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Clinical Breathing Mechanics Differ Based on Test and Position

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Context: Altered diaphragm function is linked to decreased core stabilization, postural changes, and decreased function. Two clinical tests used to assess breathing are the Hi-lo and lateral rib expansion (LRE) tests. It is currently unknown how breathing classification based on these tests differ and how their results are affected by varying test positions. ***Objective:*** To compare the results of breathing tests when conducted in varying test positions. ***Design:*** Prospective cross-sectional study. ***Setting:*** University laboratory. ***Participants:*** A total of 50 healthy adults (females 31 and males 29; age 29.3 [4.1] y; height 170.0 [10.4] cm; weight 70.7 [15.1] kg). ***Intervention(s):*** Hi-lo and LRE tests in supine, seated, standing, and half-kneeling body positions. All tests were recorded and later scored by a single examiner. A generalized estimating equations approach with breathing test and body position as factors was used for analysis. Pairwise comparison with Bonferroni correction was used to adjust for multiple tests. Statistical significance was set at $P = .05$, 2 tailed. ***Main Outcome Measures:*** Hi-lo and LRE tests were scored based on the presence or absence of abdominal excursion, LRE, and superior rib cage migration. Following scoring, results were classified as functional or dysfunctional based on observation of these criteria. ***Results:*** A significant breathing test × test position interaction ($P < .01$) was noted, as well as main effects for test ($P < .01$) and test position ($P < .01$). All Hi-lo test positions identified significantly more dysfunctional breathers in positions of increased stability demand ($P < .01$), except between standing and half-kneeling positions ($P = .52$). In the LRE test, all positions were similar ($P > .99$) except for half-kneeling, which was significantly different from all other positions ($P < .01$). ***Conclusions:*** The Hi-lo test and LRE tests assess different breathing mechanics. Clinicians should use these tests in combination to gain a comprehensive understanding of a person's breathing pattern. The Hi-lo test should be administered in multiple testing positions.

Keywords: respiratory mechanics, dual diaphragmatic role, Hi-lo test, lateral rib expansion test, postural stability demand

The clinical assessment of breathing and the use of breathing exercises in the rehabilitation of musculoskeletal conditions has increased over the last decade.[1] Altered breathing mechanics have been linked to numerous musculoskeletal conditions,[2–7] and breathing exercises are being recognized as an important component of rehabilitation programs for conditions such as low back pain.[8–11] The diaphragm is the primary muscle of respiration and when functioning normally, should produce observable breathing mechanics of abdominal motion, anterior–superior chest expansion, and lateral rib expansion (LRE), commonly referred to as "diaphragmatic breathing."[10,12] The diaphragm also contributes significantly to postural stability through the regulation of intraabdominal pressure during inhalation.[2,9,13]

Diaphragmatic breathing has been shown to contribute to improved core stability,[13] improved functional movement,[14,15] improved posture,[16] and reduced instance of low back pain.[2,5,7,17,18] Dysfunctional breathing occurs when poor diaphragm function results in altered breathing mechanics, including reduced abdominal excursion and rib cage expansion and increased reliance on accessory breathing muscles (eg, scalenes, sternocleidomastoid) for respiration.[4,10] Increased accessory muscle activation leads to superior rib cage migration instead of rib cage expansion, where accessory muscles are called upon to elevate the rib cage during inhalation due to inefficient diaphragm contraction.[6] As body positions change and postural demands increase, such as when moving from supine to seated to standing positions, the diaphragm's ability to maintain both respiration and postural stabilization roles may be challenged, thus increasing the propensity for altered breathing mechanics in positions of greater stability demand. Dysfunctional breathing patterns commonly present in patients with postural deficits,[16] low back pain,[2,5,7,18] neck pain,[19] temporomandibular joint pain,[3] and scapular dyskinesis,[20] yet targeted breathing exercises have been shown to effectively restore diaphragmatic breathing patterns, decrease pain, and restore function.[8,11]

Considering the dual role of the diaphragm in respiration and postural control, and evidence demonstrating a multifaceted benefit to restoring proper breathing mechanics, clinicians are encouraged to assess a patient's breathing pattern during the clinical examination.[1] However, challenges exist regarding how to effectively and efficiently assess breathing patterns in a clinical setting using validated and reliable tests. Two commonly used clinical assessments of breathing are the Hi-lo test and LRE test.[1]

The Hi-lo test is an observational assessment of abdominal excursion and anterior–posterior chest expansion during normal and maximal respirations; the LRE test is an observational and palpatory assessment of LRE during normal and maximal respirations.[12] The Hi-lo and LRE tests have been described as either supine or seated position tests. Given the dual role of the diaphragm as both a respiratory and postural muscle, it is possible that breathing mechanics will change significantly from supine to seated positions as postural demands increase. To date, limited research[21,22] has been conducted on the measurement properties of these assessments, and no research has investigated how results vary between the 2 clinical tests and how the test results may change when conducted in different test positions that vary levels of postural demand on the body. Therefore, the purpose of this study was to compare results of the Hi-lo and LRE tests when

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conducted in varying test positions. The primary aim was to examine differences between the Hi-lo and LRE tests, with a secondary aim of examining how individual breathing test results change with varying test positions. We hypothesized that the Hi-lo and LRE tests measure different components of breathing mechanics and expected to find different breathing test results between the Hi-lo and LRE tests; we also anticipated differences in individual breathing test results among the test positions.

Methods

Design

A prospective cross-sectional study design was used. The independent variables included breathing test (Hi-lo and LRE) and test position (supine, seated, standing, and half-kneeling). The dependent variable was breathing pattern (functional and dysfunctional).

Participants

A convenience sample of 50 participants (females 31 and males 29; age 29.3 [4.1] y, height 170.0 [10.4] cm; weight 70.7 [15.1] kg) who met the inclusion criteria were tested. Given the limited evidence on Hi-lo and LRE tests, otherwise healthy individuals were recruited to explore measurement issues in varying test positions prior to using a patient population. The recruitment strategy included community advertisements, email, and word of mouth. Individuals who were at least 18 years old and who self-identified as physically active were included in this study. Physically active was operationally defined as participating in exercise at or above the intensity of a brisk walk at least twice per week. Individuals were excluded if they self-reported a current respiratory condition that limited their ability to breathe normally (eg, uncontrolled asthma, cold, congestions, infection); had a current musculoskeletal injury prohibiting them from performing the tests pain-free; had a history of a vestibular cochlear or balance disorder; current or residual symptoms from a head injury; or if they were pregnant. The institutional review board at A.T. Still University approved the study and informed consent was obtained from all participants.

Procedures

Participants attended a single test session lasting approximately 30 minutes. First, participants completed a demographic and health history questionnaire, and responses were reviewed with investigators to confirm study eligibility. Study investigators developed the health history questionnaire to capture demographic information (eg, gender, age, height, mass); health history (eg, conditions affecting respiratory function, smoking); past and current musculoskeletal injury history; and current activity level.

Next, each participant performed the Hi-lo and LRE tests in the supine, seated, standing, and half-kneeling test positions. Test order was randomized within a test position. For the Hi-lo test, participants were instructed to place 1 hand on the superior aspect of their chest and the other hand on their abdomen in each test position (Figure 1). For the LRE test in seated, standing, and half-kneeling positions, the examiner palpated the participant's spine (approximately T9–T10 spinous process) with the thumbs and hands rested over the participant's lower rib cage (Figure 2). For the LRE test in supine, the examiner's hands were placed on the participant's anterolateral rib cage. For both Hi-lo and LRE tests, participants were instructed to perform 4 consecutive normal breaths followed by 2 maximal breaths.[1] All tests were video recorded and later scored by a single examiner.

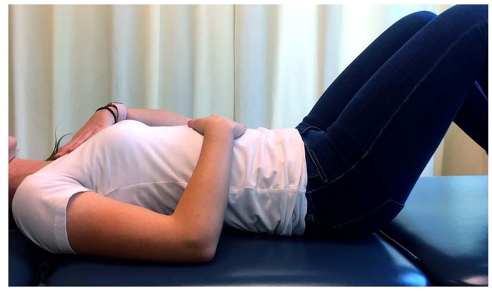

Figure 1 — Participant posture for the Hi-lo breathing test in the supine test position.

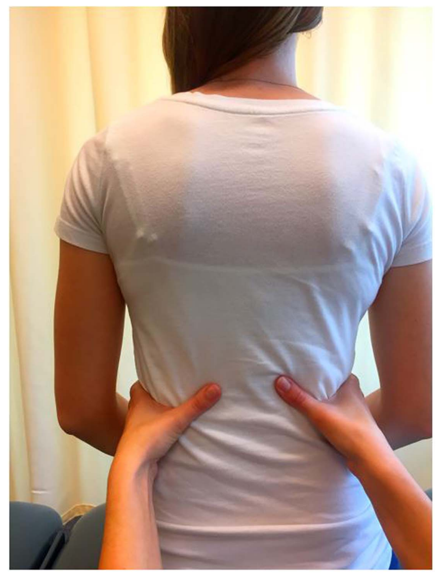

Figure 2 — Participant posture for the lateral rib expansion test in the seated test position.

Following data collection for all participants, the recordings were first edited with Camtasia (version 2.10.8; Techsmith, Okemos, MI) to deidentify the participants by cropping out their faces and were then organized by breathing test (Hi-lo and LRE) and test position (supine, seated, standing, and half-kneeling), creating 8 final videos. The videos were scored by a single investigator. Scoring of the breathing tests consisted of visual observation to identify the presence or absence of specific test criteria during 4 normal breaths and 2 maximal breaths. For the Hi-lo test, observable criteria included (1) any visible abdominal expansion and (2) any visible superior migration of the thoracic cage. Scoring of the LRE test was conducted by identifying the presence or absence of (1) any visible LRE and (2) any visible superior migration of the thoracic cage. Videos were viewed once and scored, with no rewinding or pausing of videos during scoring.

The scores for the test criteria for each breathing test and test position combination were then classified into either a functional or dysfunctional breathing pattern based on the presence or absence of the individual test criteria. For the Hi-lo test, the functional breathing category was assigned to participants who displayed visible abdominal expansion movement and no visible superior

Table 1 Indicators of Breathing Pattern Classification by Breathing Test and Test Position

Breathing test	Indicators of breathing pattern classification	Breathing pattern	Test position			
			Supine	Seated	Standing	Half kneeling
Hi-lo	Lack of abdominal excursion	Dysfunctional	0.0%, n = 0	10.2%, n = 5	16.0%, n = 8	16.0%, n = 8
	Presence of superior thoracic cage migration		6.0%, n = 3	8.2%, n = 4	8.0%, n = 4	12.0%, n = 6
	Both present		0.0%, n = 0	22.4%, n = 11	38.0%, n = 19	30.0%, n = 15
	Both absent	Functional	94.0%, n = 47	59.2%, n = 29	38.0%, n = 19	42.0%, n = 21
	Total		100.0%, n = 50	100.0%, n = 49	100.0%, n = 50	100.0%, n = 50
Lateral rib expansion	Lack of lateral thoracic cage expansion	Dysfunctional	38.0%, n = 19	0.0%, n = 0	6.0%, n = 3	2.1%, n = 1
	Presence of superior thoracic cage migration		8.0%, n = 4	42.6%, n = 20	38.0%, n = 19	85.4%, n = 41
	Both present		8.0%, n = 4	4.3%, n = 2	6.0%, n = 3	2.1%, n = 1
	Both absent	Functional	46.0%, n = 23	53.2%, n = 25	50.0%, n = 25	10.4%, n = 5
	Total		100.0%, n = 50	100.0%, n = 47	100.0%, n = 50	100.0%, n = 48

Note: Values are represented as percent (%) and frequency (n).

migration of the thoracic cage; for the LRE test, the functional breathing category was assigned to participants who exhibited visible LRE and no visible superior migration of the thoracic cage.

Pilot testing to establish a priori intrarater reliability included 10 participants and utilized similar scoring and processing methods as described in this study. All pilot testing videos were scored on the same date and rescored at least 2 weeks later. Absolute agreement between the 2 scoring sessions was calculated for the Hi-lo test at 90%, 80%, 80%, and 100% for supine, seated, standing, and kneeling positions, respectively. Absolute agreement between the 2 scoring sessions was calculated for the LRE test at 67%, 70%, 80%, and 80% for supine, seated, standing, and kneeling positions, respectively.

Statistical Analyses

Collected data were summarized descriptively using mean, SD, percent, and frequency. Cross-tabulations were used to calculate the percent and frequency of functional and dysfunctional breathing pattern observations by breathing test and test position, and the test criteria present or absent within each breathing category (functional and dysfunctional) by breathing test and test position. Differences in outcome (functional and dysfunctional) were analyzed using a generalized estimated equations approach with a logit link. Breathing test and test position, as well as the interaction of the 2 terms (full factorial), were entered as factors. Post hoc pairwise comparisons with Bonferroni correction were used to control Type I error inflation due to multiplicity. The criterion for tests of statistical significance was set at $P < .05$ (2 tailed). Data were analyzed using SPSS (version 24; IBM Corporation, Armonk, NY).

A sample size analysis indicated that 50 participants with 8 repeated measurements (test × test position) would yield .80 power, $\alpha = .05$, 2 tailed, to detect an odds ratio of 2.1.

Results

Of the 50 participants tested, 3 participant video files were lost, including 1 participant for the Hi-lo test in the seated testing position and 2 participants for the LRE test in the half-kneeling testing position, accounting for total participant number differences in presented results.

The test criteria for breathing pattern category by breathing test and test position are presented in Table 1. A significant breathing test × test position interaction ($P < .01$) was observed, as well as main effects for breathing test ($P < .01$) and test position ($P < .01$). In light of the significant interaction, we analyzed the tests separately by test position.

Based on the results of the Hi-lo test, 96.0% (47/50) of participants were classified as functional breathers in the supine test position, 59.2% (29/49) in the seated test position, 38.0% (19/50) in the standing test position, and 42.0% (21/50) in the half-kneeling test position. There was a significant effect for test position ($P < .01$) within the Hi-lo test. Specifically, there were significantly more functional breathers in the supine position compared with all other test positions ($P < .01$). There were significantly fewer functional breathers in seated compared with supine ($P < .01$) test positions, but significantly more functional breathers compared with standing and half-kneeling test positions ($P < .01$). There were significantly fewer functional breathers in standing and half-kneeling than supine ($P < .01$) and seated ($P < .01$) test positions; no differences were found between standing and half-kneeling test positions ($P = .52$).

For the LRE test, 46.0% (23/50) of participants were classified as functional breathers in the supine test position, 53.2% (25/47) in the seated test position, 50.0% (25/50) in the standing test position, and 10.4% (5/48) in the half-kneeling test position. There was a significant main effect for test position ($P < .01$) within the LRE test. Pairwise comparisons found all positions to be similar ($P > .99$) except for the half-kneeling test position, which had significantly more dysfunctional breathers compared with all other test positions ($P < .01$).

Discussion

To date, there is limited research on the Hi-lo and LRE tests as assessments of breathing mechanics and diaphragm function. Our study examined differences between these breathing tests, and how the test results were affected by the test position. We found that the

Hi-lo and LRE tests classified functional and dysfunctional breathers differently and that the Hi-lo test results were affected by testing position, with functional breathing decreasing as postural demands increase.

Altered breathing mechanics may manifest in multiple ways, so it is important to utilize appropriate clinical tests to measure different aspects of normal breathing. Because the Hi-lo and LRE tests inherently measure unique mechanics of breathing, we expected to find the results of the breathing tests to be independent of each other. This hypothesis was supported by our significant main effect for breathing test, which shows the Hi-lo and LRE tests to examine independent mechanics of breathing. Therefore, we recommend the Hi-lo and LRE tests be used in combination to gain a comprehensive assessment of breathing mechanics. Using both tests together will allow the clinician to identify changes in abdominal excursion, loss of LRE, and increased use of accessory breathing muscles, all of which can be related to altered diaphragm function.

The Hi-lo test has been described in positions of supine, seated, and standing[12,22]; however, comparison of these different body positions has not been previously studied to determine how position may affect breathing mechanics and test results. We performed the Hi-lo test in supine, seated, standing, and half-kneeling positions and found significant differences between test results in positions of supine, seated, and standing. These findings suggest that as postural demand increased, frequency of functional breathing decreased. There were progressively fewer participants categorized as functional breathers as they moved from supine to seated to standing. These findings support previous research that has linked changes in breathing patterns with increased postural demands.[2,5,7,14]

Previously, postural demands have been shown to alter diaphragm function in persons suffering from low back pain, suggesting that changes in postural demands may overload the dual role of the diaphragm and result in compromised breathing mechanics.[5–7] Kolar et al[5] identified changes in diaphragm excursion in persons with low back pain when performing isometric resistance to upper and lower limb excursions. Roussel et al[7] found changes in normal breathing mechanics, including abdominal excursion, in persons with low back pain while performing lumbopelvic motor control tests. O'Sullivan et al[14] reported similar results in persons with sacroiliac pain while performing straight leg raises. Collectively, previous research has shown that increased postural demands on the body result in increased demands on the diaphragm as a postural muscle. The results of the current study suggest that breathing mechanics, including abdominal excursion and the presence of superior rib cage migration, are affected by body position and that the results of the Hi-lo test may change as postural demands increase and breathing mechanics are compromised. Based on these results, clinicians should perform the Hi-lo test in multiple body positions to determine whether the diaphragm is able to adequately respond to changes in postural demands while maintaining normal breathing mechanics. We suggest beginning with the seated position, as this provides a moderate level of postural demand. Regression to a supine testing position would follow for those persons who have a dysfunctional breathing pattern when seated, and progression to standing would be appropriate for those who demonstrate normal breathing mechanics when seated.

In contrast to the Hi-lo test, we did not see significant changes in the LRE test results across the body positions of supine, seated, and standing. The LRE tests assess for LRE and superior rib cage migration, with functional breathing classified with LRE of 1.5 to 2 cm and no significant superior rib cage migration. LRE is an indicator of adequate diaphragm contraction that results in a change in the volume of the thoracic cavity without the need for excessive accessory muscle activation to lift the rib cage superiorly.[10] We did not find a significant difference in LRE test results across body positions in supine, seated, and standing, suggesting that LRE may not be influenced by increased postural demands on the body in these positions. We did see a significant difference in LRE test results for the half kneeling test position, where only 5/48 participants were classified as functional breathers. This finding suggests that the postural demand of the half-kneeling position may have an impact on LRE when compared with supine, seated, and standing positions. Interestingly, only about half of participants were classified as functional breathers (46.0%, 23/50) in the supine test position compared with 96% (47/50) of Hi-lo supine tests. A number of factors can contribute to a lack of LRE during breathing, including altered diaphragm activation, stiffness of the ribs, and postural alignment.[4,10] Given these results, it appears that the LRE test can be performed in supine, seated, or standing positions.

Limitations and Future Research

This study is not without limitations. The LRE test is described as a palpation and observation based test; however, the current study used only video observation of the test being performed to identify breathing criteria. Little is known about the clinical utility and measurement properties of the LRE test, so it is unknown how scoring the test through observation of the test performance may affect results. However, we believe that visually watching the test being performed and observing for lateral expansion of the ribs through the movement of the clinician's hands does represent an acceptable result for the LRE. The LRE test is commonly described as a seated or standing test with palpation occurring posteriorly—we also tested in supine using an anterior palpation approach, which may explain the lower absolute agreement that was found for this test position during pilot testing. Intrarater and interrater reliability of the Hi-lo and LRE tests have not been previously reported.

Future research on the clinical utility of the Hi-lo and LRE tests to establish intrarater and interrater reliability is warranted. In addition, studies examining differences in breathing patterns across healthy and pathologic populations using the Hi-lo and LRE tests would provide additional insight into the validity of these tests.

Conclusions

Assessment of breathing mechanics should be included in the examination of patients presenting with pain, postural deficits, poor motor control, and poor core stability because diaphragmatic function could be a contributing factor to each of these conditions. When assessing for breathing pattern dysfunction, the Hi-lo and LRE tests should be used in combination because they assess different components of breathing mechanics. Based on the results of the current study, the Hi-lo tests should be performed in multiple testing positions to determine how postural demands affect breathing mechanics, whereas the LRE test can be administered in supine, seated, or standing positions. Combination of both tests will provide the clinician with a comprehensive assessment of breathing mechanics.

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