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Physiological and Psychophysical Comparison between a One and Two-Handed Identical Lifting Task

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Abstract- The 1991 NIOSH (National Institute for Occupational Safety and Health) revised lifting equation's objective is to prevent or reduce lifting-related injuries, especially of the low back. However, the lifting equation is only applicable to two-handed lifting tasks. One- and two-handed repetitive lifting tasks are a consistent part of many occupations. Understanding the metabolic demands of one- and two-handed lifting tasks is important in job design strategies related to productivity and injury prevention. This study compared the metabolic response of an identical lifting task performed with either one or two hands. Thirty-three healthy volunteers participated (21 males, 12 females; 26±5 yr; 177.5±6.9 cm; 72.5±9.8 kg; grip strength, right = 43.8±11.4 kg, left = 42.6±12.4 kg; all right hand dominant). Subjects transferred a 12.5 kg milk crate individually back and forth from the floor to a table. Standard milk crate handles established identical coupling for each hand. Distance crate traveled from floor to table was 152.4 cm horizontally and 74.9 cm vertically. Subjects performed three, 5 minute work bouts in random order with either the dominant hand, non-dominant hand, or both. Three minutes of rest was allowed between each bout. Pace was constant at 8 lifts per minute. Lifting technique was self-selected by the subject. Metabolic parameters were monitored throughout the work bouts. Steady state data from minute 2 to minute 5 was used for analysis with ANOVA. Results were as follows: (mean (sd); d=dominant, nd=non-dominant, b=both hands) ml/kg/min: d = 14.3 (2.8), nd = 14.4 (3.0), b = 15.7 (3.2); l/min: d = 1.0 (0.2), nd = 1.0 (0.2), b = 1.1 (0.2); kcal/min: d = 5.1 (1.0), nd = 5.1 (1.0), b = 5.6 (1.1); RER: d = 0.9 (0.1), nd = 0.9 (0.1), b = 0.9 (0.1); HR: d = 103.4 (12.2), nd = 105.4 (11.5), b = 107.1 (12.0); RPE: d = 9.4 (1.9), nd = 10.0 (1.9), b = 9.4 (1.9). No significant difference ($p<0.05$) occurred on any parameter between the three conditions. In conclusion, there were no differences in metabolic cost or perceived exertion when performing a paced, one- or two-handed identical lifting task with self-selected lifting technique.

Keywords- *Revised NIOSH lifting equation, grip, work.*

I. INTRODUCTION

Work-related musculoskeletal disorders (MSDs) are a major portion of work-related injuries and have significant economic and social costs [1, 2, 3]. The objective of the revised NIOSH (National Institute for Occupational Safety and Health) lifting equation is to prevent or reduce lifting-related injuries, especially of the low back [4]. The equation has wide use as a method to assess work stress, risk, and modifications of a given lifting task [5]. Components of the equation represent the biomechanical, physiological, and psychophysical domains. The equation consists of a load constant and 6 task variables that are weighted and multiplied together to determine the recommended weight limit (RWL) for a given lifting task. The weightings are determined through task analysis, expressed as coefficients, and serve to reduce the RWL. Using the RWL and the weight of a given lifting task (load), one can calculate the Lifting Index (LI), which is a measure of physical stress associated with a given manual lifting task (LI = load/RWL) [6]. The greater the LI, the higher the stress and risk associated with a given work task [2]. However, the lifting equation is only applicable to two-handed lifting tasks.

One- and two-handed repetitive lifting tasks are a consistent part of many occupations [7]. Often, the same task involves a variety of lifting strategies to ease fatigue and boredom, and adapt to various constraints such as a spacing (clearance), reach, etc. [3, 7, 8]. This point recognizes that MSDs occur in a complex system with many factors [8, 9, 10]. It is therefore important to isolate and analyze physiological and psychophysical work stress in a variety of conditions [3]. This basic research can then be applied to better analyze various tasks within work systems. 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, 11, 12, 13, 14]. To our knowledge, no studies have assessed the physiological and psychophysical stress of identical lifting tasks performed with one and two hands.

Physiological work stress 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 [15, 16]. Energy expenditure or caloric cost (kcal/min) is determined from oxygen (O_2) use during an 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) [15]. To limit the metabolic stress and fatigue resulting from a given work task, NIOSH has set task-specific kcal/min limits (e.g. 33- 50% of maximum) for repetitive lifting tasks of various durations (e.g., 0-8 hrs) [4].

Psychophysical work stress can be assessed while performing a work task using the rating of perceived exertion (RPE) scale devised by Borg [16]. 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 [15].

Understanding the physiological and psychophysical demands of one- and two-handed lifting tasks is important in job design strategies related to productivity and injury prevention. Therefore, the purpose of this study was to compare the physiological and psychophysical work stress, as measured by metabolic cost (O_2 consumption, caloric cost, heart rate) and RPE, between an identical lifting task performed with either one or two hands.

II. METHODS

A. Experimental Design

In order to answer the research question of whether physiological and psychophysical work stress changed when performing an identical lifting task with one or two hands, 33 subjects were recruited to complete three lifting tasks. In this repeated measures comparative study design, the lifting task was identical, using a 12.5 kg milk crate with good coupling (i.e., grip) for each hand. However, three randomly ordered lifting conditions (right hand, left hand, or both hands) were employed. Physiological work stress was monitored using a metabolic cart and heart rate monitor and psychophysical work stress was assessed with RPE.

B. Subjects

Thirty-three healthy males and females (21 male, 12 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 (SD) age, height, and body mass were: age = 25.8 (5.4) yrs, mass = 72.5 (9.8) kg, ht = 177.5 (6.9) cm, respectively. All participants were right hand dominant. Mean (SD) grip strength as assessed using a Jamar (Lafayette, Indiana, USA) hand grip dynamometer was: right grip = 43.8 (11.4) kg and left grip = 42.6 (12.4) kg. 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 object used during the experiment for the lifting task was a milk crate with good 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 [6]: 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).

D. Procedure and Measurement

After 5 minutes of seated rest, participants transferred the 12.5 kg milk crate back and forth from the floor to a table. At each location (floor or table) the milk crate was set down completely and hand grip was released; the participant then reset themselves and re-grasped the milk crate to complete the next transfer. During 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 [17, 18, 19] workers often encounter lifting tasks unrelated to their size or sex [17, 18, 19], so a standard table was chosen as a common height that many workers would encounter during lifting tasks. Participants performed three, 5 minute work bouts with the milk crate. Order (i.e., right hand, left hand, or both hands) 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 [20]. Rating of perceived exertion (RPE) was assessed immediately at the end of each 5 minute work bout using the Borg 6-20 scale [16]. Standardized instructions for using the RPE scale [15] 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 [15].

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 (right hand, left hand, or both hands) were used for analysis with ANOVA. 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 33 participants at completion of the study.

III. Results and Discussion

This study compared the physiological and psychophysical work stress, as measured by metabolic cost (O_2 consumption, caloric cost, heart rate) and RPE, between an identical lifting task performed with either one or two hands. Results of the study showed no significant difference in physiological or psychophysical stress when participant's performed an identical lifting task with good coupling factors (12.5 kg milk crate) with one or two hands (Table 1). Participants worked at an average of 54% of their estimated maximum heart rate (eMHR = 220-age) and an RPE of 9.6 (between very light and fairly 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 [15] 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 ~36% of maximal capacity during the three lifting tasks. Recognizing that this comparison is not task specific, it still sheds light on the intensity of the present lifting tasks.

As previously stated, we found no studies which assessed the physiological and psychophysical stress of identical lifting tasks performed with one and two hands. Previous work in our lab [3] compared the physiological and psychophysical work stress between a two-handed lifting task performed with identical weight but different coupling factors (i.e., hand-to-object interface or grip). As in this study, for good coupling a 12.5 kg milk crate was used for the lifting task; while for poor coupling a 12.5 kg dog food bag was used. Contrary to predictions, results demonstrated a significantly higher metabolic cost and perceived exertion 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 however, averaging 14.3 ml/kg/min and 8.7 respectively with both lifting conditions combined.

In a slightly related study from 1983, Garg [21] studied the physiological and psychophysical responses to one-handed lifting in the horizontal plane among 10 female college students. The objective was to assess if upper limits for one-handed lifting tasks should be based on 33 or 50% of maximum lifting capacity. The task consisted of lifting and moving (i.e., either towards or away from themselves 38 or 63.5 cm) a loaded dumbbell which was positioned on a work table. The highest load used in the study was 5.7 kg. Subjects were able to support themselves with their non-working hand while leaning against the table. Load, distance, and frequency were varied over 12 conditions. Average oxygen uptake data ranged from 0.19 to 0.44 L/min; while heart rate ranged from 89 to 106 bpm; and RPE ranged from 8.0 to 13.9. The large differences between this study and the present study, complicates direct comparison and highlights the tremendous variability possible in real-world lifting tasks.

A limitation of this study is the lack of a biomechanical analysis. Recently a study did compare two-handed lifting with one-handed lifting with and without supporting the upper body with the free hand while lifting over an obstacle [7]. One-handed lifting increased asymmetry in movements in and moments around the lumbar spine; but, that one-handed lifting, especially with hand support, reduces L5S1 loading. This work supports the earlier conclusions of Marras and Davis [14] and Ferguson et al. [13]. Again, direct comparison with our study is difficult.

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

Metabolic Parameters	Lifting Conditions		
	Dominant Hand	***Non-Dominant Hand***	***Both Hands***
$ml \cdot kg^{-1} \cdot min^{-1}$	14.3 (2.8)	14.4 (3.0)	15.7 (3.2)
LO_2/min	1.0 (0.2)	1.0 (0.2)	1.1 (0.2)
kcal/min	5.1 (1.0)	5.1 (1.0)	5.6 (1.1)
HR (bpm)	103.4 (12.2)	105.4 (11.5)	107.1 (12.0)
RPE	9.4 (1.9)	10.0 (1.9)	9.4 (1.9)

Note: No significant difference ($p<0.05$) occurred on any parameter between the three conditions.

In conclusion, when performing real-world lifting tasks, individuals routinely lift with both one and two hands. Often lifting methods are dictated by the object (e.g., shape, size, handles), while in other cases, people may rotate between one- and two-handed techniques to minimize fatigue or boredom [3, 7]. In terms of physiological and psychophysical stress, when good coupling exists, results of this study provide support for lifting strategies that use one and two hands as we found the physiological and psychophysical stress to be the same. Future studies should employ different lifting scenarios and coupling factors to further understand the physiological and psychophysical stress of work related lifting tasks.

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