

# Correlation of Core Endurance with Breath Hold Time in Normal Young Adults

Dr. Sushama A Bhandare<sup>1</sup>, Dr. Khushbu Arun Lichade\*<sup>1</sup>, Dr. Vishakha Mulaokar<sup>2</sup>

<sup>1</sup>Assistant Professor, Department of Physiotherapy, Seth GSMC & KEMH, Mumbai, India 400012

<sup>1</sup>Postgraduate Student, Department of Physiotherapy, Seth GSMC & KEMH, Mumbai, India 400012

<sup>2</sup>Postgraduate Student, Department of Physiotherapy, Seth GSMC & KEMH, Mumbai, India 400012

Email address: physiotherapistdrkhushbu@gmail.com

**Abstract**— Core endurance refers to the ability of the trunk muscles to sustain prolonged contraction and maintain stability, whereas breath-hold time (BHT) is a measure of cardiopulmonary reserve, reflecting the duration an individual can voluntarily hold their breath. The diaphragm, an essential component of the core, plays a crucial role in respiration and breath control. This study aims to investigate the correlation between core endurance and BHT in normal young adults, given the paucity of literature on this subject. A correlational study was conducted with 62 participants (31 males, 31 females) aged 20 to 25 years. Core endurance was assessed using the McGill protocol, which evaluates flexor, extensor, and side bridge endurance times. BHT was recorded after a standardized rest period, with the best of three trials considered. Spearman correlation analysis demonstrated a significant moderate positive correlation between BHT and Flexion Completion Time ( $r = 0.400$ ,  $p = 0.001$ ), Extension Completion Time ( $r = 0.468$ ,  $p < 0.001$ ), Right Side Bridge Completion Time ( $r = 0.337$ ,  $p = 0.007$ ), and Left Side Bridge Completion Time ( $r = 0.327$ ,  $p = 0.01$ ). The study concluded that core endurance had a significant positive correlation with BHT, suggesting that individuals with greater core endurance tended to have better breath-holding capacity.

**Keywords**— Breath Hold Time, Core Endurance, McGill protocol, Normal young adults.

**Abbreviations**— FCT = Flexion completion time, ECT = Extension completion time, RSBCT = Right side bridge completion time, LSBCT = Left side bridge completion time, BHT = Breath hold time, F = flexion, E = extension, RSB = right side bridge, LSB = left side bridge

## I. INTRODUCTION

The core consists of a group of trunk muscles that surrounds the spine and abdominal organs [1]. The core muscles refer to the muscles in the torso that help stabilize the spine, pelvis, and shoulder girdle, providing a stable base for movement. These muscles are important for posture, balance, and movement. The core is composed of several interconnected muscle groups i) Deep Core Muscles which are the stabilizers and ii) Superficial Core Muscles which are the Movers [29].

Core strength is the trunk muscles capacity to produce force. Based on this, core strength can be evaluated from the perspective of maximum strength, power or even ability to maintain force over time, which is called strength-endurance [3]. Core endurance refers to the capacity to sustain a posture or carry out repeated movements over time. Core endurance contributes to prolonged core stabilization, enabling efficient and sustained force generation and transfer during both athletic performance and everyday functional activities. [3] [4] Core endurance plays an important role in maintaining postural stability. It refers to the ability of core muscles to sustain contraction over extended periods, which is crucial for effective force transfer and stability during various physical activities. Breathing is the physiological process of moving air in and out of the lungs, which allows for oxygen to be absorbed into the bloodstream and carbon dioxide to be expelled. Breath-holding refers to the voluntary or involuntary cessation of breathing, often explored in scientific studies to understand respiratory physiology, diving physiology, and various adaptive mechanisms of the human body [32]. The duration of the breath hold is measured in seconds. It is

dependent on multiple variables such as lung volumes, respiratory muscle functioning, disease states and training level and is frequently used as an indicator of pulmonary function owing to its positive correlation to spirometric indices [5] [7]. Normal duration is 45-55 seconds, [37][38] Indian Male (60+) 28 +/- 8 and for Indian Female (60+) 26 +/- 6; [39] diminished cardiac or pulmonary reserve is indicated by duration of 20 seconds or less [6] [7]. Breathe hold time, which reflects the duration an individual can hold their breath, has been associated with diaphragm function and core stability. The diaphragm, a key component of the core, is involved in respiration and forms the superior boundary of the core. Understanding the interplay between core endurance and respiratory functions is important, particularly in activities requiring sustained postural control and endurance. Previous studies have established a relationship between core strength and breath hold time, suggesting that individuals with greater core strength may exhibit longer breath hold times [9]. This correlation underscores the importance of core stability in respiratory control and overall endurance. However, while there is substantial evidence linking core strength with breath hold time, research specifically exploring the relationship between core endurance and breath hold time remains limited. Core endurance, which pertains to the ability of core muscles to sustain contraction over time, might influence breath hold capacity in a manner distinct from core strength [23][24] Understanding this relationship could provide valuable insights into how core endurance impacts respiratory function and postural control.

The objective of this study was to investigate the correlation between core endurance and breath hold time in normal young

adults. There is a direct linear correlation established between abdominal core strength and breath holding time. As a result, both diaphragmatic contraction and the abdominal core muscles have an impact on the intra-abdominal pressure during breath holding. If there occur reduced tone or decreased strength in either of the musculature the intra-abdominal pressure is affected leading to increased spinal loading and increased intra disc pressure and resulting low back ache. Thus, in activities where breath holding is necessary especially during weight lifting, adequate contraction of the core as well as the diaphragm is beneficial to unload the spine. Consequently, specific muscle training for abdominals can improve results and reduce the chances of backache [9]. The aim of this study was to find out correlation of core endurance with breath hold time in normal young adults as the correlation of core strength to breath hold time is already established a need arises due to paucity of literature about correlation of core endurance to breath hold time.

## II. METHOD

The study population comprised normal young adults, specifically individuals within the typical age range of young adulthood who are not affected by any diagnosed physical or psychological disorders that could impact the outcomes of the study. Participants were selected based on their availability and willingness to participate in the study. The duration of the study was set to a total of six months, during which time participants were recruited, data was collected, and preliminary analysis was conducted. A convenient sampling method was used to select participants. The sample size consisted of 62 participants.

The breath hold time (BHT) is another straightforward evaluation procedure that requires the person to hold their breath for as long as they can until they reach the breaking point.

**Core Endurance:** Core endurance is often assessed using the McGill Torso Muscular Endurance Test Battery. The first component, the flexor endurance test, measures the endurance of deep core muscles such as the transverse abdominis, quadratus lumborum, and erector spinae. This test involves maintaining a static, isometric contraction of the anterior trunk muscles, holding a specific position until fatigue prevents further endurance.

The trunk lateral endurance test, also known as the side-bridge test, is the second test in the battery. It assesses the endurance of the lateral core muscles, which include the transverse abdominis, obliques, quadratus lumborum, and erector spinae. Like the flexor test, this is a timed isometric assessment performed separately on both sides of the trunk.

The trunk extensor endurance test, which is the third element, measures the endurance of the muscles that extend the back, such as the erector spinae, longissimus, iliocostalis, and multifidus. This test also requires the participant to maintain a static position involving isometric contraction of the posterior trunk muscles until exhaustion.

For each test, the duration the participant was able to maintain the required position—flexor endurance time, right

and left side-bridge times, and trunk extensor endurance time was recorded.

## III. STATISTICAL ANALYSIS

The Statistical Package for Social Science (SPSS) software, version 26, was employed for statistical analysis. Using the Shapiro-Wilk test, the sample size distribution's normality was confirmed. Spearman correlation test was used to examine the relationship of BHT with Flexion Completion Time, Extension Completion Time, Right Side Bridge Completion Time and Left Side Bridge Completion Time. The results indicate a significant moderate positive correlation of BHT with Flexion Completion Time ( $r=0.400, p=0.001$ ), Extension Completion Time ( $r=0.468, p<0.001$ ), Right Side Bridge Completion Time ( $r=0.33, p=0.007$ ) and Left Side Bridge Completion Time ( $r=0.327, p=0.01$ ).

| Tests of Normality |              |    |         |
|--------------------|--------------|----|---------|
|                    | Shapiro-Wilk |    |         |
|                    | Statistic    | df | P Value |
| FCT (in sec)       | 0.651        | 62 | <0.001  |
| ECT (in sec)       | 0.901        | 62 | <0.001  |
| RSBCT (in sec)     | 0.805        | 62 | <0.001  |
| LSBCT (in sec)     | 0.809        | 62 | <0.001  |
| BHT                | 0.917        | 62 | <0.001  |
| F:E                | 0.659        | 62 | <0.001  |
| RSB:LSB            | 0.574        | 62 | <0.001  |
| RSB:E              | 0.754        | 62 | <0.001  |
| LSB:E              | 0.653        | 62 | <0.001  |

FCT = Flexion completion time, ECT = Extension completion time, RSBCT = Right side bridge completion time, LSBCT = Left side bridge completion time, BHT = Breath hold time, F = flexion, E = extension, RSB = right side bridge, LSB = left side bridge.

## IV. RESULT

A total of 62 participants participated in the study of which 31 (50%) were male and 31 (50%) were female between the age group of 20 to 25, with a mean age of 22.95.

TABLE 1. Gender-wise Distribution of the study participants

| Gender | Count | Percentage |
|--------|-------|------------|
| Female | 31    | 50.00%     |
| Male   | 31    | 50.00%     |

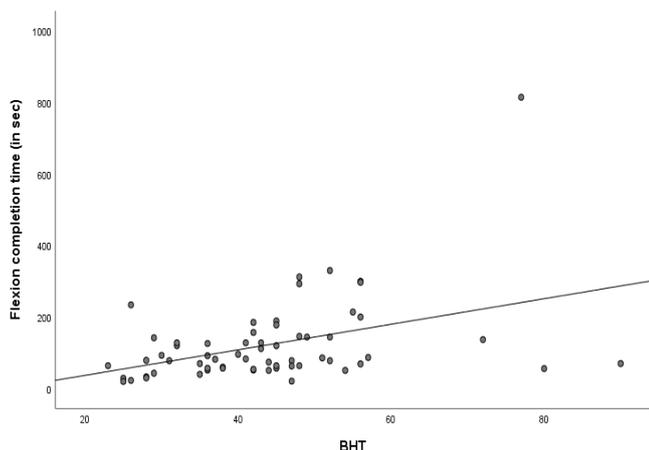
TABLE 2.

| Variables      | Mean   | Standard Deviation | Median |
|----------------|--------|--------------------|--------|
| Age            | 22.95  | 1.4                | 23     |
| weight         | 59.04  | 9.56               | 57     |
| height         | 164.73 | 8.47               | 164.5  |
| FCT (in sec)   | 121.52 | 117.74             | 82.5   |
| ECT (in sec)   | 101.08 | 69.2               | 84.5   |
| RSBCT (in sec) | 47.35  | 29.85              | 39     |
| LSBCT (in sec) | 47.03  | 28.98              | 39     |
| BHT            | 43.65  | 13.35              | 43     |

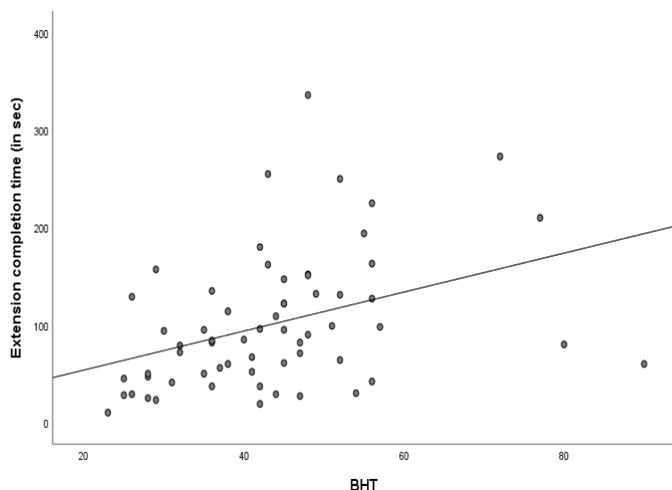
FCT = Flexion completion time, ECT = Extension completion time, RSBCT = Right side bridge completion time, LSBCT = Left side bridge completion time, BHT = Breath hold time

This graph shows flexion completion time on y-axis measured in seconds against their breath hold time on the x-

axis also measured in seconds. This graph suggests a weak positive correlation of flexion completion time and breath hold time.

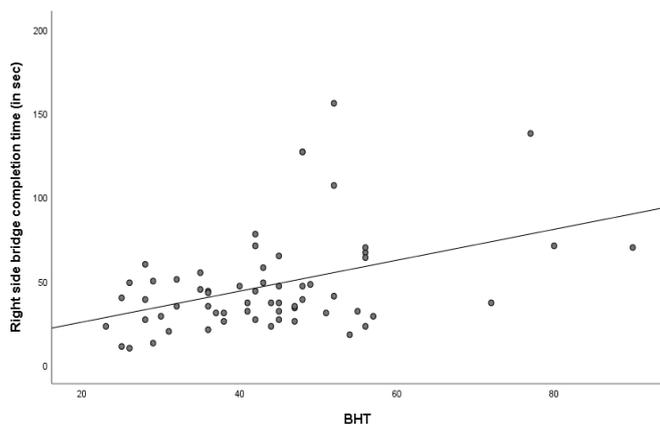


Graph no. 1 Correlation between flexion completion time and breath hold time

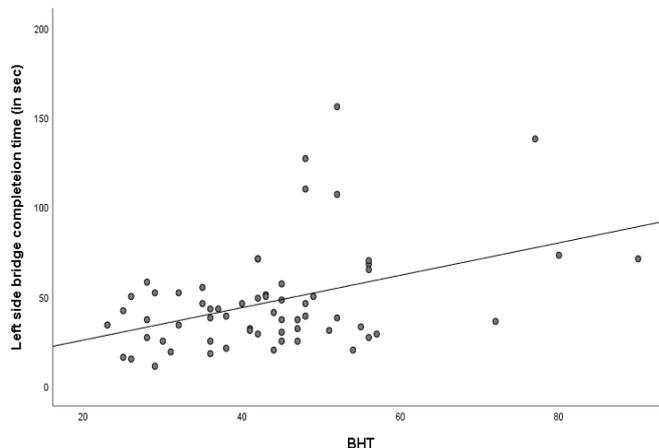


Graph no. 2 Correlation between extension completion time and BHT

This graph shows extension completion time and breath hold time on y-axis and breath hold time on x-axis. This graph suggests there is weak positive correlation of extension completion time and breath hold time.



Graph no. 3 Correlation between Right side bridge completion time



Graph no. 4 Correlation between Left side bridge completion time and BHT

This graph shows left side bridge completion time and breath hold time on y-axis and breath hold time on x-axis both are measured in seconds. This graph suggests there is weak positive correlation of left side bridge completion time and breath hold time

TABLE 3.

|             |                         | FCT<br>(in sec) | ECT<br>(in sec) | RSBCT<br>(in sec) | LSBCT<br>(in sec) |
|-------------|-------------------------|-----------------|-----------------|-------------------|-------------------|
| B<br>H<br>T | Correlation Coefficient | 0.4             | 0.468           | 0.337             | 0.327             |
|             | P Value                 | 0.001*          | <0.001*         | 0.007*            | 0.01*             |
|             | N                       | 62              | 62              | 62                | 62                |

In all cases, the P-values indicate that the observed correlations are statistically significant, meaning there is evidence that BHT is related to these completion times.

There is a significant positive correlation between BHT and all four completion times, with extension showing the strongest relationship. This suggests that individuals with longer BHT tend to have a longer time for which they can hold the positions, although the strength of this relationship varies.

TABLE 4. Showing no. of participants with good and poor BHT

| Breath Hold Time | Good | 28 | 45.20% |
|------------------|------|----|--------|
|                  | Poor | 34 | 54.80% |

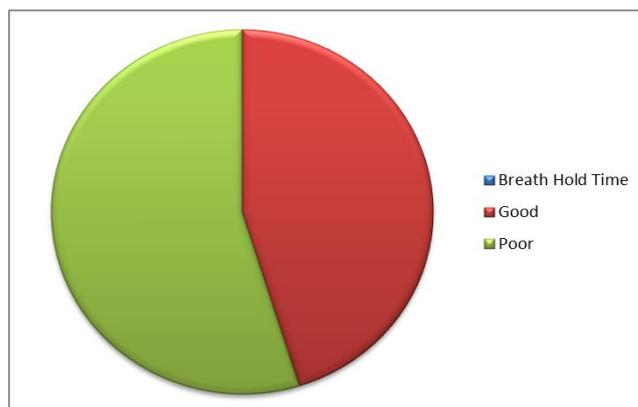
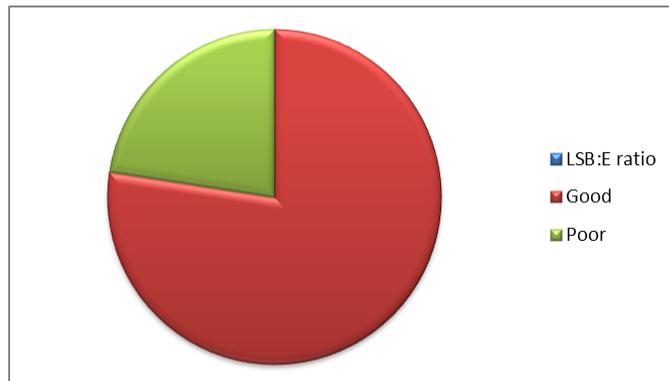
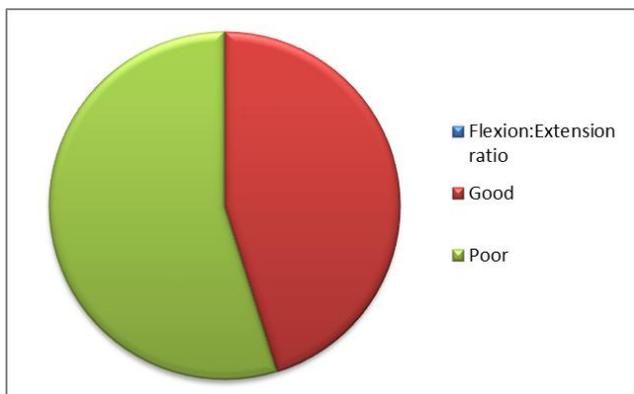


TABLE 5. Showing no. of participants with good and poor Flexion: Extension

| Flexion: Extension | Good | 28     | 45.20% |
|--------------------|------|--------|--------|
| Poor               | 34   | 54.80% |        |



V. DISCUSSION

Core stability is of great importance for force transfer balance with the spine, pelvis and kinetic chain. Core stability training combined with breathing exercises with core stability training leads to improved results, including better lumbar spine function, pain relief, and increased low-back muscular endurance in patients with chronic low back pain has been proven earlier [1]. This study investigated the relationship between core endurance and breath hold time (BHT) in normal young adults, finding a moderately significant correlation between these two variables. In this study the mean completion time of flexion was 121.52 seconds, extension 101.08 seconds, Right Side Bridge 47.35 seconds and Left Side Bridge 47.03 seconds. The mean breath-hold time in this study was 43.65 seconds, with 45.2% of participants demonstrating good breath-holding capacity, defined as holding their breath for 45 seconds or longer. In a study by Andy Waldhelm and colleagues, [45] the intra-tester reliability of clinical measurements assessing five core stability components which are strength, endurance, flexibility, motor control, and function were evaluated. The four core endurance tests included the trunk flexor test, trunk extensor test, and bilateral side bridge tests. Among these, core endurance tests demonstrated the highest reliability. Reliable tests were identified across all five categories, but overall, core endurance tests were found to be the most reliable, followed by flexibility, strength, neuromuscular control, and functional tests in that order. The Mc’Gill’s torso muscular endurance test battery consist a Ratio of comparison based on which the relationship between muscles is recorded as good and poor. A balanced relationship between core muscle groups is indicated by specific endurance ratios. A flexion-to-extension ratio of less than 1.0 suggests optimal muscular balance, where the extension completion time exceeds the flexion completion time. Similarly, for the right-to-left side bridge ratio, a balanced core is reflected by a difference of no more than 0.05 between the two sides. Additionally, the side bridge (each side) to extension ratio should be less than 0.75 to indicate proportional endurance between lateral and posterior core muscles.

During diaphragmatic contraction, the diaphragm pulls the central tendon downward, leading to an increase in the vertical diameter of the thoracic cavity, thereby facilitating effective inhalation. However, this expansion is quickly counteracted by

TABLE 6. Showing no. of participants with good and poor RSB: LSB

| RSB:LSB Rating | Good | 14     | 22.60% |
|----------------|------|--------|--------|
| Poor           | 48   | 77.40% |        |

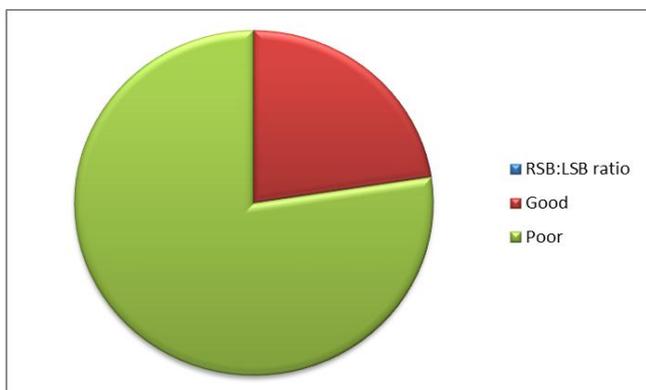


TABLE 7 Showing no. of participants with good and poor RSB: E

| RSB: E rating | Good | 48     | 77.40% |
|---------------|------|--------|--------|
| Poor          | 14   | 22.60% |        |

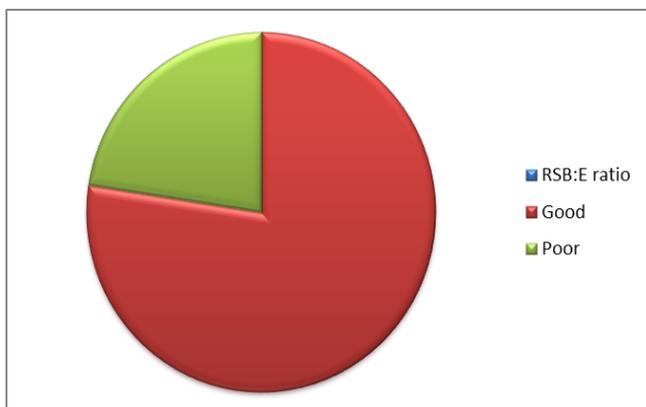


TABLE 8 Showing no. of participants with good and poor LSB: E

| LSB: E rating | Good | 48     | 77.40% |
|---------------|------|--------|--------|
| Poor          | 14   | 22.60% |        |

the vertical elements of the mediastinum and, more significantly, by the resistance from the abdominal organs. These organs are held in place by the 'abdominal girdle,' which consists of the strong core muscles. Without these muscles, the abdominal contents would shift forward and downward, and the central tendon would not be stabilized, preventing the diaphragm from effectively elevating the lower ribs. Thus, the interaction between the abdominal muscles and the diaphragm plays a vital role in ensuring optimal diaphragmatic function. [9] [16] While Hodges' early research emphasized the Transverse Abdominis (TrA) in core stability, [15] his more recent findings indicate that the core is a dynamic system, relying on the coordinated integration of the pelvic floor, TrA, diaphragm, and multifidus. Kolar et al. highlighted the significant role of the diaphragm during limb movements. In a separate study, Kolar investigated the association between back pain, core stability, and diaphragmatic function. [16] [44] He examined 18 patients with chronic low back pain (LBP) and 29 without, measuring diaphragm activity during tidal breathing and isometric flexion of the upper and lower limbs against external resistance. The study found that individuals with LBP exhibited smaller diaphragm excursions and a higher diaphragm position. The researchers concluded that "the respiratory movement of the diaphragm is synchronized with its stabilizing function, and dysfunction of this synchronization in individuals with weak diaphragm stabilization leads to spinal segment overload." This implies that inadequate and poorly coordinated diaphragm activation may compromise spinal stability [16] [44]. In this study it was found that there is significant positive correlation between BHT and all four completion times, with extension showing the strongest relationship. The connection between back extensor muscles and breath-holding efficiency is well-supported by research emphasizing the importance of core strength, spinal stability, and proper posture in enhancing respiratory mechanics. Strengthening these muscles can lead to improved breath-holding performance through better trunk control and lung capacity expansion, making it a critical focus in athletic and rehabilitation settings. The back extensor muscles (particularly the erector spinae and multifidus) play an important role in stabilizing the spine, which indirectly affects respiratory function. Breath-holding involves voluntary apnea, during which the diaphragm, along with accessory respiratory muscles, like the back extensors, works to maintain trunk stability. A strong core, including the back extensors, can improve the efficiency of breath-holding by providing better posture and more control over abdominal and thoracic pressure[40] [41].

This study suggest that individuals with higher core endurance also exhibit longer breath hold times indicating an interplay between core stability and respiratory function. When compared to core stability training alone, combining breathing exercises with core stability training can lead to improved results, including better lumbar spine function, pain relief, and increased low-back muscular endurance in patients

with chronic low back pain. [26] The correlation observed aligns with previous research indicating that core endurance can influence various aspects of physical performance and stability. Strengthening the erector spinae and other muscles in the posterior chain is often included in respiratory muscle training programs aimed at improving breath-holding efficiency.

## VI. CONCLUSION

The study concludes that there is moderately significant correlation between core endurance and breath hold time in normal young adults.

## VII. LIMITATIONS AND FUTURE SCOPE

Limitations of this study are that the sample size was relatively small, age group and comprised only normal young adults. Future research can be done on a larger and more diverse population across different age groups and fitness levels such as wrestlers, weight lifters and in the occupation like laborers, porters and sedentary job for better statistical inference. Additionally, exploring the underlying physiological mechanism in greater detail could provide more insights into how core endurance specifically affects lung functions.

## REFERENCES

- [1] Akuthota V, Ferreiro A, Moore T, Fredericson M. Core stability exercise principles. *Curr Sports Med Rep*. 2008 Feb;7(1):39-44. doi: 10.1097/01.CSMR.0000308663.13278.69. PMID:18296944.
- [2] Huxel Bliven KC, Anderson BE. Core stability training for injury prevention. *Sports Health*. 2013 Nov;5(6):514-22. doi: 10.1177/1941738113481200. PMID: 24427426; PMCID: PMC3806175.
- [3] Santos MS, Behm DG, Barbado D, DeSantana JM, Da Silva-Grigoletto ME. Core Endurance Relationships With Athletic and Functional Performance in Inactive People. *Front Physiol*. 2019 Dec 18;10:1490. doi: 10.3389/fphys.2019.01490. PMID: 31920697; PMCID:PMC6930174.
- [4] McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*. 1999 Aug;80(8):941-4. doi: 10.1016/s0003-9993(99)90087-4. PMID: 10453772. [Core endurance definition]
- [5] Sudha BS, Sunitha MS, Nataraj SM, Dhar M. A study of reduction in breath-holding time in smokers and recovery among ex-smokers in bus depot workers. *Int J Health Allied Sci*. 2012;1(3):166.
- [6] Bagavad GM, Roopa S, Subhashini AS, Sulthan KS. Effect of physical training on breath holding time in Indian subjects. *Indian journal of physiology and pharmacology*. 2014;58(1):108-9.
- [7] Bhandare SA, Rasal SS, Sathe AM, Nagpure VR, Parmar UB, Iyer SK. Effect of physiotherapy on single breath count and breath holding time in COVID-19 patients. *Int J Res Med Sci [Internet]*. 2021 Sep. 28 [cited 2023 Apr. 14];9(10):3062-7.
- [8] Parkes MJ. Breath-holding and its breakpoint. *Exp Physiol*. 2006 Jan;91(1):1-15. doi: 10.1113/expphysiol.2005.031625. Epub 2005 Nov 4. PMID: 16272264.
- [9] Nagarwala, Raziya. (2018). Correlation between core strength and breath holding time in normal young adults Raziya Nagarwala, Prarthana Dhotre, Isha Gelani. *Journal of orthopedic and rehabilitation* 2011, 75-78.
- [10] Abdelraouf OR, Abdel-Aziem AA. The relationship between core endurance and back dysfunction in collegiate male athletes with and without nonspecific low back pain. *International journal of sports physical therapy*. 2016 Jun;11(3):337.
- [11] Trembach N, Zabolotskikh I. Evaluation of Breath-Holding Test in Assessment of Peripheral Chemoreflex Sensitivity in Patients with Chronic Heart Failure. *Open Respir Med J*. 2017 Dec 27;11:67-74. doi: 10.2174/1874306401711010067. PMID: 29387285; PMCID:

- PMC5750724.
- [12] "breath-holding test." Farlex Partner Medical Dictionary. 2012. Farlex 24 Sep. 2024
- [13] Mayer JM, Nuzzo JL, Chen R, Quillen WS, Verna JL, Miro R, Dagenais S. The impact of obesity on back and core muscular endurance in firefighters. *Journal of obesity*. 2012 Nov 19;2012.
- [14] Parkes MJ, Green S, Stevens AM, Clutton-Brock TH. Assessing and ensuring patient safety during breath-holding for radiotherapy. *Br J Radiol*. 2014 Nov;87(1043):20140454. doi: 10.1259/bjr.20140454. Epub 2014 Sep 5. PMID: 25189121; PMCID: PMC4207152.
- [15] Hodges PW, Richardson CA. Delayed postural contraction of the transversus abdominis muscle in low back pain. *Spine*. 1996;21(22):2620-2624.
- [16] Nelson, Nicole L.. "Diaphragmatic Breathing: The Foundation of Core Stability." *Strength and Conditioning Journal* 34 (2012): 34–40.
- [17] McGill SM, Karpowicz A, Bullock-Saxton J. The role of core endurance in postural stability: Evidence from breath hold studies. *Clinical Biomechanics*. 2006;21(10):837-844.
- [18] Han, Ji Won and Kim, Young Mi. 'Effect of Breathing Exercises Combined with Dynamic Upper Extremity Exercises on the Pulmonary Function of Young Adults'. 1 Jan. 2018 : 405 – 409.
- [19] Solanki HP. Effect of core stability training on breath holding time and respiratory rate among volleyball players. *International Journal of Physical Education, Sports and Health*. 2021;8(5):82-5
- [20] Mannion AF, Porchet F, Dvorak J, et al. The role of core endurance in athletic performance: An evidence-based review. *Orthopaedic Journal of Sports Medicine*. 2018;6(2):2325967118756994.
- [21] West JB. *Respiratory Physiology: The Essentials*. 10th ed. Philadelphia: Lippincott Williams & Wilkins; 2016.
- [22] McGill SM. *Low Back Disorders: Evidence-Based Prevention and Rehabilitation*. 3rd ed. Champaign, IL: Human Kinetics; 2015.
- [23] Zemková E, Zapletalová L. The Role of Neuromuscular Control of Postural and Core Stability in Functional Movement and Athlete Performance. *Front Physiol*. 2022 Feb 24;13:796097. doi: 10.3389/fphys.2022.796097. PMID: 35283763; PMCID: PMC8909639.
- [24] Mazzarino M, Cattaneo R, Roda C. The role of abdominal muscles in controlling intra-abdominal pressure and its effect on respiratory mechanics. *J Appl Physiol*. 1998;84(5):1613-1620.
- [25] Pelosi P, Quintel M, Malbrain ML. Effect of intra-abdominal pressure on respiratory mechanics. *Acta Clin Belg*. 2007;62 Suppl 1:78-88. PMID: 17469705.
- [26] Yu D, Yu Y, Peng Q, Luo J, He X. Clinical efficacy of breathing training combined with core stability training in chronic nonspecific low back pain. *Pak J Med Sci*. 2023 Jul-Aug;39(4):1008-1012. doi: 10.12669/pjms.39.4.6918. PMID: 37492324; PMCID: PMC10364287.
- [27] Joice M, Oliveira, Vanessa L. Clark, Karina C. Furlanetto, Peter G. Gibson, Vanessa M. McDonald, Core Function in Adults With Severe Asthma and Its Relationship With Breathing Symptoms, *The Journal of Allergy and Clinical Immunology: In Practice*, ISSN 2213-2198.
- [28] I.A.Kapandji: *The Physiology of the Joints*. Volume three *The Trunk and The Vertebral Column*. 2nd edition: pg 150.
- [29] Bjerkefors A, Ekblom MM, Josefsson K, Thorstensson A. Deep and superficial abdominal muscle activation during trunk stabilization exercises with and without instruction to hollow. *Man Ther*. 2010 Oct;15(5):502-7. doi: 10.1016/j.math.2010.05.006. Epub 2010 Jun 8. PMID: 20570549.
- [30] Akuthota V, Nadler SF. Core strengthening. *Arch Phys Med Rehabil*. 2004 Mar;85(3 Suppl 1):S86-92. doi: 10.1053/j.apmr.2003.12.005. PMID: 15034861.
- [31] Borghuis J, Hof AL, Lemmink KA. The importance of sensory-motor control in providing core stability: implications for measurement and training. *Sports Med*. 2008;38(11):893-916. doi: 10.2165/00007256-200838110-00002. PMID: 18937521.
- [32] Hibbs AE, Thompson KG, French D, Wrigley A, Spears I. Optimizing performance by improving core stability and core strength. *Sports Med*. 2008;38(12):995-1008. doi: 10.2165/00007256-200838120-00004. PMID: 19026017.
- [33] Lindholm P, Lundgren CE. The physiology and pathophysiology of human breath-hold diving. *J Appl Physiol* (1985). 2009 Jan;106(1):284-92. doi: 10.1152/jappphysiol.90991.2008. Epub 2008 Oct 30. PMID: 18974367.
- [34] Ferrigno M., Ferretti G. (1997). "The Physiology of Breath-Hold Diving". *Undersea and Hyperbaric Medicine Journal*
- [35] Bain AR, Drvis I, Dujic Z, MacLeod DB, Ainslie PN. Physiology of static breath holding in elite apneists. *Exp Physiol*. 2018 May 1;103(5):635-651. doi: 10.1113/EP086269. PMID: 29512224.
- [36] Gertler R. *Respiratory Mechanics*. *Anesthesiol Clin*. 2021 Sep;39(3):415-440. doi: 10.1016/j.anclin.2021.04.003. PMID: 34392877; PMCID: PMC8360707.
- [37] Atul P Kulkarni, J V Tivatia, Vijaya P Patil, R P Gehdoo. *Objective Anaesthesia Review: A Comprehensive Textbook for the Examinee*, 3rd edition 2013; 79-80
- [38] Vipin Aggarwal et al. Correlation of breath holding time with spirometry test - An alternative non technician dependent surrogate test for spirometry. *MedPulse International Journal of Medicine*. March 2018; 5(3): 69-73. <https://www.medpulse.in/Medicine/>
- [39] Ramita Raheja et al An Evaluation of Breath Bolding Time between Male and Female in Elderly Population from India *International Journal of Physiology*5(2):80 January 2017
- [40] Roussel N, Nijs J, Truijten S, Verweken L, Mottram S, Stassijns G. Altered breathing patterns during lumbopelvic motor control tests in chronic low back pain: a case-control study. *Eur Spine J*. 2009 Jul;18(7):1066-73. doi: 10.1007/s00586-009-1020-y. Epub 2009 May 10. PMID: 19430948; PMCID: PMC2899579.
- [41] Yoon, Hyun Sik, Cha, Young Joo, and You, Joshua (Sung) Hyun. 'Effects of Dynamic Core-postural Chain Stabilization on Diaphragm Movement, Abdominal Muscle Thickness, and Postural Control in Patients with Subacute Stroke: A Randomized Control Trial'. 1 Jan. 2020 : 381 – 389.
- [42] Hedhli A, Slim A, Ouahchi Y, Mjid M, Koumenji J, Cheikh Rouhou S, Toujani S, Dhahri B. Maximal Voluntary Breath-Holding Tele-Inspiratory Test in Patients with Chronic Obstructive Pulmonary Disease. *Am J Mens Health*. 2021 May-Jun;15(3):15579883211015857. doi: 10.1177/15579883211015857. PMID: 33993797; PMCID: PMC8127757.
- [43] Hintze C, Stemmer A, Bock M, Kuder TA, Risse F, Dinkel J, Prüm H, Puderbach M, Fink C, Biederer J, Kauczor HU. A hybrid breath hold and continued respiration-triggered technique for time-resolved 3D MRI perfusion studies in lung cancer. *Rofo*. 2010 Jan;182(1):45-52. doi: 10.1055/s-0028-1109713. Epub 2009 Oct 26. PMID: 19859857.
- [44] Kolar P, Sulc J, Kyncl M, Sanda J, Neuwirth A, Kriz J, Kobesova A. Stabilizing function of the diaphragm: Dynamic MRI and synchronized spirometric assessment. *J Appl Physiol* 109: 1064–1071, 2010.
- [45] Waldhelm, Andy, Li Li. 2012. "Endurance Tests Are the Most Reliable Core Stability Related Measurements." *Journal of Sport and Health Science*, 1 (2): 121-128. doi: 10.1016/j.jshs.2012.07.007
- [46] Gay SB, Siström CL, Holder CA, Suratt PM. Breath-holding capability of adults. Implications for spiral computed tomography, fast-acquisition magnetic resonance imaging, and angiography. *Invest Radiol*. 1994 Sep;29(9):848-51. PMID: 7995705.