World Academy of Science, Engineering and Technology
International Journal of Health and Medical Engineering
Vol:13, No:12, 2019

Effect of Ambient Oxygen Content and Lifting Frequency on the Participant's Lifting Capabilities, Muscle Activities, and Perceived Exertion

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***Abstract*—**The aim of this study is to assesses the lifting capabilities of persons experiencing hypoxia. It also examines the behavior of the physiological response induced through the lifting process related to changing in the hypoxia and lifting frequency variables. For this purpose, the study performed two consecutive tests by using; (1) training and acclimatization; and (2) an actual collection of data. A total of 10 male students from King Saud University, Kingdom of Saudi Arabia, were recruited in the study. A two-way repeated measures design, with two independent variables (ambient oxygen (15%, 18% and 21%)) and lifting frequency (1 lift/min and 4 lifts/min) and four dependent variables i.e., maximum acceptable weight of lift (MAWL), Electromyography (EMG) of four muscle groups (anterior deltoid, trapezius, biceps brachii, and erector spinae), rating of perceived exertion (RPE), and rating of oxygen feeling (ROF) were used in this study. The results show that lifting frequency has significantly impacted the MAWL and muscles' activities. The oxygen content had a significant effect on the RPE and ROE. The study has revealed that acclimatization and training sessions significantly reduce the effect of the hypoxia on the human physiological parameters during the manual materials handling tasks.

***Keywords*—**Lifting capabilities, muscle activities (sEMG), oxygen content, perceived exertion.

I. Introduction

It is well-established that more than a quarter of all work injuries are related to manual materials handling (MMH) actions [1], [2]. This threat particularly prevails in the service and manufacturing sector where the majority of the work is manual, including lifting. Several studies on the European workforce have revealed that about one-third of workers carry heavy weights in more than a quarter of their working hours [2]. Similarly, a study on the USA workforce has shown that that overexertion during lifting, holding, carrying, pulling an object, were the primary cause of injury in the workplace in 2002, which today ranks among the top five causes of injury [3]. Numerous studies have reflected manual handling tasks, particularly lifting among the primary causes of general injury, notably lower back pain (LBP) [4]-[10].

LBP not only impacts the well-being of the individual, but also contributes as a major economic burden given its costly treatment such as hospital visits, hospitalization, and more [11]. The National Institute for Occupational Safety and Health (NIOSH) in 1981 documented the rising problem of occupational LBP injuries and published the Guide of Work Practices for Manual Lifting. The guide summarized the earlier lifting review in 1981 and highlighted the association between LBP and work-related lifting factors. The Application Manual, published in 1994, was updated in light of the reviewed NIOSH lifting equation [12].

Ferguson et al. [13] proposed that higher demands of manual jobs have influenced the job nature where a higher rate of job rotation between the warehousing workers is observed, indicating that workers are fleeing jobs that may lead to LBP disorders. Differences in workers characteristics (such as, age, body dimensions, sex, physical fitness, muscle strength), environment conditions (humidity and temperature), and task requirements (load location, lifting frequency, vertical height range, size and shape of container lifting speed), make it challenging to devise a standardized and safe allowable weight to be lifted by an individual. Consequently, these factors must be considered in determining that safe allowable weight bounds [14], [15].

Various studies have drawn attention to the risk of musculoskeletal injury related to working in a humid environment [14]-[20]. The study [21] categorized temperature as a significant environmental risk factor. In a humid environment, it is observed that the self-selected workload in a lifting job was reduced to 20%. Furthermore, an increase of 0.2°C - 0.3°C was revealed in rectal temperature, whereas the heart rate increased to 9-10 beats/min [14], [15], [17]. Similarly, [19] add that humidity has an impact on physiological strain when equipment or work is manually handled in the hot environment. Liang et al. [22] reported that working in a humid environment raises heart rate, core temperature, and blood pressure.

Although, many studies have been carried out in the field of manual work handling in different environments, the aspect of environmental conditions where the oxygen content is low still remains an unexplored area. It is because either studies have neglected it or have shown limited interest in examining it. Thereby, the objective of the current study is to examine the influence of manual lifting in hypoxia on lifting capacity and body physiological responses. Consequently, the study has hypothesized that hypoxia and lifting frequency has a significant effect on the MAWL, muscles' activities (EMG),

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and perceived exertion.

II. Methods

A. Study Design

An experimental study design is adopted in this study for investigating the manual lifting in hypoxia on lifting capacity and body physiological responses. A quantitative approach is employed in the study based on its effectiveness for deriving quantifiable results and its use in the previous studies conducted in the field of human factors and ergonomics (Industrial Engineering). A two-way repeated measures design, with two independent variables (ambient oxygen (15%, 18% and 21%) and lifting frequency (1 lift/min and 4 lifts/min)) and four dependent variables (1. MAWL, 2. EMG of four muscle groups (anterior deltoid, trapezius, biceps brachii, and erector spinae), 3. RPE, and 4. ROE) were used in this study (Fig. 1).

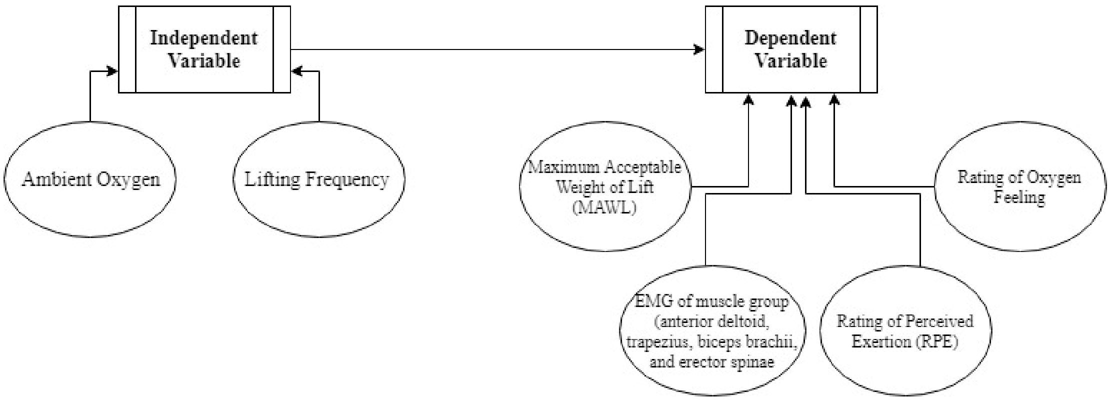

Fig. 1 Independent and dependent variables

B. Participants

The population of the study constitutes students enrolled at King Saud University, KSA. Based on the inclusion criteria, a total of 10 students were recruited with a mean age of 25.6 years and standard deviation of 2.1 years (Table I). The average body mass was 68.2 kg with a standard deviation of 5.7 kg, and average stature was 165.4 cm with a standard deviation of 1.7 cm.

TABLE I
Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
No previous lower limb disorder	Have experienced lower limb disorder
No LBP disorders	Have LBP disorders
No heart problem/ disease	Occurrence of heart problem/ disease

C. Ethical Considerations

Before the study, an approval was obtained from the Institutional Review Board. Also, before performing the research, participants were communicated with the objective and scope of the study, along with the confidentiality and anonymity of the collected data. The researcher also communicated the participants' right to withdraw at any time during the research. Accordingly, all participants signed consent forms approved by the Human Participants Review Sub Committee.

D. Equipment

All experiments in the study were performed inside the environmental chamber. An eight-channel Biomonitor ME6000, MT-ECG-1 preamplifier, and Mega Win 3.0.1 software (Mega Electronics Ltd., Kuopio, Finland) were used to record the EMG signals; whereas, a two-handled box (40 cm x 60 cm x 22 cm) was used for lifting the loads and headphones were used to reduce the noise inside the chamber. Other materials and equipment include 70%- isopropyl-alcohol swaps, cotton squares, band-aid, Ag/AgCl solid adhesive pre-gelled electrodes EMG signal acquisition (Ambu A/S, Denmark), and high-viscosity electrolyte gel for active electrodes.

III. Experimental Design and Procedures

The study has conducted six treatments for each two independent variables (Fig. 1) and their combinations levels. Shapiro and Wilk [23] test was applied to test the normality of data. Statistical significance was set at 95% level of confidence. The study has used IBM SPSS (Statistical Package for Social Sciences) version 22 to analyze the data. The experiment had two stages; i.e., acclimatization and training study, and experimental lifting study.

A. Acclimatization and Training Study

The training and acclimatization study was proposed to raise the participant's flexibility, strength, and endurance of a muscle. Every subject was provided a 2-hour session for acclimatization, and training lasted for 14 consecutive days. Acclimatization and training sessions were similar to those used by Ramadan [17]. On the first day, every participant was trained in ambient oxygen of 18% to be familiar with the protocol of the study before being exposed to ambient oxygen of 15%. For the next 13 days, every participant was exposed to ambient oxygen of 15%, while simultaneously and gradually increasing the physical demand.

B. Equipment

After ending the training and acclimatization stage, the experimental study and collection of data were started. Every participant did lift under every one of the six conditions of experiment in 6 days (one condition every day). Before starting the lifting task, every participant was equipped with EMG electrodes placed on the interest muscles. SENIAM 5 [24] determined procedures were followed for placed electrodes of the EMG. Following which, maximum voluntary contraction (MVC) was measured and recorded for every muscle. Every maximum voluntary contraction MVC test continued for 5 s. The researcher performed a loud, continuous, and strong verbal encouragement to reduce the limitation of muscle contraction capacity due to low motivation and inhibitory effects [25]. The experiment was carried out thrice with a 3-minute break between to relieve the fatigue of the muscle. To remove the impacts of different study day and locations of the electrode, the maximum voluntary contraction was recorded before each session to be used for normalizing the data of the EMG of its corresponding session.

The lifting task was performed for every participant within the chamber under the six conditions of the experiment. Weights were lifted from knuckle to shoulder using the freestyle in the sagittal plane with no twisting. Participants were lifting the weights inside a two-handle box (40 cm x 60 cm x 22 cm). After a participant had lifted the box to the shoulder, it was then returned to the knuckle level by an assistant. Every participant was allowed five minutes pre-work rest, followed by 15 minutes of lifting to determine his MAWL psychophysically.

When a participant decided the MAWL for a session, he continues lifting for five minutes with that MAWL. After five minutes of lifting, the participant was allowed a break of five minutes to recover and rest; and then, followed by the second replication, which is the same as the first replication where he determines his MAWL during 15 minutes, the participant continues lifting for five minutes with that MAWL. The difference between the two replications was in the given starting weights; such that, in one replication it started with 30% of 1RM, while in the other replication, it started from no weight, and was random for every session. Following it, the participant took a five-minute break to rest and recover after the second lifting replication. Also, the order of the sessions was completely randomized. Throughout the two replications of the five minutes of lifting using the MAWL, EMG signals were measured and recorded. After each of the lifting replications sessions, the participants were asked to provide the ratings for the oxygen feeling and perceived exertion.

IV. Results

A. MAWL

Frequency of lifting had a significant effect on MAWL, $F [1, 8] = 5.374$, $p < 0.05$. The participant's MAWL while lifting at 1 lift/minute [mean (SD) =18.608 kg (3.65)] was significantly higher than their cardiac costs as compared to lifting at 4 lifts/minute [mean (SD) = 14.563 kg (3.81)].

B. EMG Muscle Activities

Only frequency of lifting had a significant effect on the normalized root mean square EMG (MVC%) of the biceps brachii [$F (1, 9) = 110.203$, $p < 0.00001$], anterior deltoid muscle [$F (1, 9) = 125.352$, $p < 0.00001$], trapezius muscle [$F (1, 9) = 16.643$, $p < 0.003$], and erector spinae muscle [$F (1, 9) = 11.694$, $p < 0.008$]. MVC% of the biceps brachii muscle, anterior deltoid muscle, trapezius muscle, and erector spinae muscle had significantly higher square EMG (MVC%) with a lifting frequency of 4 lifts/min when compared to the MVC% of a lifting frequency of 1 lift/ min. Table II shows the mean and standard deviation (SD) for root mean square EMG (MVC%) of muscles during levels of lifting frequency.

TABLE II
MEAN AND STANDER DIVISION (SD) FOR ROOT MEAN SQUARE EMG (%MVC)

Muscles	1 lift/minute		4 lifts/minute	
	Mean	SD	Mean	SD
Biceps brachii	12.90%	4.34%	21.11%	6.22%
Anterior deltoid	12.29%	4.23%	20.56%	5.39%
Trapezius	14.25%	7.96%	22.34%	8.60%
Erector spinae	20.05%	10.79%	27.03%	8.73%

C. Subjective Measures

1. RPE

The experiment showed that only oxygen content had a significant effect on the RPE, [$F (2, 8) = 5.213$, $p < 0.036$]. Such as, the RPE was significantly higher when oxygen content was 21% as compared to its rating when oxygen content was 18% and 15%. Moreover, RPE was significantly lower when oxygen content was 18% in contrast to the oxygen content of 15%.

2. Rating of Oxygen Feeling (ROF)

ROF was only significantly affected by oxygen content, [$F (2, 8) = 4.959$, $p < 0.04$]. It can be observed that ROF was significantly higher when oxygen content was 21% than at 18% and 15%.

V. Discussion and Conclusions

The study intended to assess the lifting capabilities of persons experiencing hypoxia. Primarily, it focused on the behavior examination related to the physiological response induced through the lifting process related to those variables. The study assumed that hypoxia and frequency of lifting have a significant effect on the MAWL, muscles' activities (EMG) and perceived exertion. The outcomes of the experiment showed that increasing lifting frequency from 1 lift/minute to 4 lifts/minutes decreases the MAWL to be lifted. These findings are found corresponding to previous studies where an increased lifting frequency caused a decrease in mean weight lifted by 21.74% as compared to 22.08% that was reported by [26], 19.8% found by [27] and 15.51% found by [28].

Mital [28] states that the reductions in MAWL could be lower because of the differences in environmental conditions and also in the population recruited. Such as, the present study had students as participants, whereas [28] had workers as its participants. In general, the MAWL decreases as lifting frequency increases, which escalates the intensity of the workload. However, the study found no effect of oxygen content on MAWL. This may be due to the acclimatization and training that participants performed before the inception of the experiment.

MVC% for the biceps brachii muscle activity during the lifting experiment was significantly lower for the light workload conditions present in a lower lifting frequency. A significant increase of MVC% by approximately 63.6% was related to the higher frequency of lifting. The biceps brachii muscle responded to the increased workload intensity in the form of increased muscle activity to provide the required effort for performing the lifting task under the new conditions. The anterior deltoid muscle MVC% was significantly lower for the lower lifting frequency, which increased by 67.3% for the higher lifting frequency.

Also, the trapezius muscle MVC% was significantly lower for the lower lifting frequency and increased by 65.8% for the higher lifting frequency. Finally, the erector spinae muscle MVC% was significantly lower for the light workload conditions represented in lower lifting frequency. A significant increase of MVC% by approximately 34.8% was related to the higher lifting frequency. The results of the EMG analysis of the four different muscle groups indicated variable responses to the variations in the workload intensity represented in the form of lifting frequency.

At this juncture, the study concludes that the significant increase in the RPE was related to higher levels of oxygen content (21%), indicating oxygen content as an indicator for the work intensity. In addition, the rating of oxygen feeling (ROF) decreased by 14.3% from at oxygen content 15%. Furthermore, the rating of oxygen feeling (ROF) increased by 6.67% at oxygen content 18% from oxygen content 15%.

Acknowledgment

The author is very thankful to all the associated personnel in any reference that contributed in/for the purpose of this research. Further, the research holds no conflict of interest and is self-funded.

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