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ORIGINAL RESEARCH

DEVELOPMENT OF A SCREENING PROTOCOL TO IDENTIFY INDIVIDUALS WITH DYSFUNCTIONAL BREATHING

Kyle Kiesel, PT, PhD[1]
Tonya Rhodes[1]
Jacob Mueller, ATC[1]
Alyssa Waninger[1]
Robert Butler, PT, PhD[2]

ABSTRACT

Introduction: Dysfunctional breathing (DB) has been linked to health conditions including low back pain and neck pain and adversely effects the musculoskeletal system. Individuals with DB often have decreased pain thresholds and impaired motor control, balance, and movement. No single test or screen identifies DB, which is multi-dimensional, and includes biochemical, biomechanical, and psychophysiological components. Several tools assess and test for DB, but no screen exists to determine whether additional testing and assessment are indicated.

Purpose/Background: The purpose of this study was to develop a breathing screening procedure that could be utilized by fitness and healthcare providers to screen for the presence of disordered breathing. A diagnostic test study approach was utilized to establish the diagnostic accuracy of the newly developed screen for DB.

Methods: A convenience sample of 51 subjects (27 females, 27.0 years, BMI 23.3) were included. To test for DB related to the biochemical dimension, end-tidal CO2 (ETCO2) was measured with a capnography unit. To test for DB related to biomechanical dimension, the Hi-Lo test was utilized. To test for DB related to the psychophysiological dimension, the Self Evaluation of Breathing Symptoms Questionnaire (SEBQ) and Nijmegen questionnaires were utilized. Potential screening items that have been shown to be related to DB in previous research and that could be performed by non-health care personnel were utilized to create the index test including activity level, breath hold time (BHT), respiration rate, and the Functional Movement Screen (FMS™).

Results: There were no strong correlations between the three measures of DB. Five subjects had normal breathing, 14 failed at least one measure, 20 failed at least two, and 12 failed all three. To develop screening items for each dimension, data were examined for association with failure. BHT and a four-item mini-questionnaire were identified as the most closely associated variables with failure of all three dimensions. A BHT of < 25 seconds and four questions were combined and yielded a sensitivity of 0.89 (0.85-0.93) and a specificity of 0.60 (0.18-0.92) for clinical identification of DB.

Conclusion: Easily obtained clinical measures of BHT and four questions can be utilized to screen for the presence of DB. If the screen is passed, there is an 89% chance that DB is not present. If the screen is failed, further assessment is recommended.

Level of Evidence: 2b

Key Words: Breath holding, disordered breathing, hypocapnia, sensitivity

[1] University of Evansville, Evansville, IN, USA
[2] Director of Performance, St. Louis Cardinals, St. Louis, MO, USA

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CORRESPONDING AUTHOR
Kyle Kiesel
Professor of Physical Therapy
University of Evansville
1800 Lincoln Avenue
Evansville, Indiana 47722
USA
E-mail: Kk70@evansville.edu

INTRODUCTION

Dysfunctional breathing (DB) is a commonly occurring condition in the general population. It is estimated that as high 50-80% of adults have some level of DB.[1,2] The term DB has been created to identify those individuals who display divergent breathing patterns and have breathing problems that cannot be attributed to a specific medical diagnosis, such as asthma.[3] Normal breathing, considered to be diaphragmatic breathing, includes synchronized motion of the upper rib cage, lower rib cage, and abdomen and requires proper use of the diaphragm.[4]

DB has been linked to a number of common chronic health conditions such as low back pain (LBP),[5,6] neck pain,[7] anxiety,[8] and depression.[2] It has been reported that approximately 50% of individuals with LBP[9] and 83% of individuals with anxiety demonstrate some form DB.[10] A wide-range of individuals likely possess some level of DB, and currently there is no widely accepted screen or index test that exists to identify these individuals.[2] Identification and subsequent intervention for those with DB may be an important missing component of musculoskeletal health care as DB is known to be associated with many common musculoskeletal conditions and may also be a risk factor for the development of musculoskeletal dysfunction.[11] DB may be an important factor to consider relative to the prevention and recurrence of movement oriented dysfunction[12] and, therefore, may have a place in conditioning and fitness programs as well.

The primary reason to screen for DB in individuals who are physically active or currently have musculoskeletal pain is its close relationship with normal core function.[9,13] To better understand core structure and function as it relates to DB, it is important to note the core can be divided into two basic anatomical units,[14] the outer core and the inner core. The outer core is composed of large multiarticular muscles such as the erector spinae, rectus abdominis, and external obliques. The function of the outer core is to provide postural stability, resist external load, produce movement, and transfer rotational energy for activities such as throwing and hitting.[15] The inner core can be conceived as a cylinder made up of the pelvic floor as the base, the diaphragm as the top, the transverse abdominis muscle as the anterior border, and the lumbar multifidus muscles as the posterior border.[16] The function of the inner core is both physiological and mechanical, its main role is to provide the muscle activation required to sustain respiration, continence, and segmental spinal stabilization.[16] The inner core receives ongoing subconscious input from the central nervous system (CNS), which automatically maintains respiration,[9] continence, and segmental stabilization in anticipation of a spinal perturbation. This is a highly automated, delicately functioning system with the ability to simultaneously regulate physiological functions (respiration and continence) while allowing for control of translation and shear forces (segmental stabilization) between spinal segments during both low and high load activities.[17]

Core muscle dysfunction, including atrophy and abnormal activation, has been linked to many common musculoskeletal problems including LBP,[9] ACL injury,[18] neck pain,[7] and an overall increased injury risk.[19] Subjects with DB have been shown to demonstrate concurrent core dysfunction including altered postural responses during limb movements[5] and altered inner core muscle activation.[9,13] Further, normal breathing has been described as forming the foundation for all movement patterns[12] while DB has been shown to be related to clinical measures of dysfunctional movement with subjects with DB scoring lower on the Functional Movement Screen (FMS™) than those with normal breathing.[11]

It is thought that core muscle function is altered in those with DB in a compensatory manner. The physiological drive to maintain respiration leads to core muscles functioning to assist breathing to a greater extent than during normal functional breathing.[16,20] This relationship between normal breathing and core function is so intimately linked that perhaps the most fundamental assessment of core function should start with some type of breathing screen or test. Core exercises are often prescribed as part of rehabilitation, fitness, and strength and conditioning programs with no attention paid to breathing function. It may be desirable for fitness and health care professionals who prescribe core exercises to utilize a breathing screen to determine if subsequent breathing pattern assessment and treatment is necessary in conjunction with planned rehabilitation, training, or conditioning.

There is currently no accepted screening procedure to identify if a person may have DB and, therefore, requires further testing and assessment. Research has shown that DB is multi-dimensional, calling for a variety of tests needed for an accurate diagnosis.[11] Recently, researchers have identified the three most common dimensions or categories of DB which include the biochemical, biomechanical and psychophysiological dimensions.[21] It has been suggested that any comprehensive assessment for DB should include tools that capture all three of these dimensions as they are often found to be independent from each other.

The biomechanical dimension of DB refers to individuals who are in an abnormal mechanical breathing pattern. A subject demonstrating a breathing pattern disorder would be lacking what is considered a normal diaphragmatic breathing pattern while at rest. A clinical measure to determine presence of DB in the biomechanical dimension is the Hi-Lo Breathing Assessment. The most common disordered breathing pattern at rest is described as upper chest breathing or apical breathing. In this pattern, an upper chest expansion is dominant during the inspiratory phase of breathing.[22] Another example of a disordered breathing pattern has been described as a paradoxical pattern where the lower abdomen is drawn in, rather than outward, during the inspiratory phase.[23]

The biochemical dimension refers to individuals who are in a state of hypocapnia demonstrating reduced levels of CO2 in the blood. Capnography is a reliable and time sensitive clinical measure of respiratory function that measures the partial pressure of CO2 in exhaled air termed end tidal CO2 (ETCO2).[24,25] ETCO2 has good concurrent validity when compared to direct blood measures. A value of 35 mmHg and below is commonly used as a cut-point to define hyocapnia.[26]

The psychophysiological dimension, sometimes called the breathing symptoms dimension, is the least commonly identified and explored category of DB and is characterized by individuals who may breathe normally during most daily activities, however, breathing may become abnormal in certain, often stressful situations. This suggests a lack of the individual's system to adapt to a meaningful breathing strategy at times; however, the system does have the ability to function in a normal manner. In such cases, measures of DB can often appear normal during routine clinical testing. Self-reported questionnaires may be useful capture this dimension of DB and include the Nijmegen Questionnaire,[27] and the more recently developed Self Evaluation of Breathing Symptoms Questionnaire (SEBQ). The SEBQ was developed, in part, to assess respiratory symptoms and breathing behaviors reported to be associated with DB for individual who may not demonstrate consistent breathing dysfunction in the biomechanical or biochemical dimensions.[21]

While there are several assessment and testing tools described in the literature to identify individuals with each of the three different dimensions of DB, no one reference test has emerged that can be used to capture all three dimensions. Currently, there is no accepted clinical screening procedure to determine if a subject could even benefit from further breathing assessment and testing. Therefore, there is a need for a breathing screening procedure that could be utilized by both fitness and healthcare professionals. A screen, defined as "a preliminary procedure, such as a test or examination, to detect the most characteristic sign or signs of a disorder that may require further investigation" should be highly sensitive in nature.[28] That is, when the screening procedure yields a negative result (passing the screen), the tester is confident that the condition does not exist. When the screening procedure yields a positive result (not passing the screen), the condition may exist and further testing and assessment is warranted. Because of the growing evidence linking DB to a wide variety of health conditions, a sensitive screening tool, designed to capture those individuals who would likely benefit from a detailed breathing assessment and subsequent intervention, would be desirable. If a battery of tests can be combined and used as a screen to identify those in the fitness and general population who have disordered breathing, it could be deployed as a screening tool for disordered breathing in the fitness and general population. Therefore, the purpose of this study was to develop a breathing screening procedure that could be utilized by fitness and healthcare providers to screen for the presence of disordered breathing.

METHODS

Subjects: A convenience sample of 51 individuals, including 27 females, (26.5 years, BMI 22.7) and 24 males (28.3 years, BMI 24.9) consented for participation in this study which was approved by the Institutional Review Board at the University of Evansville. Data for this prospective diagnostic test study were collected in a University lab setting from September to November 2015. Potential subjects were excluded if they were currently participating in rehabilitation for any disorder, if they had a neurological or cardiovascular comorbidity known to impair musculoskeletal function, or if they could not read or speak English. To determine if DB was present, reference measures were obtained for each of the three dimensions of DB. The data collection process was done in the same manner at each data collection session with the same three testers performing the same tests each time in the same order. The reference measures and the potential screening tests measures were combined in a manner that was designed to be as efficient as possible and allowed for blinding of the testers to the results of the reference measures. After consent was obtained, resting capnography data was collected as subjects completed the questionnaires. Next, the Hi-Lo test was performed, followed by the BHT tests and then, lastly, the FMS™ was performed.

Reference Measures

Biomechanical Dimension

To determine if a subject had a biomechanical breathing problem, the Hi-Lo Breathing Assessment[29] was utilized as the reference. The Hi-Lo is a manual assessment to determine if a subject is in a normal diaphragmatic breathing pattern or if they are in an abnormal pattern. It was performed in the sitting position with the tester standing or kneeling at the front and slightly to the side of the subject. The tester placed one hand on the subject's sternum and one hand on their upper abdomen to determine whether thoracic or abdominal motion is dominant during breathing. Assessment for paradoxical breathing is also performed by determining if the abdomen moves in a direction opposite to the thorax during breathing; this is evident during inhalation if the abdomen moves toward the spine, and during exhalation if the abdomen moves in an outward direction. The scoring process was as follows: Is the upper chest dominant? If yes scores as dysfunctional and stop, if no continue. Is the pattern paradoxal? If yes score as dysfunctional and stop, if no continue. Is diaphragm dominant? (greater volume and diaphragmatic movement is first), if yes score as functional, if no score as dysfunctional. The Hi-Lo test reliability has been reported by others as acceptable,[23] and the researchers in this study achieved 88% agreement with a Kappa = .75 on 43 subjects assessed during data collection.

Biochemical Dimension

To determine if a subject had a biochemical breathing problem, capnography was utilized as the reference measure. Capnography is a measurement taken via nasal cannula to determine ETCO2. The average resting value over a three minute data collection period was utilized to obtain the measure, and the standard value of < 35 mmHg was utilized as the cut-off for dysfunction.[24-26] The capnography unit (CapnoTrainer, Better Physiology Ttd. Boulder, CO, USA) was calibrated according to the manufacturer recommended procedure prior to each data collection session. Respiration rate in breaths per minute was calculated from the capnography data.

Psychophysiological Dimension

To address the psychophysiological dimension, two separate breathing questionnaires were administered. The Nijmegen Questionnaire is a 16-item questionnaire developed in the 1980's to identify patients who have breathing dysfunction that emphasizes relationships with common diseases. A cut score of ≥ 22 on the Nijmegen was utilized to define DB.[30] The Self-Evaluation of Breathing Questionnaire (SEBQ), Version 3[31] is a questionnaire that includes 25 questions to determine self-perception of breathing dysfunction. Test-retest reliability has been shown to be high[32] and a cut score of ≥ 25 on the SEBQ was utilized to define DB for this study. The SEBQ is a new tool, and there is no established cut-score confirmed in the literature to define those with this dimension of breathing dysfunction. Expert opinion suggests a score of 25 as an appropriate cut-score. All subjects completed both questionnaires and scoring above the established cut-score on either questionnaire was used as the reference measure for the psychophysiological dimension.

Screening Tests

Clinical tests that the researchers hypothesized may be associated with DB were also performed. Tests administered included those that were most closely associated with DB from the current literature. Additionally, each test had to be easily obtained by a non-healthcare provider so the screen could be employed in a fitness setting.

Breath hold time (BHT) was measured by testing the functional residual capacity, also known as the controlled pause method which is a measure of how long a subject can hold their breath starting at the end of a normal exhale until first involuntary muscle activity was noted by the tester. This BHT test is described by Courtney and Cohen[33] to be the most reproducible method because involuntary motion of the respiratory muscles has been found to be more of a consistent measure of breaking point of breath holding than the self-report of the sensation of the urge to breathe, which is an alternative method to assess BHT. The researches measured inter-tester reliability on BHT between two testers and found the $ICC_{3,2}$ = 0.88 (0.78-0.93). BHT has been shown to be reduced in those with DB, and it has been suggested that reduced BHT may indicate problems in respiratory control that result in DB.[33,34] The BHT test was performed with the subject in sitting. They were instructed to sit quietly and breathe normally, then, at the end of a normal exhalation, to pinch their nose and hold the breath. The time was started when the subject pinched the nose and was stopped at the first involuntary movement of the respiratory muscles or when the subject unplugged the nose, as determined by the tester.

Respiration rate (RR) was measured in breaths per minute. Higher than normal RR have been shown to be associated with DB.[22] The RR data was obtained from the capnography unit data output.

Activity level was measured using a standard questionnaire. The questionnaire, similar to the Tegner Activity Scale, is scored from a high of 10 (competitive sports) to a low of 1 (sedentary). The questionnaire can be found in Appendix 1. It was hypothesized that those with lower activity levels would be more likely to have DB.

The FMS™ was used as a measure of movement dysfunction. Previous research has demonstrated that those scoring lower on the FMS™ (more dysfunctional movement) also had a greater tendency to demonstrate signs of DB.[11] In the research, Bradley and Esformes demonstrated that subjects who scored lower on the FMS™ were more likely to demonstrate an abnormal biomechanical breathing pattern (upper chest breathing) and more likely to be hypocapnic, demonstrating significantly lower ETCO2 values. These findings were present both when the composite score with a cut point of ≤ 14 on the FMS™ was utilized to define movement dysfunction and when a "pass/fail" approach (pass = no 0's and no 1's, fail = any score of 0 or 1) was utilized to define movement dysfunction. The FMS™ is a reliable[35-41] (ICC values ranging from 0.76-0.90 and Kappa values from 0.70-1.0) movement-screening tool created to rank basic movement patterns. The FMS™ includes seven movements: overhead deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability pushup, and rotary stability. Each of these patterns is graded on a 0-3 ordinal scale where 0 represents pain with the movement, 1 represents dysfunctional movement, 2 represents acceptable movement, and 3 represents optimal movement.

STATISTICAL METHODS

The first step was to dichotomized subjects according to their performance on the reference tests for DB. Subjects who scored below the stated cut-score on one or more of the reference tests were classified as having DB, and those above the cut score on each of the reference tests were classified as having normal breathing. Next, the data were explored to help determine what index tests should be included as a screen for DB. One-way ANOVA's were utilized to determine if there were any significant differences between subjects who were classified as DB compared to those who were not on the clinical tests and measures obtained to create the index test. The clinical tests and measures included activity level, breath hold time, respiration rate and the FMS™. Next, 2x2 contingency tables and routine diagnostic test statistics were utilized to test different combinations of the measures with the goal of identifying those measures that would yield the greatest sensitivity relative to an individual subject's probability of being positive on any of the 3 dimensions of DB as described.

RESULTS

Five subjects demonstrated normal breathing, 13 failed at least one measure, 21 failed at least two, and 12 failed all three. There were no correlations between the three measures of DB.

Activity Level

There was a difference in activity level between those who passed (6.78) and failed (4.81), $p < 0.01$, the Hi-Lo test. There was a difference in activity level between those who passed (5.53) and those who failed (4.25), $p = 0.02$, the questionnaires. No difference in activity level was found between those who were above or below the normative value for ETCO2 of 35 mmHg ($p = 0.83$) (Tables 1-3).

Table 1. *Clinical tests results for biochemical dimension of dysfunctional breathing as defined as a resting End-Tidal CO2 (ETCO2) < 35mmHg.*

	Pass N = 24	Fail N = 27	F	p value
Activity Level	5.4 (1.5)	5.3 (2.3)	0.05	0.83
Breath Hold Time	22.9 (8.5)	21.4 (9.5)	0.38	0.54
FMS™ score	14.4 (2.4)	13.9 (2.4)	0.53	0.47
Respiration Rate	15.0 (3.3)	16.7 (3.9)	2.70	0.11

Activity Level Questionnaire is on a 10-point scale with higher values indicating higher activity level (standard deviation).
Breath Hold Time= Breathing holding at Functional Residual Volume measured in seconds (standard deviation).
FMS™= Functional Movement Screen which includes seven different movements each scored on a 0-3 ordinal scale.

Table 2. *Clinical tests results for biomechanical dimension of dysfunctional breathing (Hi-Lo Test).*

	Pass N = 14	Fail N = 37	F	p value
Activity Level	6.8 (1.2)	4.8 (1.9)	12.6	< 0.01
Breath Hold	25.5 (9.5)	20.9 (8.6)	2.8	0.10
FMS™ score	16.0 (1.6)	13.5 (2.3)	13.3	< 0.01
Respiration Rate	16.2 (3.8)	15.8 (3.7)	0.07	0.79

Activity Level Questionnaire is on a 10-point scale with higher values indicating higher activity level (standard deviation)
Breath Hold Time- Breathing holding at Functional Residual Volume measured in seconds (standard deviation).
FMS™- Functional Movement Screen which includes 7 different movements each scored on a 0-3 ordinal scale.

Table 3. *Clinical tests results for the breathing symptoms dimension of dysfunctional breathing as measured by the Self-Evaluation of Breathing Symptoms Questionnaire (SEBQ) >25 or Nijmegen Breathing Questionnaire >22.*

	Pass N = 47	Fail N = 4	F	p value
Activity Level	5.5 (1.9)	3.3 (1.9)	5.40	0.02
Breath Hold	22.4 (9.3)	18.8 (3.9)	0.58	0.45
FMS™	14.4 (2.3)	11.8 (2.9)	4.70	0.03
Respiration Rate	15.8 (3.7)	17.1 (3.9)	0.43	0.52

Activity Level Questionnaire is on a 10-point scale with higher values indicating higher activity level (standard deviation).
Breath Hold Time- Breathing holding at Functional Residual Volume measured in seconds (standard deviation).
FMS™- Functional Movement Screen which includes 7 different movements each scored on a 0-3 ordinal scale.

Table 4. *Mean, standard deviation and ANOVA results between subjects in each dysfunctional breathing dimension(s) and clinical tests hypothesized to be associated dysfunctional breathing.*

	0 n=5	At Least 1 n=13	At Least 2 n=21	All 3 n=12	F	p value
Age Mean and (SD)	29.4 (9.9)	25.9 (6.0)	28.8 (9.5)	24.1 (4.9)	1.16	0.34
BMI Mean and (SD)	25.4 (3.7)	23.3 (2.7)	22.3 (3.3)	24.6 (5.6)	1.42	0.25
Activity Level	5.8 (1.3)	6.3 (1.8)	5.1 (1.7)	4.5 (2.5)	2.06	0.12
Breath Hold	23.9 (5.8)	24.3 (9.5)	21.6 (9.5)	20.1 (9.2)	0.53	0.66
FMS™	16.0 (1.9)	14.8 (2.7)	14.2 (2.0)	12.8 (2.6)	2.67	0.06
Respiration Rate	15.7 (2.0)	16.4 (3.9)	15.4 (3.7)	16.5 (4.2)	0.29	0.83

Activity Level Questionnaire is on a 10-point scale with higher values indicating higher activity level (standard deviation).
Breath Hold Time- Breathing holding at Functional Residual Volume measured in seconds (standard deviation).
FMS™- Functional Movement Screen which includes 7 different movements each scored on a 0-3 ordinal scale.

Breath Hold Time

There was not a significant difference in BHT between those who passed (25.53 seconds) and failed (20.88 seconds) the Hi-Lo (p = 0.10). There were no significant differences in BHT or ETCO2 between those who passed or failed the questionnaires (Tables 1-3).

Functional Movement

There was a difference in composite FMS™ scores between those who passed (16.0) and failed (13.5) the Hi-Lo ($p < 0.01$). There was a difference in composite FMS™ scores between those who passed (14.41) and failed (13.5) the questionnaires (p = 0.03). No difference in composite FMS™ scores was found between those above or below the normative value for ETCO2 of 35 mmHg (p = 0.47) (Tables 1-3). When the FMS™ was considered from a pass/fail perspective (fail = any 1's or 0's), there was a difference in ETCO2 between those who passed (36.59 mmHg) and those who failed (33.87 mmHg) the FMS™ (p = 0.03).

Respiration Rate

There were no differences RR between subjects who passed or failed any of the measures of DB (Tables 1-3).

Severity

There were no significant differences in mean values of each of the clinical tests performed and severity of DB considering subjects that had no positive reference tests, n = 5, at least one positive test (n = 13), at least two positive tests (n = 21) and all three positive tests (n = 12) (Table 4).

Table 5. *Results from using Pass/Fail on the FMS™ only as a potential screen to predict those with dysfunctional breathing.*

	Dysfunctional Breathing Present	Normal Breathing
FMS™ Fail	24	1
FMS™ Pass	22	4

FMS™ Fail= subject scores a 0 or 1 on any movement;
FMS Pass= Subject scores no 0's or 1's on movements.

Sensitivity = 0.52 (0.47-0.54)
Specificity = 0.80 (0.31-0.98)
Positive LR = 2.61 (0.68-51.31)
Negative LR = 0.60 (0.46-1.70)

The only clinical test that related in some manner to all three dimensions of DB was the FMS™. Although a correlation exists between lower scores on the FMS™ and DB, when tested as a screen for DB using the FMS™ Pass/Fail criteria only, the results yielded a low sensitivity of 0.52 (Table 5).

Because activity level had relationships with some aspects of DB, a ROC curve was utilized to determine if there was a meaningful cut-point that discriminated between those with and without DB. There was no clear cut-point with the AUC from the ROC curve = 0.44.

Exploration of the data continued for trends and possible combinations of tests or questions that could provide the best clinical screen that captured those subjects who had 1, 2, or all 3 dimensions of DB.

Because BHT of < 20 seconds has been described in the literature as a clinical measure related to those with DB, it was tested alone as a possible screen at two different cut points. When using BHT alone with a 20 second cut-off the sensitivity was 0.54 (0.49-0.58) and specificity was 0.60 (0.18-0.92) (Table 6). Then the cut score of BHT at 25 seconds was assessed, and the sensitivity improved to 0.74 (0.69-0.77) (Table 7).

The BHT cut score of 25 seconds improved the sensitivity but there were still a fairly high number of false negatives, 12 subjects that were above the cut-score on the BHT of 25 seconds but were still diagnosed by the reference as having at least one dimension of DB present.

Next, the data from the questionnaires were analyzed to determine if adding in one or more questions could help to strengthen the proposed breathing screen. Each question from the questionnaires was investigated by identifying those questions that were most often scored at the higher levels of dysfunction. The SEBQ is scored on a four-level ordinal scale (0- never/not true at all; 1- occasionally/a bit true; 2- frequently-mostly true; and 3- very frequently/very true) so any question from the SEBQ scored as a 2 or 3 was utilized. The Nijmegen is scored on a similar five-point ordinal scale but it is scaled 0-4 (0- Never, 1- Rare, 2- Sometimes, 3- Often, and 4- Very Often) so any question scored as a 3 or 4 was utilized. Frequency counts of those questions that subjects most often scored at these higher levels of dysfunction were calculated and it was determined that SEBQ questions #5 and #25 and Nijmegen questions #2 and #14 were the most important questions to ask to help to identify those who have some level of DB. Those subjects who answered at least one of the four questions at this higher level, did have a statistically significant relationship, Chi-Square = 0.03 (see Appendix 2). Because of this significant relationship, a mini-questionnaire was created that consisted of these four questions and added this to the 25 second BHT cut-off to see if the sensitivity improved with the addition of the questions. With the combination of the BHT cut-score of 25 and the mini-questionnaire as the reference test, the sensitivity increased to 0.89 (0.85-.093) with LR- = 0.18 and a specificity of 0.60 (0.18-0.92) with LR+ = 2.33 (Table 8).

Table 6. *Results from using only the breath hold test (BHT) < 20 seconds as a potential screen to predict those with DB.*

	Dysfunctional Breathing Present	Dysfunctional Breathing Absent
BHT < 20 sec	25	2
BHT >20 sec	21	3

Dysfunctional Breathing defined as any one of the following:
Resting End-Tidal CO of < 35 mmHg
Positive Hi Lo Breathing Assessment
Scoring above the threshold on either the Self-Evaluation of Breathing Symptoms Questionnaire (>25) or the Nijmegen Breathing Questionnaire (>22)

Sensitivity = 0.54 (0.50-0.58)
Specificity = 0.60 (0.18-0.93)
Positive LR = 1.36 (0.60-7.82)
Negative LR = 0.76 (0.46-2.85)

Table 7. *Results from using the breath hold time (BHT) of < 25 as a potential screen to predict those with dysfunctional breathing.*

	Dysfunctional Breathing Present	Dysfunctional Breathing Absent
BHT < 25	34	2
BHT ≥ 25	12	3

Dysfunctional Breathing defined as any one of the following:
Resting End-Tidal CO of < 35mmHg
Positive Hi Lo Breathing Assessment
Scoring above the threshold on either the Self-Evaluation of Breathing Symptoms Questionnaire (>25) or the Nijmegen Breathing Questionnaire (>22)

Sensitivity = 0.74 (0.69-0.77)
Specificity = 0.60 (0.18-0.93)
Positive LR = 1.85 (0.84-10.39)
Negative LR = 0.44 (0.24-1.73)

DISCUSSION

In this study, four questions and a breath hold time test, used in combination, were found to be highly sensitive to identify those with some dimension of dysfunctional breathing. Only tests that could be performed by non-healthcare personnel were considered, to allow the screen to have utilization in fitness applications as well as the rehabilitation fields. When screening for a possible measureable disorder,

Table 8. *Results for the final screen for dysfunctional breathing including breath hold time of < 25 seconds and/or any one question positive from the mini-questionnaire.*

	Dysfunctional Breathing Present	Dysfunctional Breathing Absent
Screen Positive	41	2
Screen Negative	5	3

Sensitivity = 0.89 (0.85-0.93)
Specificity = 0.60 (0.18-0.92)
Positive LR = 2.23 (1.03-11.92)
Negative LR =0.18 (0.08-0.85)

the tool used should be highly sensitive, that is, when the screen is negative you are fairly confident that the disorder is not present. It is important to realize when the results of a highly sensitive screen are positive, it may not confirm the disorder, rather, it suggests further testing or assessment is warranted. It is recommended that in those individuals, either fitness or rehabilitation clients who are positive on this screen, further testing and assessment for DB be performed by a qualified healthcare provider.

There is no standardized and well-accepted clinical assessment for DB. A comprehensive review by CliftonSmith and Rowley[42] stated that the lack of a definitive assessment tool makes diagnosing breathing disorders difficult. They suggest that a comprehensive assessment should include a wide variety of measures including an accurate medical history and understanding of the subjects musculoskeletal status, a visual and hands on assessment of breathing and muscle status, self-reported questionnaires, a breathing hold time, peak expiratory flow rate and pulse oximetry. Additionally, spirometry and capnography may be used if available. As the awareness of DB grows there will be a need to standardize assessment tools for both rehabilitation and fitness settings.

Several authors have demonstrated that breathing re-training programs are effective,[43-45] but the outcome tools utilized and the populations studied vary widely making it challenging to become widely accepted in the medical literature. It would be ideal to standardize a breathing screen, tests, and an assessment to better understand which intervention approach is most effective for each type of DB. To do this will require an approach similar to the treatment based classification system utilized for patients with acute low back pain where clinically captured data allows for the creation of diagnostic categories.[46,47] Establishing diagnostic categories of DB may serve to clarify the complex nature DB and help to standardize future research efforts.

Data from this study are similar to those of Courtney et al[21] who demonstrated that DB has three distinct dimensions and that they often do not correlate well, suggesting a need to screen for the condition of DB overall and then have further assessments that can be performed to identify which dimension(s) of DB, if any, are present. These data are in agreement with Bradley[11] as well where they showed a relationship between two of the three dimensions of DB but that all three were not closely correlated, again suggesting the need to assess for all three dimensions. The current study did show a relationship between AL and two of the three dimensions, biomechanical and breathing symptoms. The BHT was not significantly correlated with any dimension of DB from a univariate perspective, but did contribute to the final screen.

The results from the current study were similar to Bradley[11] in that we both showed a relationship between being a predominately thoracic breather and having poor movement. While Bradley reported a correlation between lower ETCO2 and lower FMS™ scores, the data from this study was analyzed differently. When the FMS™ was considered as a pass/fail variable, there was a relationship with lower ETCO2 and failing the FMS™, but when the FMS™ was analyzed as a continuous variable there were not differences in FMS™ scores between those above or below the normative value for ETCO2 of 35 mmHg ($p = 0.47$). Because the FMS™ mean scores for most populations have a small range, normally between 13-15 on the composite score, and the composite score in and of itself may not be that useful, the recommendation is to consider FMS™ information on a pass/fail basis as much as possible. One can conclude an individual failing the FMS™ is more likely to be a thoracic breather and have a lower ETCO2. Additionally, scoring lower on the FMS™ from a composite perspective will more likely be associated with failing the SEBQ, demonstrating the presence of breathing symptoms. But, taken together, using only the FMS™ score to screen for DB yielded a sensitivity of only 0.52 and, therefore, is not recommended. In this case, although the FMS™ had a statistical relationship with DB, it yielded a low sensitivity because there were 22 subjects who passed the FMS™, but did have some dimension of DB. These were false negatives that lowered the sensitivity. From these data, the FMS™ alone should not be used as a screen for breathing.

While there was a univariate trend in lower BHT being related to the biomechanical dimension, when BHT was applied with a cut score of 25 seconds, the sensitivity strengthened substantially; along with adding in the mini-questionnaire, all three dimensions of DB were captured. A breath hold time of 20 seconds has been proposed as a cut-off to identify those with hyperventilation syndrome. Jack et al[34] reported a mean BHT of 20 (SD 12) seconds in individuals with known breathing dysfunction which compares closely to the mean of 21.9 (SD 9.3) seconds from the current study in those who were considered positive on any one or more of the reference tests used for DB.

A limitation to this study is that the sample size is considered small to establish a new screening tool. The next step is to perform a validation study of the breathing screen with another sample of subjects. Additionally, only five subjects passed all the tests performed for DB indicating a high incidence (90%) of DB in this population, which is higher than expected. The threshold of 25 seconds is challenging to achieve and it will take further research in more diverse samples to determine if this threshold can be validated. Also, the activity level questionnaire utilized in the current research is a modified version of the Tegner Activity Scale.[48] Although similar, this tool has not been validated in the literature to date.

CONCLUSION

Easily obtained clinical measures of BHT and four questions can be utilized to screen for the presence of DB. If the screen is passed, there is a 89% chance that DB is not present. If the screen is failed, further assessment is recommended to determine if DB breathing is present and if so, which dimension is affected. Additionally, these findings help to validate previous findings that link movement and breathing dysfunction.

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Appendix 1. *Activity rating scale.*

Instructions: *This survey is used to assess your overall activity level. Read through each of the activity levels listed and please* ***circle the number that best corresponds with your average activity level over the last two months.***

10	*Competitive team sports* (4-7 days per week, varsity team or professional level)---requires jumping, cutting and hard pivoting such as football, basketball, soccer, volleyball, gymnastics, rugby
9	*Competitive sports* (4-7 days per week, varsity team or professional level)---requires running, twisting, and turning such as tennis, racquetball, handball, ice hockey, field hockey, skiing wrestling, track and field, baseball, lacrosse
8	*Competitive endurance athlete* (4-7 days per week) including aerobic activity such as running, swimming, biking and may include associated strength training or associated group program or intense fitness programs such as crossfit, insanity, kettlebells etc……
7	*Recreational sports/fitness* (at least once per week)---requires jumping, cutting and pivoting such as football, basketball, soccer, volleyball, gymnastics, rugby, tennis, racquetball, handball etc….. And associated individual or group workouts at least an additional 3 days per week
6	*Fitness athlete* (Less than 4 days per week) including aerobic activity such as running, swimming, biking and may include associated individual strength training or associated group program or intense fitness programs such as crossfit, insanity, kettlebells etc……
5	*Fitness* (4-7 days per week) including group programs such as aerobics, spinning, zumba, and/or other bouts of exercise such as running, swimming, biking for fitness and may include associated weight training
4	*Fitness* (Less than 4 days per week) including group programs such as aerobics, spinning, zumba, and/or other bouts of exercise such as running, swimming, biking for fitness and may include associated weight training
3	*Recreational fitness/sports* (at least once per week)-- aerobic exercise such as walking or bike riding or swimming. Recreational sports such as tennis, golf etc…. for leisure only
2	*Occasional fitness/sports* (Less than once per week)-- aerobic exercise such as walking or bike riding or swimming. Recreational sports such as tennis, golf etc…. for leisure only
1	*Sedentary*- No planned physical activity for fitness or leisure purposes

Appendix 2

Tabulations of how the mini-questionnaire was developed showing the questions with the highest frequency counts of subjects who scored either of the 2 higher levels of dysfunction. Each question is scored on a four-point ordinal scale from each of the self reported questionnaires utilized.

The Nijmegen is scored on a five-point ordinal scale from 0-4 (0- Never, 1- Rare, 2- Sometimes, 3- Often, and 4- Very Often) so any question scored as a 3 or 4 was utilized.

These 2 questions from the Nijmegen were the most frequently scored at the high end of dysfunction (a score of 3 or 4):

Do you feel tense? 10 subjects

Do you feel a cold sensation in your hands or feet? 14 subjects

The SEBQ is scored on a 4-point ordinal scale from 0-3. (0- never/not true at all, 1- occasionally/a bit true, 2- frequently-mostly true, and, 3- very frequently/very true)

so any score of 2 or 3 was utilized. These two questions from the SEBQ were the most frequently scored at the high end of dysfunction (a score of 2 or 3):

Do you notice yourself yawning? 8 subjects

Do you notice breathing through your mouth at night? 8 subjects

Below is the 2 x 2 table used to calculate the Chi Square demonstrating a significant difference between frequency of subjects scoring the four questions and presence of dysfunctional breathing.

	Dysfunctional Breathing Present	Dysfunctional Breathing Absent
At least one question scored 2 or 3?	26	0 (.5)
No questions scored 2 or 3	20	5

Dysfunctional Breathing defined as any one of the following:
Resting End-Tidal CO of < 35mmHg
Positive Hi Lo Breathing Assessment
Scoring above the threshold on either the Self-Evaluation of Breathing Symptoms Questionnaire (>25) or the Nijmegen Breathing Questionnaire (>22)
Chi Square significant, $p = 0.03$