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Metabolic and Psychophysical Comparison of a One-Handed Lifting Task with Different Coupling Factors

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***Abstract*-** In lifting tasks involving manual material handling the coupling component relates to the quality of the hand-to-object interface (grip). Good coupling is theorized to reduce lifting and grip stress, whereas poor coupling is theorized to increase lifting and grip stress. Choosing to lift with one hand is a decision often made by the worker. Understanding the metabolic demand of one-handed lifting tasks is important in job design strategies related to productivity and injury prevention. This study compared the metabolic cost and perceived exertion between a one-handed lifting task performed with identical weight but different coupling and container factors. Twenty volunteers participated (13 M, 7 F; mean 26 ± 6 yr; 178 ± 8 cm; 74 ± 11 kg; grip strength, R = 45 ± 13 kg, L = 43 ± 14 kg. Participants transferred either a 12.5 kg milk crate or 12.5 kg bag of dog food individually back and forth from the floor to a table by gripping with their dominant hand. Participants performed two, 5 minute work bouts with either the milk crate or dog food bag in random order. Three minutes of rest were allowed between the bouts. Pace was constant at 8 lifts per minute. Metabolic and psychophysical parameters were monitored throughout the work bouts. Steady state data from minutes 2 – 5 was used for analysis with paired T-Test. Results: mc = milk crate; df = dog food; oxygen cost ($ml \cdot kg^{-1} \cdot min^{-1}$): mc = 15.0 ± 3.1, df = 13.1 ± 1.9; $l \cdot min^{-1}$: mc = 1.1 ± 0.2, df = 1.0 ± 0.2; $kcal \cdot min^{-1}$: mc = 5.3 ± 1.2, df = 5.1 ± 1.1; RER: mc = 0.9 ± 0.0, df = 0.9 ± 0.1; HR (bpm): mc = 104.1 ± 10.3, df = 100.3 ± 9.9; RPE: mc = 9.7 ± 2.0, df = 9.3 ± 1.7. Significant difference ($p<0.05$) occurred in oxygen cost ($ml \cdot kg^{-1} \cdot min^{-1}$) and heart rate (bpm) between the two conditions. No difference was observed in rating of perceived exertion (RPE). In conclusion, a significantly higher oxygen cost and heart rate were observed when participants performed a paced, 12.5 kg one-handed lifting task with good coupling factors (milk crate), than when lifting a 12.5 kg dog food bag with poor coupling factors. When lifting stress is measured by relative oxygen consumption and heart rate, these results are in contrast to expectations that poor coupling factors would increase stress of a lifting task.

***Keywords*-** *NIOSH Lifting Equation; Grip; Work Tasks*

I. INTRODUCTION

Manual material handling at work and at home is related to a significant number of injuries and musculoskeletal disorders (MSDs) with substantial social and economic costs [1-3]. One-handed lifting is a consistent part of many of these tasks that lead to MSDs [4-7]. In fact, often multiple lifting strategies (e.g., one- and two-handed strategies) and postures are employed over the course of the work and home-based day [3-8]. This helps to ease boredom, reduce fatigue, and meet the environmental demands (e.g., space constraints, one's reach, etc.) of the task [3, 7-9]. Basic research that isolates and assesses strategies employed during diverse lifting tasks in various environments is important for better understanding of factors that impact MSDs.

During one-handed lifting tasks, coupling (grip) factors are potentially more important than during two-handed lifting tasks due to the single human-object interface [9-11]. Coupling relates to the quality of this grip (or the interface between the hand and the object being lifted). Coupling can impact the forces necessary to grip and move and object, the location of the hand during a lift, and the stress on the wrist [12-14]. Per the Revised NIOSH (National Institute for Occupational Safety and Health) Lifting Equation [14], coupling can be rated good (e.g., an optimally designed container with handles or hand-hold cutouts of optimal design), fair (e.g., an optimally designed container with handles or hand-hold cutouts of less than optimal design), or poor (e.g., a bulky container of less than optimal design or a non-rigid bag that sags in the middle with no handles or hand-hold cutouts). Scenarios with good coupling are thought to reduce grip and lifting stress, whereas poor coupling is thought to increase grip and lifting stress [14]. However, the lifting equation is only applicable to two-handed lifting tasks.

Recognizing that MSDs occur in a complex system with many factors [15-22], understanding the metabolic and psychophysical demands of one-handed lifting tasks is important in job design strategies related to productivity and injury prevention. However, only a few scientific studies have looked at work stress related to one-handed lifting tasks, and these have focused on biomechanical (e.g., low back stress) factors [7, 23-26]. To our knowledge, no studies have assessed the physiological and psychophysical stress of one-handed lifting tasks performed with identical weight but different coupling factors. Therefore, the purpose of this study was to compare the metabolic cost and psychophysical work stress between a one-handed lifting task with identical weight but different coupling and container factors.

II. METHODS

A. Experimental Design

In order to answer the research question of whether metabolic and psychophysical work stress changed when performing a one-handed lifting task with identical weight but different coupling and container factors, 20 volunteers were recruited to complete two lifting tasks. In this repeated measures comparative study design, one lifting task used a 12.5 kg milk crate with good coupling (i.e., grip) for each hand, whereas the other lifting task used a 12.5 kg bag of dry dog food with poor coupling factors. All other aspects of the lifting tasks were identical. Order of task performance was random.

Physiological work stress was assessed as a function of metabolic response to the work tasks focusing on variables such as oxygen consumption, caloric cost, and heart rate [27, 28]. Energy expenditure or caloric cost (kcal/min) was determined from oxygen (O_2) use during the activity using the basic mathematical relationship where kcal/min equals liters (L) of O_2 use per minute multiplied by 5 kcal (kcal/min = LO_2/min x 5 kcal) [27]. Psychophysical work stress was assessed using the rating of perceived exertion (RPE) scale devised by Borg [28]. This is an accepted and valid subjective method of assessing perceived stress of an activity and takes into account a combination of factors such as perceived fitness, effort and fatigue levels, and environmental conditions [27].

B. Subjects

Twenty healthy participants (13 male, 7 female) volunteered to participate in this study. This geographic area has a heavy industrial sector that requires material and package manual handling, and the majority of these participants had performed manual labor for employment in the past year. Mean $\pm$ SD of age, height, and body mass were: age = 26 $\pm$ 6 yrs, mass = 74 $\pm$ 11 kg, ht = 178 $\pm$ 8 cm, respectively. This study was approved by the University's Institutional Review Board for protection of humans prior to data collection and all participants signed an informed consent document to participate.

C. Experimental Apparatus

The objects used during the experiment for the lifting task were a milk crate with good coupling and a bag of dry dog food with poor coupling.

The milk crate dimensions and hand-hold cut-out design were identical for each hand and optimal per the guidelines set forth in the Applications Manual [14]: side width = 33 x 33 cm; height = 28.6 cm; with semi-oval, smooth, non-slick hand cutouts centered in width, 11.4 cm in length; and 4.5 cm in height, the top of the cutouts was 25.4 cm from the bottom of the crate, and the container was 0.6 cm thick. The crate was loaded with a stable fixed weight equaling 12.5 kg (crate plus weight load). Coupling classification did not change for any condition throughout the range of the lift (raising or lowering).

The dog food bag consisted of 12.5 kg of dry dog food (bag plus dog food). The dimensions of the dog food bag were somewhat bulky; width = 38 cm x ~ 20 cm (note: the bag was a non-rigid container), and height while standing up was ~ 28.6 cm (note: in order to standardize lifting distance, the shape of the dog food bag was configured to approximate the height of the milk crate; and, during pilot testing, despite the non-rigid container, the dog food had minimal settling during a trial). The paper dog food bag also allowed the dog food to shift slightly during lifting and transferring. At pickup, the fingers naturally gripped the loose folds of the top of the paper dog food bag. However, during production, the dog food bag was coated with glossy, smooth, thick paper for brand identification, which caused the fingers to slip easily. Coupling classification did not change for any condition throughout the range of the lift (raising or lowering).

D. Procedure and Measurement

After 5 minutes of seated rest, participants transferred either a 12.5 kg milk crate or a 12.5 kg bag of dog food back and forth from the floor to a table by gripping with their dominant hand (note: Mean (SD) grip strength as assessed using a Jamar (Lafayette, Indiana, USA) hand grip dynamometer was: right grip = 45 $\pm$ 13 kg and left grip = 43 $\pm$ 14 kg). At each location (floor or table) the milk crate or dog food bag was set down completely and hand grip was released; the participant then reset themselves and re-grasped the milk crate or dog food bag to complete the next transfer. During the one-handed lifting, the free hand was not allowed to be used for support (i.e., on the person's body or the table). Distance traveled from floor to table was 152 cm horizontally and 75 cm vertically. While recognizing that anatomical (e.g., height, limb length) and physiological (e.g., fitness) differences may alter stress of a given lifting task [29-31] workers often encounter lifting tasks unrelated to their size or sex [29-31], so a standard table was chosen as a common height that many workers would encounter during lifting tasks. Participants performed two, 5 minute work bouts with either the milk crate or dog food bag. Order (i.e., milk crate or dog food bag) was determined randomly. Three minutes of rest was allowed between work bouts. Pace was constant at eight lifts per minute. Lifting technique was self-selected by the participant and no foot placement instructions were given.

Metabolic parameters (O_2 consumption, caloric cost, heart rate) were measured throughout the work bouts using a Parvomedics metabolic cart (Parvomedics, Sandy, Utah, USA), and a Polar heart rate monitor (Polar, Lake Success, New York, USA). The extremely precise measurement of metabolic data this type of computerized metabolic system allows was further enhanced by use of steady-state data from minutes 2 to 5 to compare the lifting tasks [32]. Rating of perceived exertion (RPE) was assessed immediately at the end of each 5 minute work bout using the Borg 6-20 scale [28]. Standardized instructions for using the RPE scale [27] were given to each subject. Specifically, participants were asked to focus on how hard they felt the work task was in totality, combining all feelings of inner exertion, stress, and fatigue without focusing on any one factor such as arm or leg fatigue [27].

E. Statistical Analyses

Steady state metabolic data (O_2 consumption, caloric cost, heart rate) from minute 2 to minute 5 and RPE of each work bout (milk crate or dog food bag) were used for analysis with T-Test. Analysis revealed no effect of gender on the physiological or psychophysical results; therefore, the data were pooled for analysis and reporting. Alpha level was set a priori at $p < 0.05$ for significance. Assuming an effect size of 1.0 SD to be noteworthy, 80% power can be approached (alpha = 0.05) with 11 participants. This study had 20 participants at completion of the study.

III. Results and Discussion

This study compared the metabolic and psychophysical work stress, as measured by O_2 consumption, caloric cost, HR and RPE, between a one-handed lifting task with identical weight and different coupling and container factors. Results of the study showed significant greater ($p<0.05$) relative O_2 consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) and HR (bpm) when lifting the milk crate with good coupling than when lifting the dog food bag with poor coupling; no difference was exhibited in caloric cost or psychophysical stress (RPE) when participants performed a one-handed, 12.5 kg lifting task with different coupling (i.e., good and poor) and container factors (Table 1).

Participants worked at an average of 53% of their estimated maximum heart rate (eMHR = 220-age) and an RPE of 9.5 (between very light and light) on a category scale of 6-20. When comparing the participant's combined average O_2 cost in $ml \cdot kg^{-1} \cdot min^{-1}$ during task performance with normative percentile value data [27] for maximal treadmill O_2 consumption (50^{th} percentile combined average maximal O_2 consumption for men and women age 20-29 yrs = 41 $ml \cdot kg^{-1} \cdot min^{-1}$), participants worked at ~34% of maximal capacity during the two lifting tasks. While this comparison is not specific to this work task, it still sheds light on the intensity of the present lifting tasks. Relative to manual labor, to limit the metabolic stress and fatigue resulting from a given work task, NIOSH has set task-specific $kcal \cdot min^{-1}$ limits (e.g. 33- 50% of maximum) for repetitive lifting tasks of various durations (e.g., 0-8 hrs) [12].

As previously stated, we found no studies which assessed the physiological and psychophysical stress of a one-handed lifting task performed with identical weight, but different coupling and container factors. In a similar study, Adams et al. [3] compared the physiological and psychophysical work stress between a two-handed lifting task performed with identical weight (12.5 kg) but different coupling factors. As in this study, for good coupling during the lift a milk crate was used; while for poor coupling a bag of dog food was used. Contrary to predictions, a significantly higher metabolic cost (O_2 consumption, HR, $kcal \cdot min^{-1}$) and psychophysical stress (RPE) were observed when subjects performed a paced two-handed lifting task with good coupling factors than when using an object with poor coupling factors. Metabolic cost and RPE were very similar to the present study, averaging 14.3 $ml \cdot kg^{-1} \cdot min^{-1}$ and 8.7 respectively with both two-handed lifting conditions combined.

TABLE I. Metabolic Cost and Perceived Exertion Between a One-Handed Lifting Task with different coupling [mean (sd)]

Metabolic Parameters	***Milk Crate***	***Dog Food***
$ml \cdot kg^{-1} \cdot min^{-1}$	15.0 (3.1)	13.1 (3.9)*
$l \cdot min^{-1}$	1.1 (0.2)	1.0 (0.2)
$kcal \cdot min^{-1}$	5.3 (1.2)	5.1 (1.1)
HR (bpm)	104.1 (10.3)	100.3 (9.9)*
RPE	9.7 (2.0)	9.3 (1.7)

* Note: Significant difference ($p<0.05$) occurred between the two lifting conditions.

In agreement with this previous study [3], the contention is that despite poor coupling, the malleable nature of the dog food bag (i.e., the container) may allow the bag to be molded against and possibly supported by the lower torso during the work task; thereby reducing the shift in the center of gravity. In contrast, the rigidity of the milk crate allowed for minimal variability in handling and a potential shift of the load away from the center of gravity. During study debriefing, participants speculated about this point without prompting from the researchers. Additionally, they commented about increased wrist stress when lifting the milk crate; however this did not manifest itself in participant's RPE. A limitation of this study is the lack of a biomechanical analysis.

Recently, Sevene et al. [4] compared the physiological and psychophysical stress between a one-handed and two-handed identical lifting task using a standard milk crate (good coupling) weighing 12.5 kg. The paced lifting task was identical to this study. No differences were found in metabolic or psychophysical stress when performing a paced, one- or two-handed identical lifting task with self-selected lifting technique. Similar to the current study, when performing the lifting task with either hand, participants O_2 consumption averaged 14.4 $ml \cdot kg^{-1} \cdot min^{-1}$ and HR averaged 104.4 bpm; RPE averaged 9.7.

In conclusion, this study demonstrated a significantly higher metabolic cost when performing an identical one-handed lifting task with poor coupling vs. good coupling; no difference was observed in psychophysical stress between tasks. One-handed lifting tasks are routinely performed in work and daily life. Environmental factors such as work space, object parameters (e.g., shape, size, handles), fitness, fatigue, boredom, and personal choice all influence this decision [3, 7, 19, 21]. In terms of physiological and psychophysical stress, this study adds additional support to the complex nature of assessing lifting tasks. Coupling (grip) represents one influential variable in a complex system [1, 3, 6, 11, 12]; elements related to the object (e.g., size, weight) [3, 21], the environment (e.g., space, temperature, pacing) [4, 5, 17, 18, 24], and the individual (e.g., fitness) [5, 6, 15, 18, 27, 31], etc. all play significant roles in strategies employed to minimize work-related stress and decrease injuries.

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