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Breath control during manual free-style lifting of a maximally tolerated load

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Abstract

Clear evidence links voluntary breath control, intra-abdominal pressure, and lumbar stability. However, little is known regarding optimal breath control during manual materials handling. No studies have examined natural breath control while lifting a maximal load. Fourteen healthy subjects lifted a loaded crate from the floor to a table while respiratory flow data were collected. The loads lifted began at 10% of body weight and increased up to 50% (if tolerated) by 5% increments. Data from the minimum, moderate and maximum loads were analyzed. Uniform and consistent breath holding during lifting of a maximally-tolerated load did not occur. Across all three loads frequency of inspiration was highest immediately prior to lift-off and significantly higher inspired volume occurred at lift-off of the load compared with preparation for lifting. Holding the breath does not appear to be related to lifting of a maximally tolerated load from floor to table.

Keywords

Respiration; Intra-abdominal pressure; Lumbar stability; Lifting; Breathing

1. Introduction

The enormous costs and burdens of low back pain on individuals and society as a whole are well-established (Frymoyer et al. 1983, van Tulder et al. 2002, Woolf and Pfleger 2003). Predictors of low back pain appear to be both psychosocial (Bigos et al. 1986, Bigos et al. 1991, Ready et al. 1993, Gatchel et al. 1995) and mechanical in origin (Marras et al. 1995, Norman et al. 1998). Workers who participate in manual material handling of heavy loads are more likely to develop back injuries (Rowe 1971, White and Gordon 1982, Jensen 1987), in part due to the torsional and compressive loads experienced during the task (Bhattacharya and Ghista 1985, Leskinen et al. 1987, Delisle et al. 1996, Cheng et al. 1998).

As a result, low back pain prevention programs have aimed to improve lifting behaviors in order to reduce mechanical stress to the spine and encourage maintenance of spinal stability

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Relevance: The findings demonstrate that consistent patterns of naturally occurring breath control during lifting of a maximal load can be identified, and do not include uniform breath holding. The findings may assist in creating models for optimal breath control which will minimize risk of injury during manual material handling tasks.

throughout the lift (McGill 2002), although recent reports have questioned the efficacy of such interventions (Martimo *et al.* 2008). Currently, training programs for lifting focus on maintenance of the load close to the body's center of gravity, minimizing trunk rotation, matching load magnitude to lifter's capacity and the avoidance of fatigue (Garg 1997). Advice regarding how to breathe during the task has not been included in standard lifting recommendations to date. This is true despite clear evidence that voluntary breath control influences intra-abdominal pressure (IAP) (McGill *et al.* 1990, Cresswell *et al.* 1992, Cresswell *et al.* 1994, Goldish *et al.* 1994, Hagins *et al.* 2004) and that IAP has been shown, both indirectly (McGill *et al.* 1990, Cholewicki *et al.* 1999, Essendrop *et al.* 2002, Hodges *et al.* 2004) and directly (McGill *et al.* 1994, Cholewicki *et al.* 1999, Shirley *et al.* 2003), to influence lumbar stability. Indirect measures in these studies included computer modelling and the measurement of trunk oscillations or trunk resistance in response to perturbation while direct measures included measures of applied force and displacement of individual segments

Previous studies examining the link between breath control, IAP, and lumbar stability share a similar approach in that they use various methods of breath control (e.g., breath holding, expiration) to determine if IAP or lumbar stability changes. From this evidence, contradictory recommendations have been made about how to breathe during lifting. Authors have suggested that lifting should be performed during expiration (Lewit 1980), during breath holding (Hemborg *et al.* 1985), or during inspiration with an open glottis (Shirley *et al.* 2003).

An alternative approach to examine the link between breath control and lumbar stability is to investigate how one naturally breathes during functional tasks rather than asking individuals to perform the activity while inspiring, expiring or breath holding. If it is assumed that breath is optimized to achieve task completion without injury, then studies investigating the way one naturally breathes during lifting may reveal consistent patterns that can serve as a basis for improved advice during lifting. Previously we examined the natural control of breath during a full body lifting task performed with non-maximal loads and found that inspired volume tended to increase with load and peak at the moment of lift-off with individuals inspiring immediately preceding lift-off (Hagins and Lamberg 2006). However, since many low back injuries result from the repetitive lifting of near maximal loads it is important to examine the question of what occurs during the lifting of maximal loads. Specifically, is there a threshold value of load magnitude beyond which breath behaves in different and more consistent patterns than that observed for non-maximal loads? For example, many authors suggest anecdotally that maximal loads will uniformly create breath holding (Morris *et al.* 1961, Hemborg *et al.* 1985, McGill 1993, McGill *et al.* 1994).

We hypothesized that a more uniform and consistent pattern of breath would exist during maximally tolerated loads demonstrating that breath control is a critical feature used to optimize lumbar stability when mechanical challenge to the lumbar spine is high. We expected that inspiration and inspired volume would increase rapidly immediately prior to lift-off and that breath holding would occur during and immediately after lift-off, maintaining inspired volume and theoretically facilitating increased lumbar stability via increases in IAP. We also considered that additional factors may influence natural breath control during lifting, which are currently unexamined: 1) gender and 2) current level of physical activity.

2. Methods

Fifteen healthy subjects provided informed consent, completed a medical release form and the Baecke Physical Activities Questionnaire (Baecke *et al.* 1982). This study was conducted within the Physical Therapy Department of Long Island University (LIU), Brooklyn Campus, New York, USA, and was approved by the LIU Institutional Review Board. The inclusion criteria consisted of males and females with good overall health. The exclusion criteria

consisted of: history of spinal surgery and/or any recent surgery within the year that may impact the ability to lift (abdominal surgery, etc.), moderate or severe respiratory conditions, recent history of low back pain (within 6 months), or cardiac conditions (arrhythmias, angina).

2.1. Procedures

Height and weight were measured and subjects were fitted with a facemask that covered the nose and mouth and attached to a mesh headpiece (Hans Rudolph Inc., Wyandotte, MO, USA). The facemask attached to a pneumotachograph (Hans Rudolph Inc., Wyandotte, MO, USA) to record airflow. Subjects were given 2 minutes to acclimate to wearing the facemask. Following acclimation, a 2 minute standing respiratory baseline was measured and two vital capacity (VC) measurements were performed.

While wearing the facemask, subjects completed multiple series of four self-paced lifts of a standard plastic “milk” crate with dimensions of 47 cm long by 27 cm wide and a height of 31.8 cm. Handles were located on opposing “wide” sides. Each trial required lifting the crate positioned on the floor directly in front of the participant to a platform positioned at the level of their greater trochanter and ninety degrees to the right. There were no constraints on the type of lift performed (e.g., stoop or squat) with the exception that the subject had to begin the lift directly facing the crate to be lifted. Therefore the lift was considered “freestyle” and to represent each subject’s preferred method of lifting.

The floor and platform were instrumented with pressure sensors (Motion Lab Systems, Baton Rouge, LA., USA) to indicate when the crate was removed from the floor and when it was placed on the platform. The load lifted for each series began at 10% of body weight and increased in 5% increments up to a maximum of 50% of body weight as tolerated. To approximate real world lifting conditions, subjects were able to use their preferred lift style but were instructed to lift at a rate they would choose if expecting to lift continuously for 30 minutes.

Subjects performed two practice trials prior to each series. Following practice subjects were asked, “Do you think that you could lift this weight four times without too much strain?” If the subject responded “NO” the experiment was halted. If the subject responded “YES”, they completed the next series at this load. A verbal cue was provided to the subject independent of the respiratory cycle to initiate the beginning of a lifting series. Following the completion of a series, subjects were provided with a short rest during which they rated the lifting experience using the Borg Revised Rating of Perceived Exertion (RPE) Scale (Roitman and Herridge 2001). The revised RPE scale is comprised of numbers between 0–10, which allows for a subjective rating of exertion (0 is no effort, 10 is maximal effort). Use of the Borg scale to rate exertion during resistance exercise has been explored and found that reported RPE increased with work performed (Gearhart *et al.* 2001). We recognize that reliability and validity for use of the revised RPE scale to rate activity such as that completed in this study is lacking, but included it to help insure that the three levels of load analyzed were different as perceived by the subjects.

2.2 Data Analysis

A multi-channel data acquisition system (Model AT-MIO-64F-F, National Instruments Corporation, Austin, TX) in conjunction with LabVIEW® for Windows (Version 6.0, National Instruments Corporation, Austin, TX, USA) was used to sample and store data at 250 Hz from three channels: the floor sensor (time of lift-off); the platform sensor (time of placement); and the pneumotachograph (airflow direction, rate, and magnitude). An analysis program using Matlab® (Version 5.3.0; The Mathworks Inc., Natick, MA) was created to perform signal processing and determine all magnitude and timing values. Inspiration, expiration, or breath

holding were categorized depending on the direction, or non-direction of airflow. A complete description of methods can be found in our previous paper (Hagins and Lamberg 2006). Since variations in volume occur due to body size, volume is expressed as a percentage of each individual's vital capacity.

Each series consisted of four consecutive trials. To minimize the effects the start cue may have had on respiration, the first trial from each series was discarded. Additionally, since this was a serial task requiring non-stop consecutive lifting, the end of a trial constituted the beginning of the next; thus data from trial three was not used in the analysis. Only data from trials two and four of each series were included. These trials were divided using lift-off as the central point. The "pre-lift" began with placement of the crate from the previous trial onto the platform (Start) and continued until the next crate was lifted-off of the floor. The "post-lift" began with lift-off and continued until the crate was placed on the platform.

As expected, subjects varied in their ability to complete series with the heavier loads. Therefore, three loads were used for analysis; the minimum (MIN), the moderate (MOD), and the maximum (MAX) load lifted for each subject. The MOD load was determined by finding the median percent load for each subject. In cases where subjects lifted an even number of loads, creating two potential values, the higher value was used.

To control for the variation in lifting rate each pre- and post-lift period was expressed as 100% and divided into quartiles. Therefore, volume and flow direction (inspiration, expiration, or breath hold) were identified at nine points: four during the pre-lift (Start, -75%, -50%, -25%), the lift-off, and four during the post-lift (+25%, +50%, +75%, Placement). To determine physical activity the Baecke (Baecke *et al.* 1982) was scored and rank ordered. The seven highest scores were used to classify subjects as having a high activity level; the seven lowest scores were used to classify subjects as low activity level.

2.3 Statistical analysis

A 3×9 (load by time) repeated measures ANOVA was used to identify differences in volume as a percent of vital capacity with load as the independent variable and inhaled volume as the dependent variable. Friedman's repeated measures ANOVA on ranks were used to determine whether frequency of inspiration, expiration, or breath holding differed at each of the nine time points. Separate 2×3 mixed model ANOVAs were used to determine the effects of gender (male or female) and current physical activity level (high or low) on volume at lift-off for each load (load as the dependent variable and inhaled volume as the dependent variable). Student-Newman-Keuls post hoc tests were conducted when the omnibus test was significant. Statistical significance was considered at the $P < 0.05$ level.

3. Results

Seven men and eight women participated in the study. One subject (female) was not included in the analysis due to self-report (after a maximally tolerated load testing of only 20% body weight) that she was not sufficiently motivated to complete the study. Mean tidal volume across all subjects at baseline was 458 ml (12% of mean VC). The average time required to complete the pre- and post-lift across all three loads was 2.03 and 1.8 seconds, respectively. Individual subject characteristics are reported in Table 1.

Table 2 displays a descriptive breakdown of each series of lifts, including the number of subjects able to complete the series, the mean load and range of loads, and the mean reported RPE at a given percent of body weight. For the MIN, MOD, and MAX loads analyzed in this study, the mean percent of body weight lifted, the load and the RPE at that percent body weight

were, respectively: MIN: 10% BW, 7.0 (1.6) kg, 1.5 RPE; MOD: 26% BW, 18.3 (5.7) kg, 5.3 RPE; MAX: 40% BW, 29.0 (10.4) kg, 9.0 RPE.

3.1 Effects of Load on Inspired Volume

Load ($F_{2,13} = 5.12$, $P=0.01$) and time ($F_{8,26} = 18.11$, $P<0.001$) had significant main effects on inspired volume, but both were significantly modified by an interaction effect ($F_{16,104} = 1.72$, $P=0.04$). Figure 1 depicts volume for each load lifted as a function of time. Post hoc analyses showed volume was significantly higher when lifting the MAX load as compared with lifting the MIN or MOD load at lift-off and +75% post-lift ($P<0.05$). In addition, when lifting the MAX load the volume was significantly higher as compared with lifting the MIN load at -75% pre-lift, +25% post-lift, and at placement ($P<0.05$). Volume did not differ between the MOD and MIN load at any time during the lift ($P>0.05$).

3.2 Effects of Time on Inspired Volume

Volume changed depending on the load lifted and the portion of the lift cycle engaged in. As can be seen in Figure 1, generally, across all loads the inspired volume increased around lift-off. Specifically, volume for each of the three loads were significantly higher at +25% post-lift as compared with all pre-lift periods ($P<0.05$) (with the exception of the start when lifting the MIN load; $P>0.05$). Similarly, at lift-off, volume was significantly higher when lifting the MOD and MAX loads as compared with all pre-lift periods ($P<0.05$). Details of all significant differences are described in the figure 1 legend.

3.3 Effects of Load and Time on type of breath (inspiration, expiration, breath holding)

As shown in figure 2, the frequency of inspiration (figure 2a), expiration (figure 2b), and breath hold (figure 2c) changed throughout the lift depending on the load lifted. In general, for all loads the frequency of inspiration increased just prior to lift-off, while during the post-lift expiration and breath holding predominated. Lifting the MAX load did not create a uniform type of breath control at lift-off or during the post lift as expected. Details of all significant differences are described in the figure 2 legend.

3.4 Effects of Activity Level and Gender on Volume at Lift-off

The mean inspired volume at lift-off, collapsed across load was higher for those classified as participating in low levels of physical activity (28% of VC) than those having higher levels of physical activity (21% of VC). While this difference may result in clinical usefulness, it did not quite reach a level of statistical significance ($F_{1,12}=4.47$; $P=0.056$). With regards to gender, the mean inspired volume at lift-off was higher for females (26% of VC) than males (23% of VC) but this difference did not reach statistical significance ($F_{1,12}=1.02$; $P>0.05$).

4. Discussion

This study described naturally occurring patterns of breath control during lifting of a maximally tolerated load from floor-to-table. We expected that inspiration and inspired volume would increase immediately prior to lift-off of the load and that breath holding would occur during and immediately after lift-off of the load. We expected breath holding to maintain inspired volume and theoretically facilitate increased lumbar stability via increases in IAP. Although the study found that the frequency of inspiration and the amount of inspired volume increased for lift-off of the load, this study did not find that the lifting of maximally tolerated loads results in the uniform expression of breath holding during lift-off or during the post lift-off phase.

The findings are congruent with our previous study which used similar methods (floor-to-table lift), but failed to examine what happens when lifting maximally tolerated loads (Hagins and

Lamberg 2006). In the previous study the heaviest load was 25% of body weight while in the current study the heaviest load was individualized and resulted in a mean of 40% of body weight. Although breath holding was not found to be a uniform and consistent breath pattern during lifting of the maximal load, the current study did identify a trend to increase the occurrence of breath holding from lift-off and into the post-lift phase when lifting maximally tolerated loads (Figure 2), which achieved statistical significance at a single period (+75%) during the post-lift.

This study did not directly address the potential mechanisms by which breath control may influence IAP and/or lumbar stability. In a previous study by Shirley *et al.* (Shirley *et al.* 2003) lumbar spinal stiffness increased at values of lung volume held above tidal volume. In the current study inspired volume at lift-off for the MIN, MOD, and MAX loads were 650, 819 and 1143 ml, respectively. This is well above the typical value for tidal volume of 500ml and above the values for tidal volume measured in the current study during baseline (458 ml; 12% of VC).

Combining findings from this and our previous study suggests that increasing the level of inspired volume immediately prior to the time of lift-off is a stable and consistent pattern of natural breath control during a floor-to-table lift from extremely low magnitudes of load through maximally tolerated magnitudes of load. In both studies, increased variation in inspired volume and breath type occurred immediately post lift. Based on these findings, we speculate that motor control organization of breathing is optimized for the occurrence of the highest compressive and shearing forces which occur during the first 0.2–0.4 seconds of the lift (Gagnon and Smyth 1992, de Looze *et al.* 1993).

In addition, we found preliminary evidence that level of physical activity may influence the inspired volume at lift-off (a trend which did not quite achieve statistical significance: $P=0.56$) but it is unlikely that gender may do so. Specifically, individuals with lower levels of physical activity may require higher amounts of inspired volume during lifting tasks.

The current study examined a single type of lifting task and lifts with different parameters of tempo or constraints on the placement of the load may produce different results. Further, the participants did not have special expertise or substantial experience in lifting loads and therefore may not validly represent individuals who work as manual material handlers. The kinematics of the lift within this study were neither controlled nor measured and the findings are therefore limited to a general description of “freestyle” lifting. This being said, the primary authors observed the acquisition of all data and estimate that approximately 95% of all lifts were of the squat type.

Similar to all human movement, it is likely that natural breath control emerges out of a complex interplay between the specific characteristics of the task, the individual, and the environment (Shumway-Cook and Woollacott 2001). The degree to which the characteristics of breath control found in this study remain constant, or vary in other reproducible ways, across a variety of functional tasks will ultimately determine the relative importance and utility of breath control during lifting tasks. If patterns of breath control are predictable in normal healthy subjects and variations from these patterns can be shown to associate with low back disorders, then normal breath control patterns may be used to identify individuals with a dysfunction of the coordination of the respiratory and motor systems. Identification of these patterns would assist with development of guidelines for appropriate use of the breath during lifting, and in rehabilitative programs aimed at enhancing recovery from specific forms of low back pain.

5. Conclusions

Uniform and consistent expression of breath holding during lifting of a maximal load from floor-to-table does not occur. The most consistent pattern of natural breath control during the lifting of maximal loads is to increase inspired volume immediately prior to lift-off of the load and to modulate the amount of inspired volume relative to the magnitude of the load. Preliminary results also suggest that the current level of physical activity may have some influence on the volume of inspired air at the point of lift-off during a lifting task, while gender is unlikely to have such influence.

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Fig. 1.

Mean inspired volume for the MIN, MOD, and MAX loads. For MIN, volume was higher at lift-off and +50% compared to placement, as well as at +25% compared to -25%, -50%, -75%, and placement. For MOD, volume was higher at -25% compared to -75%, as well as at lift-off, +25% and +50% compared to all pre-lift and placement. For MAX, volume was higher at lift-off and +25% compared to pre-lift, +50%, +75% and placement, as well as at -25%, +50%, and +75% compared to -50% and -75%. In addition, at -75%, lift-off, +25%, +75%, and placement volume was higher when comparing MAX with MIN. Further, at lift-off and +75% volume was higher when comparing MAX with MOD. All differences ($p < 0.05$)

Fig 2.

Frequency of occurrence of inspiration (A), expiration (B), or breath holding (C) for the MIN, MOD, and MAX loads. Significant differences were found at: Start: MIN exp>MIN insp. -75%: MIN exp>MIN bh and insp; MOD exp<MIN or MAX exp; MAX exp>MAX bh or insp. -50%: all loads bh<insp and exp. -25%: all loads insp>bh and exp. Lift-off: MIN insp>MIN bh and exp; MIN insp>MOD or MAX insp. +50%: MIN exp>MIN bh and insp; MOD exp>MOD bh and insp; MAX exp<MIN or MOD exp. +75%: MIN exp>MIN bh and insp; MOD exp>MOD bh and insp; MAX insp<MAX bh and exp; MAX bh>MIN or MOD bh. +25% and Placement: none. Legend: Insp = inspiration; bh = breath holding; exp = expiration.

Table 1

Demographic data of participants

Subject	Sex	Age (yrs)	Ht (cm)	Wt (kg)	BMI (kg/m ²)	Baecke
1	M	22	175	78	25.4	10.6
2	M	20	160	58	22.5	11.2
3	M	19	189	84	23.4	7.2
4	F	21	173	58	19.3	5.4
5	F	23	155	52	21.7	5.5
6	F	23	163	64	24.4	5.6
7	F	23	166	59	21.3	3.6
8	M	21	201	85	21.1	11.0
9	M	25	185	98	28.6	11.1
10	F	25	165	64	23.3	8.5
11	F	25	152	43	18.6	2.1
12	M	23	173	77	25.8	10.0
13	M	27	188	88	25.0	7.0
14	F	23	173	75	25.2	7.1
MEAN		22.9	172.8	70.3	23.3	7.6
(SD)		(2.2)	(14.0)	(15.8)	(2.7)	(2.9)

M: Male; F: Female; Baecke Physical Activity Score: Total of Work, Leisure, and Sports scores

Table 2

Descriptive breakdown for lifts at different percentages of body weight

% Body Weight	# of subjects completing series (Male, Female)	Load (kg) <i>Mean(SD)</i>	Range of Load (kg)	Mean RPE
50%	4 (4,0)	40.8 (2.8)	38.6 – 44.2	8
45%	4 (4,0)	37.0 (2.5)	34.6 – 39.7	7.3
40%	10 (6,0)	30.8 (4.9)	23.8 – 39.1	7.9
35%	12 (6,6)	25.3 (5.6)	15.3 – 34.0	7.7
30%	13 (7,6)	21.4 (4.7)	13.0 – 29.5	6.4
25%	14 (7,7)	17.5 (4.0)	10.8 – 24.9	5.3
20%	14 (7,7)	13.9 (3.2)	8.5 – 19.3	3.7
15%	14 (7,7)	10.5 (2.3)	6.2 – 14.7	2.7
10%	14 (7,7)	7.0 (1.6)	4.5 – 9.6	1.5

RPE: rating of perceived exertion