The Valsalva Maneuver Revisited: The Influence of Voluntary Breathing on Isometric Muscle Strength

Elizabeth R. Ikeda, Adam Borg, Devn Brown, Jessica Malouf, Kathy M. Showers, and Sheng Li
Motor Control Laboratory, School of Physical Therapy and Rehabilitation Science, University of Montana, Missoula, Montana

Abstract

Ikeda, ER, Borg, A, Brown, D, Malouf, J, Showers, KM, and Li, S. The Valsalva maneuver revisited: the influence of voluntary breathing on isometric muscle strength. *J Strength Cond Res* 23(1): 127–132, 2009—We assessed the effects of 4 voluntary breathing conditions on maximal voluntary isometric force of large muscle groups. Ten subjects performed maximum voluntary isometric contractions (MVICs) of knee flexion and extension, shoulder abduction and adduction, and elbow flexion and extension under all breathing conditions: normal breathing, forced inhalation, forced exhalation, and the Valsalva maneuver (VM). Forced exhalation significantly increased peak force during shoulder adduction, elbow extension, and knee extension MVIC tasks ($p = 0.001$, 0.024, and 0.002, respectively); the peak force during the Valsalva maneuver was not different from forced exhalation for all tested muscle groups. No voluntary breathing condition seemed to influence the peak force during the knee flexion, elbow flexion, and shoulder abduction MVIC tasks. The results demonstrate that voluntary breathing imposes a significant impact on isometric muscle strength. Given the increased cardiovascular risks associated with the Valsalva maneuver, it is highly recommended that forced exhalation be used during exercise at maximal levels, especially in repetitive repetitions.

Key Words human, maximal voluntary isometric contraction, muscle strength, respiration

Introduction

It is a commonly held belief that exhaling forcefully against a closed glottis, the Valsalva maneuver (VM), is the optimal breathing pattern for producing maximal force. Zatsiorsky and Kraemer (21) have recommended that for ultimate force production, expiration (forced expiration or the VM) should match with the forced phase of movement, regardless of the movement direction or anatomic position—that is, a biomechanical match. Another rationale for using the VM during maximal effort is to increase intraabdominal and intrathoracic pressure, thus improving trunk stability and providing additional stiffness for proximal muscle attachments to improve muscle force production in the extremities (6). However, this view was not supported by a recent study, in which Hagins et al. (10) found that although intraabdominal pressure increased significantly with the VM over other breathing conditions during a simulated maximum lifting task, this breathing pattern was not associated with increased trunk extension force production. The VM, unfortunately, imposes negative hemodynamic effects on the cardiovascular system, such as increased blood pressure, increased heart rate, and risk of cerebral hemorrhage (7,11,16–19,22). Therefore, the VM is not recommended for strength training purposes (6), particularly in people with high systemic blood pressure (18).

Li and Laskin (13) have reported that peak force of the finger flexors increased significantly from forced inspiration to forced expiration, with parallel changes in finger flexor electromyographic activities. Interestingly, the peak forces during forced expiration were not significantly different from those produced during the VM. The authors ascribe their findings to a respiratory-motor enhancement mechanism. During forced expiration and the VM, increased respiratory-related cortical neuronal activity synchronizes with, and thus enhances, the motor drive to nonrespiratory muscles (e.g., the finger flexors), resulting in greater peak force. This proposed enhancement mechanism was further supported in a subsequent study (15), in which the initiation of forced expiration and inspiration was synchronized with deviation of constant isometric finger flexion force at submaximal levels. As a result, force variability was found to be increased compared with that measured during normal breathing.

It remains unknown, however, whether voluntary breathing could influence the muscle strength of large muscles. The VM is typically used during large-muscle strength training. Therefore, the purpose of this study was to examine the effect of voluntary breathing and to generalize the results observed in small hand muscles (13) to large muscles. The large muscles in this investigation included knee flexors and

Address correspondence to Sheng Li, sheng.li@umontana.edu.

23(1)/127–132

Journal of Strength and Conditioning Research

extensors, shoulder adductors and abductors, and elbow flexors and extensors. The hypothesis was that, as seen in small hand muscles (13), different phases (inspiration and expiration) of voluntary breathing would significantly influence the muscle strength of large muscles.

METHODS

Experimental Approach to the Problem

To examine the experimental hypothesis of the ventilation effects on strength of large muscles, 10 subjects were recruited to participate in this investigation. Men and women subjects without prior or current strength training experience were purposefully recruited because our primary interest was to investigate this phenomenon and to quantify the potential effect of ventilation. Subjects were asked to perform a brief (3–5 seconds) maximum voluntary isometric contraction (MVIC) of large muscle groups, including knee flexion and extension, elbow flexion and extension, and shoulder abduction and adduction, during 4 different breathing conditions. The conditions were normal breathing, synchronized forced inhalation, synchronized forced exhalation, and the VM. Force and breathing data were recorded for offline measurement. The peak value of force data was used to study the effect of voluntary breathing on the isometric muscle strength of large muscles. This was a within-subject study design. The treatments (conditions) were randomized to balance the presentation of treatments.

Subjects

This study had 2 sessions. In the lower extremity (LE) session, the muscle strength of the knee joint was tested in 10 healthy subjects (6 women and 4 men) with an average age of 27.8 ± 7.1 years (range, 24–46 years). Another group of 10 healthy subjects ($N = 10$, 7 women and 3 men) with an average age of 26.3 ± 3.5 years (range, 22–32 years) participated in the upper extremity (UE) session, in which the muscle strength of the shoulder and elbow joints was tested. No subjects had any prior or current experience of strength training. The University of Montana institutional review board approved this study, and all subjects gave written informed consent.

Procedures

During all testing, each subject sat on a KinCom dynamometer chair (Model 125AP, Isokinetic International, Harrison, Tenn) and breathed through a face mask connected to a pneumotachometer (Series 1110A; Hans Rudolph, Kansas City, Mo) to monitor ventilation. In the LE session, each subject's trunk was restrained in the chair; arms crossed the chest, the hips were positioned at 90° of flexion, and the left leg was supported on a foot rest (Figure 1). The right knee joint was kept at 50° of flexion for both knee flexion and extension MVIC, with the knee joint axis of rotation aligned with the axis of rotation of the Kincom motor. The force transducer was secured to the lower leg at the distal third from the knee joint. The subjects were asked to keep the ankle joint on the test side held in a neutral position to minimize variations in knee joint torque measurement (4).

In the UE session, the trunk was not supported or constrained, the feet were supported, and the hips and knees

Figure 1. Experimental settings for the lower-extremity session.

were positioned at 90° of flexion. During both the shoulder abduction and adduction MVIC tests, the left shoulder was held at 60° of abduction and 10° of flexion. The force transducer was secured to the midhumerus. During the elbow tests, the left shoulder joint was kept in the neutral position. The left elbow was positioned at 120° of flexion, with the forearm in a neutral position and the hand in a loose fist. The force transducer was secured to the distal quarter of the left forearm. Both elbow flexion and extension MVICs were measured using the same configuration. Specific instructions were given to ensure there was no tilting or leaning of the trunk during the experiments. Subjects were instructed to comfortably rest the right hand on the ipsilateral lap.

Maximum voluntary isometric contractions of knee flexion and extension, shoulder abduction and adduction, and elbow flexion and extension were tested during 4 different patterns of ventilation, including

1. normal breathing ($MVIC_{NML}$): subjects breathed in and out normally while producing as much force as they could;
2. synchronized forced inhalation ($MVIC_{IN}$): subjects produced as much force as they could while synchronizing force production with rapid, forced inhalation;
3. synchronized forced exhalation ($MVIC_{OUT}$): subjects produced as much force as they could while synchronizing force production with rapid, forced exhalation; and
4. VM ($MVIC_{VM}$): subjects produced as much force as they could while synchronizing force production with the initiation of the VM.

Subjects rested and breathed normally in the configuration described above before each trial. Two computer-generated tones indicated the beginning of a 10-second trial. Subjects initiated force production in a self-paced manner within the first 3 seconds of the trial and were verbally encouraged to maintain maximal force production for the ensuing 3–5 seconds. Force production was at a self-selected rate. They did not receive any feedback on force production during the experiment. Two trials of MVIC were recorded for each condition (ventilation and muscle group). Between 5 and 8 practice trials at submaximal levels (approximately 50% MVIC) were allowed to familiarize subjects with experimental settings and instructions. The subjects were given approximately 60-second intervals between trials and conditions to minimize fatigue. Subjects always performed $MVIC_{NML}$ tasks first for each muscle group to minimize the influence of instructions on their performance. The other 3 tasks were performed in a randomized order. This protocol has been used in a previous study (13).

Airflow and force signals were sampled at 1000 Hz by a 16-bit analog-to-digital converter (PCI 6229; National Instruments, Austin, Tex) using customized LabView software (National Instruments). All signals were saved for offline analysis using a customized Matlab (The MathWorks, Natick, Mass) program.

The peak force was calculated as the force averaged for a 100-millisecond window, centered about the instance of the maximal force, after a low-pass filtering at 20 Hz. The higher peak force of 2 trials was selected as F_{MVIC} (14). To compare the effect of breathing on maximal force-generating capability, F_{MVIC} for $MVIC_{IN}$, $MVIC_{OUT}$, and $MVIC_{VM}$ tasks were normalized to F_{MVIC} for $MVIC_{NML}$ tasks for each muscle group. Airflow signals were used to confirm subjects' performance for each task through visual inspection during offline analysis.

Statistical Analyses

The data from the investigation are presented as mean values. The statistical analyses were performed using Statistica 7 (Statsoft, Inc., Tulsa, Okla). A repeated-measures 1-way analysis of variance (ANOVA) was used to compare the absolute values of F_{MVIC} for each muscle group under different breathing conditions. The factor was task (4 levels, 4 tasks). To compare the effect of breathing on the F_{MVIC} of different muscle groups of the same joint, a 2-way ANOVA was used to compare normalized F_{MIVC} with the factors of muscle (2 levels: flexor/extensor or adductor/abductor) and breath (3 levels: inhalation, exhalation, and VM). Post hoc Tukey honestly significant difference tests were used when necessary. Intraclass correlation coefficients for reliability of the dependent measures ranged from 0.85 to 0.93. For the n size used, statistical power ranged from 0.81 to 0.88 for the variables examined in this investigation. The level of significance was set at an alpha level $p \leq 0.05$ for this investigation.

Results

Subjects performed MVICs of knee flexion and extension, shoulder abduction and adduction, and elbow flexion and extension under different breathing conditions. Overall, the influence of voluntary breathing on the peak force was muscle-specific and respiratory-phase–dependent. The peak forces are summarized in Table 1. As depicted in Figure 2, voluntary breathing dramatically influenced (e.g., isometric knee extension MVIC). On average, the peak force (F_{MVIC}) was significantly influenced by breathing patterns during knee extension ($p = 0.002$), elbow extension ($p = 0.024$), and shoulder adduction ($p = 0.001$) MVIC tasks, whereas F_{MVIC} remained unchanged during knee flexion, elbow flexion, and shoulder abduction MVIC tasks. Specifically, as compared with F_{MVIC} during the knee extension $MVIC_{NML}$ task, F_{MVIC} significantly increased during $MVIC_{IN,}$ $MVIC_{OUT}$, and $MVIC_{VM}$ tasks ($p < 0.002$), respectively. No significant differences in F_{MVIC} were found among these 3 tasks. During elbow extension, F_{MVIC} was significantly greater in the $MVIC_{OUT}$ and $MVIC_{VM}$ tasks than in the $MVIC_{IN}$ task ($p < 0.024$); F_{MVIC} in the $MVIC_{IN}$ task was not different from the $MVIC_{NML}$ task. Similarly, shoulder adduction F_{MVIC} was significantly greater in the $MVIC_{OUT}$ and $MVIC_{VM}$ tasks than in the $MVIC_{IN}$ task ($p < 0.001$). The F_{MVIC} was also greater in the $MVIC_{OUT}$ task than in the $MVIC_{NML}$ task ($p < 0.001$). A consistent finding was that there was no significant

Table 1. Peak forces (N) averaged across 10 subjects during maximum voluntary isometric contractions (MVICs) of knee flexion (Flex) and extension (Ext), elbow flexion and extension, and shoulder abduction (ABD) and adduction (ADD) under different breathing conditions.

	Knee		Elbow		Shoulder	
	Flex	Ext	Flex	Ext	ABD	ADD
$MVIC_{NML}$	325.3 (18.5)	617.4 (56.8)	255.9 (22.9)	152.6 (13.6)	219.0 (15.1)	246.3 (25.5)
$MVIC_{IN}$	314.5 (16.0)	697.8 (59.6)	263.8 (21.3)	144.8 (10.5)	228.4 (13.3)	226.0 (25.3)
$MVIC_{OUT}$	314.4 (16.3)	672.4 (61.6)	265.7 (22.8)	160.5 (12.2)	222.9 (13.7)	274.7 (23.5)
$MVIC_{VM}$	310.7 (16.0)	672.0 (62.1)	268.9 (24.0)	159.5 (12.4)	233.8 (17.4)	265.2 (24.4)

The 4 breathing conditions are normal breathing ($MVIC_{NML}$), forced inhalation ($MVIC_{IN}$), forced exhalation ($MVIC_{OUT}$), and the Valsalva maneuver ($MVIC_{VM}$). *SE* values are presented in parentheses.

difference in F_{MVIC} between $MVIC_{OUT}$ and $MVIC_{VM}$ tasks for all tested muscle groups.

When normalized to F_{MIVC} of $MVIC_{NML}$ tasks, normalized F_{MIVC} was used to compare the breathing effect on muscle strength of antagonist muscle groups of the same joint. In the LE session, the normalized F_{MIVC} was significantly greater during knee extension (111.0%) than during knee flexion (96.8%) MVIC tasks (Figure 3A). A 2-way ANOVA showed a main effect of muscle ($p = 0.014$). However, no differences in the normalized F_{MIVC} were found among different breathing conditions during either knee flexion or extension MVIC tasks.

A different pattern was observed in the UE session. No difference in the normalized F_{MIVC} was found between elbow flexion and extension MVIC tasks. A 2-way ANOVA showed a main effect of breath ($p = 0.001$) and a significant muscle × breath interaction ($p = 0.039$). Post hoc tests revealed that elbow extension F_{MIVC} during the $MVIC_{IN}$ task (97.6%) was significantly smaller than others, but no differences among the other tasks were found ($p < 0.039$) (Figure 3B). Likewise, no difference in the normalized F_{MIVC} was found between shoulder adduction and abduction MVIC tasks. There was a main effect of breath ($p = 0.028$) and a significant muscle × breath interaction ($p = 0.004$) (Figure 3C). According to post hoc analysis, shoulder adduction F_{MIVC} during the $MVIC_{IN}$ task was significantly smaller than during $MVIC_{OUT}$ and $MVIC_{VM}$ tasks ($p < 0.004$). There was no difference in F_{MIVC} between $MVIC_{OUT}$ (110.4%) and $MVIC_{VM}$ (111.5%) tasks.

Discussion

This study clearly demonstrates that voluntary breathing can influence maximal muscle strength of large lower- and upper-extremity muscles. By adopting the same protocol from a previous study (13), we generalized their results that demonstrated specificity of a breathing effect on peak force of finger muscles to the large muscle groups. During knee flexion and extension, shoulder abduction and adduction, and elbow flexion and extension MVIC tasks, the influence of voluntary breathing on the peak force was muscle-specific and respiratory-phase–dependent. Specifically, knee extension force significantly increased during forced inhalation, exhalation, and the VM as compared with the force obtained at normal breathing; both shoulder adduction and elbow extension forces were greater during forced exhalation and the VM than during forced

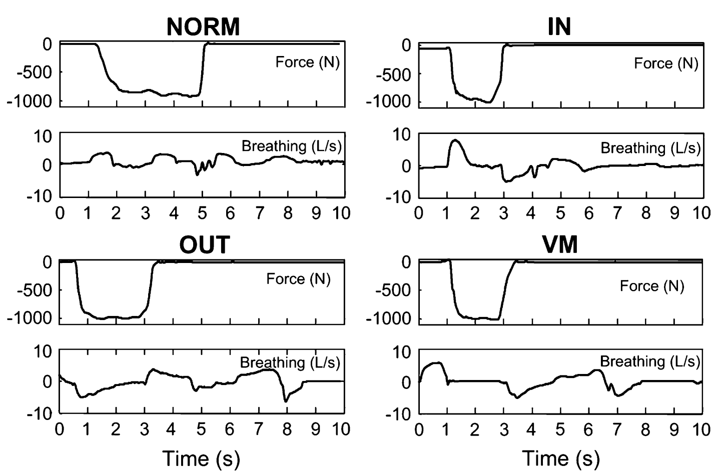

Figure 2. Typical trials during knee extension maximum voluntary isometric contraction attempts under different breathing conditions: normal breathing (NORM), forced inhalation (IN), forced exhalation (OUT), and Valsalva maneuver (VM).

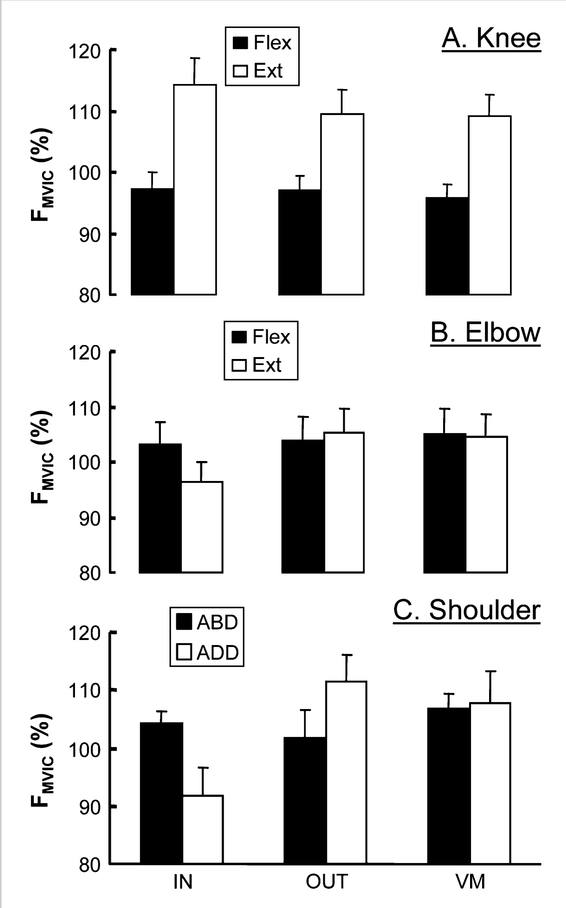

Figure 3. The effect of breathing on muscle strength. Muscle strength (F_{MVIC}, %) was normalized to the peak force during normal breathing. Flex = flexion; Ext = extension; ABD = abduction; ADD = adduction; IN = forced inhalation; OUT = forced exhalation; VM = Valsalva maneuver.

inhalation. Voluntary breathing did not seem to influence the peak force during the knee flexion, elbow flexion, or shoulder abduction MVIC tasks.

Furthermore, similar to the previous study (13), no additional benefit of using the VM was observed when compared with synchronized forced exhalation during MVICs of all tested muscle groups. Previous studies have reported increased cardiovascular risks associated with the VM during forceful movements (7,11,16–19,22). In contrast, forced exhalation could significantly reduce intrathoracic pressure and, thus, minimize the induced hemodynamic changes. For example, arterial hypertension produced during heavy weight lifting with the VM was dramatically reduced when the exercise was performed without the VM (i.e., with an open glottis) (17). Similarly, greater increases in arterial blood pressure and heart rate were observed with voluntary breath holding than without breath holding during moderate abdominal exercise (7). Therefore, it is highly recommended that forced exhalation, rather than the VM, should be used during maximal force production whenever possible (21).

Forced exhalation and forced inhalation impose contrasting effects on different movements (Figure 3). As compared with forced inhalation, forced exhalation increased the peak force during knee extension, elbow extension, and shoulder adduction. The muscle-specific, phase-dependent effect of breathing on the peak force has been reported previously. For example, Hagins et al. (10) found that the VM and forced exhalation led to unchanged trunk extension peak force, but significantly higher intraabdominal pressure, during a simulated maximum lifting task. In contrast, Li and Laskin (13) report that both forced exhalation and the VM increased finger flexion peak force to a similar extent.

The observed pattern of results may be attributed to the fact that the motor drive to nonrespiratory muscles could be modulated by voluntary breathing. Previous studies have demonstrated that the influence of voluntary breathing on the motor drive to nonrespiratory muscles is both respiratory-phase–dependent and muscle-specific (1,2,5,8,20). For instance, resistive loaded inspiration significantly enhanced tonic vibratory response in the extensor digitorum (2), but it did not affect contraction of biceps brachii (8). The latency of median nerve components of somatosensory evoked potentials was lengthened by inspiratory, but not expiratory, resistive loaded breathing, suggesting possible inhibitory effects of forceful inspiration on the wrist/finger flexors (1). Forceful inspiration, however, did not alter the magnitude of motor evoked potential from abductor digiti minimi muscle in a transcranial magnetic stimulation study (5).

These findings of the ventilation effects may be viewed as mechanical artifacts of voluntary breathing on the peak force on muscles. Greater shoulder adduction peak force may be related to increased activation of proximal muscles (e.g., shoulder adductor) during forced exhalation. This effect could be transferred to the distal finger flexors through a proximal-distal synergy (3,9,12), resulting in increased finger flexion peak force. However, using the same reasoning, an increased elbow flexion peak force during forced exhalation would be expected. In contrast, an increased elbow extension peak force was observed instead in the present study. The present pattern of results argues against mechanical artifact as a sole underlying mechanism. In combination with the aforementioned breathing effects on motor drive (1,2,5,8,20), the current results are more likely attributable to modulated motor drive resulting from respiratory-motor interactions.

Practical Applications

To summarize, the results demonstrate that voluntary breathing imposes a significant impact on isometric muscle strength. Both forced exhalation and the VM increase maximal forces during elbow extension, shoulder adduction, and knee extension to a similar extent. Voluntary breathing did not seem to influence the peak force during knee flexion, elbow flexion and shoulder abduction MVIC tasks. Although the VM is more natural during some exercises at maximal levels, especially when movements occur, given increased cardiovascular risks associated with the VM, it is highly recommended that forced exhalation be used during exercises at maximal levels, especially in repetitive repetitions.

Acknowledgments

The authors thank Dr. Woo-Hyung Park for his technical assistance. This study was supported in part by an NIH grant (1R15NS053442-01A1). There is no conflict of interest.

References

1. Balzamo, E, Pellegrin, V, Somma-Mauvais, H, and Jammes, Y. Activation of respiratory afferents by resistive loaded breathing modifies somatosensory evoked potentials to median nerve stimulation in humans. *Neurosci Lett* 270: 157–160, 1999.
2. Balzamo, E, Vuillon-Cacciuttolo, G, Burnet, H, and Jammes, Y. Influence of respiratory afferents upon the proprioceptive reflex of skeletal muscles in healthy humans. *Neurosci Lett* 236: 127–130, 1997.
3. Chabran, E, Maton, B, Ribreau, C, and Fourment, A. Electromyographic and biomechanical characteristics of segmental postural adjustments associated with voluntary wrist movements. Influence of an elbow support. *Exp Brain Res* 141: 133–145, 2001.
4. Croce, RV, Miller, JP, and St Pierre, P. Effect of ankle position fixation on peak torque and electromyographic activity of the knee flexors and extensors. *Electromyogr Clin Neurophysiol* 40: 365–373, 2000.
5. Filippi, MM, Oliveri, M, Vernieri, F, Pasqualetti, P, and Rossini, PM. Are autonomic signals influencing cortico-spinal motor excitability? A study with transcranial magnetic stimulation. *Brain Res* 881: 159–164, 2000.
6. Findley, BW, Keating, T, and Toscano, L. Is the Valsalva maneuver a proper breathing technique? *Strength Cond J* 25: 52, 2003.
7. Finnoff, JT, Smith, J, Low, PA, Dahm, DL, and Harrington, SP. Acute hemodynamic effects of abdominal exercise with and without breath holding. *Arch Phys Med Rehabil* 84: 1017, 2003.
8. Fontanari, P, Vuillon-Cacciuttolo, G, Balzamo, E, Zattara-Hartmann, MC, Lagier-Tessonnier, F, and Jammes, Y. Resistive loaded breathing changes the motor drive to arm and leg muscles in man. *Neurosci Lett* 210: 130–134, 1996.
9. Ginanneschi, F, Dominici, F, Biasella, A, Gelli, F, and Rossi, A. Changes in corticomotor excitability of forearm muscles in relation to static shoulder positions. *Brain Res* 1073–1074: 332–338, 2006.
10. Hagins, M, Pietrek, M, Sheikhzadeh, A, and Nordin, M. The effects of breath control on maximum force and IAP during a maximum isometric lifting task. *Clin Biomech (Bristol, Avon)* 21: 775–780, 2006.
11. Henderson, LA, Macey, PM, Macey, KE, Frysinger, RC, Woo, MA, Harper, RK, Alger, JR, Yan-Go, FL, and Harper, RM. Brain responses associated with the Valsalva maneuver revealed by functional magnetic resonance imaging. *J Neurophysiol* 88: 3477–3486, 2002.
12. Latash, ML. The organization of quick corrections within a two-joint synergy in conditions of unexpected blocking and release of a fast movement. *Clin Neurophysiol* 111: 975–987, 2000.
13. Li, S and Laskin, JJ. Influences of ventilation on maximal isometric force of the finger flexors. *Muscle Nerve* 34: 651–655, 2006.
14. Li, S, Latash, ML, and Zatsiorsky, VM. Finger interaction during multi-finger tasks involving finger addition and removal. *Exp Brain Res* 150: 230–236, 2003.
15. Li, S and Yasuda, N. Forced ventilation increases variability of isometric finger forces. *Neurosci Lett* 412: 243–247, 2007.
16. Looga, R. The Valsalva manoeuvre–cardiovascular effects and performance technique: a critical review. *Respir Physiol Neurobiol* 147: 39, 2005.
17. Narloch, JA and Brandstater, ME. Influence of breathing technique on arterial blood pressure during heavy weight lifting. *Arch Phys Med Rehabil* 76: 457–462, 1995.
18. O'Connor, P, Storzo, GA, and Frye, P. Effect of breathing instruction on blood pressure responses during isometric exercise. *Phys Ther* 69: 757, 1989.
19. Pott, F, Van Lieshout, JJ, Ide, K, Madsen, P, and Secher, NH. Middle cerebral artery blood velocity during intense static exercise is dominated by a Valsalva maneuver. *J Appl Physiol* 94: 1335–1344, 2003.
20. Turner, D, Sumners, P, and Jackson, S. Changes in electromyogram during upper limb muscle contraction induced by resistive loaded breathing in humans. *Neurosci Lett* 296: 45–48, 2000.
21. Zatsiorsky, VM and Kraemer, WJ. *Science and Practice of Strength Training* (2nd ed.). Champaign: Human Kinetics, 2006.
22. Zhang, R, Crandall, CG, and Levine, BD. Cerebral hemodynamics during the Valsalva maneuver: insights from ganglionic blockade. *Stroke* 35: 843–847, 2004.