitness. Treadmill VO_2max equaled 46.5 ± 7.5 mL · kg^{-1} · min^{-1}; HRmax equaled 191 ± 11 bpm. The work bout with 11.4 kg averaged 38% of VO_2max and 63% of HRmax; 15.9 kg elicited 41% of VO_2max and 72% of HRmax; at 20.5 kg, the relative cost was 49% of VO_2max and 81% of HRmax. Increased oxygen cost and HR may be attributed to the increased recruitment of motor units to transfer the heavier loads [28], and the linear relationship of HR to intensity of work [20]. Taking all three bouts into consideration, average intensity for the 30 minutes was 43% of VO_2max and 72% of HRmax (i.e., 19.8 mL · kg^{-1} · min^{-1} and 138 bpm).

Related research is limited, but in a similar study in males, Sevene et al. assessed the metabolic cost of these same weight transfers [22]. Average VO_2 and HR were 15.0 mL · kg^{-1} · min^{-1} and 109 bpm. These lower values are not surprising as participants were taller and heavier than the current women and were also experienced recreational weightlifters and laborers with high strength and fitness levels. Therefore, one can hypothesize that these tasks represented a lower relative stress to these men. Unfortunately, VO_2 max was not assessed. Interestingly, when these men self-selected pace to complete the same amount of work, they completed the tasks in an average of 7 minutes and increased work intensity to an average VO_2 of 19.6 mL · kg^{-1} · min^{-1} and HR of 123 bpm, very similar to the current study. While not task or load specific, additional work by our research group assessing the metabolic cost of repetitive lifting tasks in men and women found an average VO_2 and HR of 14.4 mL · kg^{-1} · min^{-1} and 103 bpm respectively while performing two 12.5 kg one- and two-handed lifting tasks [29-31].

Participant's treadmill VO_2max values averaged 46.5 mL · kg^{-1} · min^{-1} which equates to the 80th percentile in women aged 20-29 yrs and is classified as excellent [20]. In comparison, the 50th percentile average maximal O_2 consumption for women aged 20-29 yrs is 37.6 mL · kg^{-1} · min^{-1} [20]; in order to make this work bout intensity more representative of the normal population, if one substitutes this normative 50th percentile value in place of the actual VO_2 max

Table 1. Participant descriptive information (mean ± SD)

Age (yrs)	Height (cm)	Mass (kg)	%Body Fat	VO_2max mL · kg^{-1} · min^{-1}	HRmax (BPM)
27 ± 5	168.7 ± 6.9	68.2 ± 15.9	22.3 ± 6.9	46.5 ± 7.5	191 ± 11

VO_2max: maximal oxygen consumption, HR: heart rate.

Table 2. Metabolic and psychophysical response to lifting tasks (mean ± SD)*

Kg	VO_2 l · min^{-1}	VO_2 mL · kg^{-1} · min^{-1}	RER	HR bpm	RPE
11.4	1.2 ± 0.2	17.6 ± 2.3	0.86 ± 0.06	121 ± 22	8.4 ± 1.6
15.9	1.3 ± 0.2	19.1 ± 2.8	0.92 ± 0.05	137 ± 26	11.4 ± 1.9
20.5	1.6 ± 0.3	22.8 ± 2.8	0.95 ± 0.06	155 ± 19	15.0 ± 2.2

*All variables significantly different between each work bout ($p = 0.000$); RPE ($p < 0.01$).
VO_2: oxygen consumption, RER: respiratory exchange ratio, HR: heart rate, RPE: rating of perceived exertion.

value, participant's work intensity would equate to 47% of VO_2max at 11.4 kg, 51% of VO_2max at 15.9 kg, and 61% VO_2max at 20.5 kg. In relation to the aging workforce, and to elucidate further, the 50th percentile average maximal O_2 consumption for women age 40-49 yrs = 26.7 $mL \cdot kg^{-1} \cdot min^{-1}$ [20], raising the work intensity to 66% of VO_2max at 11.4 kg, 72% of VO_2max at 15.9 kg, and 85% VO_2max at 20.5 kg.

A potential limitation is the non-specific VO_2max treadmill running test, as this type of test results in a higher VO_2max than the typical VO_2peak achieved during a specific repetitive lifting task [24,25,32]. For example, women in a study by Nindl et al. demonstrated a VO_2peak during a repetitive lifting task that was ~16% lower than that exhibited during a treadmill running test [24]. Another potential limitation was the lack of control over the participants lifting technique, physical differences, or overall lifting efficiency which would impact oxygen cost during a given lifting task [25]. However, for sake of discussion (and for convenience as normative VO_2peak data does not exist for specific lifting tasks), one could lower the VO_2max values in the above discussion by ~15%, increasing the relative intensity of the lifting tasks. This further highlights the impact of the physiological decline of a sedentary and overweight population (i.e., only 51.6% of U.S. adults meet aerobic activity guidelines and approximately two-thirds of the U.S. adult population are classified as overweight or obese [20]), and the aging of the workforce [13,14], and has important relative implications to those performing manual material handling.

Treadmill based HRmax of 191 ± 11 bpm was close to the age-predicted estimated HRmax of 193 bpm (i.e., 220-age; SEE = 11 bpm) [20]. The HRs measured during the work bouts are impacted by the emphasis on lower or upper body lifting and the isometric nature (e.g., gripping, holding in place) of this weight transfer; this highlights the impact of muscle contraction and stress on HR and the danger of solely using HR to classify intensity of lifting tasks (i.e., these relative intensities would elicit much lower HRs if they only included aerobic activity, and estimating HRmax from an age-based formula has a large SEE) [20], making relative intensity determinations difficult. Sarcopenia also impacts the amount and quality of the musculature used during, and the relative intensity of, any lift transfer situation [15,16,20].

The revised NIOSH Lifting equation uses metabolic cost as a measure of physiological work stress [33,34], which is typically assessed as a function of metabolic response to a given work task focusing on variables such as oxygen consumption, caloric cost, and heart rate [20]. Caloric cost (kcal.min-1) is determined from oxygen (O_2) use during an activity using the mathematical relationship where kcal · min-1 equals liters (L) of O_2 use per minute multiplied by 5 kcal ($kcal \cdot min^{-1}$ = Liters O_2 · min-1 × 5 kcal) [20]. To limit the metabolic stress and fatigue resulting from a given work task, NIOSH has set task-specific kcal.min-1 limits (e.g. 33-50% of maximum) for lifting tasks of various durations (e.g., 0-8 hrs) [33]. During these work bouts, energy cost ranged from 6 to 8 $kcal \cdot min^{-1}$ (1.2 to 1.6 L/min) with fuel type as assessed by respiratory exchange ratio (RER) progressing from mixed fuel (i.e., fat and carbohydrate) to higher intensity and greater use of carbohydrate as fuel (i.e., RER ranged from 0.86 to 0.95). This $kcal \cdot min^{-1}$ intensity represented an average of 38-50% (6 $kcal \cdot min^{-1}$ / 15.9 $kcal \cdot min^{-1}$ = 38%; 8 $kcal \cdot min^{-1}$ / 15.9 $kcal \cdot min^{-1}$ = 50%) of the average maximal kcal.min-1 value (i.e. 46.5 $mL \cdot kg^{-1} \cdot min^{-1}$ × 68.2 kg / 1000 $mL \cdot L^{-1}$ = 3.17 $L \cdot min^{-1}$ × 5 $kcal \cdot min^{-1}$ = 15.9 $kcal \cdot min^{-1}$ at VO_2max). In relation to caloric cost over time, consider the difference between 6 and 8 $kcal \cdot min^{-1}$; e.g., in a 420 minute work day that equates to 840 kcals (120 kcals per 60 minutes), or a significant difference in terms of fatigue, pacing strategies, energy balance, and nutritional needs.

Regarding the percent of maximal strength these tasks required, lack of task specificity makes the comparisons more difficult. But, if one uses the bench press ratio (i.e., weight pushed relative to bodyweight) as a benchmark [20], the 50th percentile for 20-29 yr old women = 0.65; participants in this study self-reported free weight 1RM bench press ratio values between 0.77 and 1.01 (approximately 75-95 percentile of normative data) [20]. In relation to the aging workforce, and to further add perspective, the 50th percentile for the bench press ratio for women age 40-49 yrs is 0.52 [20], again highlighting the impact of one's age combined with the very low participation in resistance training on strength declines with aging (i.e., only 29.3% of U.S.

adults meet resistance training guidelines [20]). We recognize the limitation in comparing free weight lifting strength data to normative strength data that is largely based on dynamic variable resistance machines; but, this again highlights that participants in this study represent fit workers, and based on normative data one may assume the normal worker would possess lower relative strength values, raising the relative stress of any given lifting task.

Recognizing that these comparisons to cardiorespiratory and muscular fitness norms are not task specific, they still shed light on the overall intensity of the present lifting tasks; and, supports that these tasks were of moderate intensity in terms of cardiovascular and muscular physiological stress in these fit, young women. Also, in relation to %BF, these women were considered "healthy" (22% BF; Body Mass Index – BMI = 23.8 kg/m^2). As stated above, to maintain perspective of this study population to the general population, one must consider the intensity of this type of "fixed" task relative to an aging work force with declining physiological abilities; and relative to the sedentary nature (i.e., only 20.6% of U.S. adults meet both the aerobic and resistance training guidelines for public health [20]) of our largely overweight (BMI > 25.0 kg/m^2) U.S. population [20]. As previously stated, as physiological capabilities decline, a given submaximal task becomes a greater percentage of maximum capacity, therefore leading to increased fatigue and susceptibility to injury; highlighting the need for worksite health promotion programs that include comprehensive (and task specific) exercise prescriptions [35].

Regarding psychophysical stress, the RPE during the work bouts increased with weight moved, and averaged 8.4 at 11.4 kg, 11.4 at 15.9 kg, and 15.0 at 20.5 kg (i.e., between extremely/very light and hard/heavy) on a category scale of 6-20. Taking all three work bouts into consideration, average RPE for the 30 minutes was 11.6 (i.e., light). The use of RPE to monitor intensity of work-related lifting tasks is a valid, reliable, and easy tool to utilize in the workplace [12,20].

Limitations of this study include the lack of biomechanical analysis [36] and the inability to assess the individual's skill at the given task; and we recognize that work-related musculoskeletal stress would act as a training stimulus over time, resulting in positive adaptation; these factors would alter risk of developing an MSD in any given lift transfer task. Also, having an objective measure of total body strength would enhance one's ability to make generalizations.

CONCLUSION

When performing repetitive lifting tasks, metabolic cost and perceived exertion increased with weight lifted. These results have importance in relation to job pacing and design, and worksite health promotion strategies aimed at increasing production and reducing injury; especially when one considers the aging work force and the physiological decline related to aging, a sedentary lifestyle, and increased obesity.

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