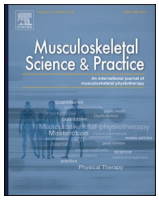
Musculoskeletal Science and Practice 71 (2024) 102949

Contents lists available at ScienceDirect

Musculoskeletal Science and Practice

journal homepage: www.elsevier.com/locate/msksp



Technical and measurement report

Inter-rater reliability of the dynamic neuromuscular stabilization diaphragm tests among individuals with non-specific low back pain and neck pain

Rajasekar Sannasi [a], Craig E. Morris [b], Andrew Busch [c], Thrishala Noronha [a], Vidhya Krishna P [a], Martin Stribrny [d], Alena Kobesova [d,*]

[a] Institute of Physiotherapy, Srinivas University, Mangaluru, Karnataka, India
[b] Rehabilitation Prague School, Prague, Czech Republic
[c] Department of Health and Human Kinetics, Ohio Wesleyan University, Delaware, OH, United States
[d] Department of Rehabilitation and Sports Medicine, Second Faculty of Medicine, Charles University and University Hospital Motol, Prague, Czech Republic

ARTICLE INFO

Keywords:
Diaphragm
Postural-respiratory function
Postural stabilization
Inter-rater
Reliability
Back pain
Neck pain

ABSTRACT

Background: The Dynamic Neuromuscular Stabilization (DNS) diaphragm test and intra-abdominal pressure regulation test (IAPRT) are qualitative clinical tests that assess postural stability provided by the diaphragm.
Objective: Evaluate the inter-rater reliability of the diaphragm test and IAPRT between an experienced and novice DNS clinician among individuals with non-specific low back pain (LBP) and neck pain.
Methods: Forty-five participants with non-specific LBP and/or neck pain were assessed by an experienced and novice DNS physiotherapist in the diaphragm test and IAPRT, and scored on a visual analog scale (VAS) according to five different criteria.
Results: Moderate reliability was noted when assessing LBP and neck pain patients in the diaphragm test and IAPRT ($p < 0.001$). Moderate reliability also existed when assessing only LBP ($p < 0.001$) or neck pain ($p = 0.002$, $p = 0.009$) independently. Patients with lower pain (NPRS score of 5 or <) demonstrated lower intra-class correlation coefficients, yet still moderate reliability in the diaphragm test ($p = 0.004$) and IAPRT ($p = 0.001$). Patients with higher pain (NPRS score of 6 or >) demonstrated greater intra-class correlation coefficients, with the diaphragm test resulting in good reliability ($p < 0.001$).
Conclusions: The diaphragm test and IAPRT demonstrate moderate reliability between an experienced and novice DNS clinician when evaluating LBP and neck pain patients, with a greater degree of reliability noted in patients suffering from higher reported pain.

1. Introduction

The diaphragm, a key respiratory muscle, also functions as an external lower esophageal sphincter and is crucial for dynamic postural stability via intra-abdominal pressurization. The diaphragm, pelvic floor, and abdominal musculature function together to increase intra-abdominal pressure (IAP) to establish and maintain spinal stiffness and stability (Cholewicki et al., 1999). The IAP generated by the diaphragm and the abdominal muscles are hypothesized to substantially reduce the forces causing spinal compression, providing an unloading effect especially during lifting tasks (Guo et al., 2021). An important etiological factor in spinal disorders related to LBP is the insufficient function and poor coordination of stabilizing muscles including the diaphragm (Kobesova et al., 2020b; Kolar et al., 2012). Suboptimal diaphragmatic function also affects the respiratory pattern and is directly associated with neck pain through the inappropriate use of accessory respiratory musculature (Tatsios et al., 2022).

Although the diaphragm procures several vitally important functions, there is no gold standard for clinical examination of the diaphragm. Diaphragm mechanics can be assessed by fluoroscopy, electromyography, dynamic magnetic resonance imaging and ultrasound imaging (Laghi et al., 2021). Such procedures provide helpful insight into diaphragm function, yet most cannot be practically or inexpensively utilized in out-patient clinical settings, as they require

* Corresponding author.
E-mail address: alenamudr@me.com (A. Kobesova).

https://doi.org/10.1016/j.msksp.2024.102949
Received 12 November 2023; Received in revised form 24 March 2024; Accepted 27 March 2024
Available online 30 March 2024

Table 1
Descriptive statistics of participants (Mean ± Standard Deviation).

Participants	Age (y)	Height (cm)	Weight (kg)	Body Mass Index
All (n = 48)	32.8 ± 12.6	163.8 ± 8.7	64.3 ± 15.0	23.8 ± 4.2
Males (n = 23)	33.3 ± 12.6	168.4 ± 7.7	70.9 ± 12.6	24.9 ± 3.9
Females (n = 25)	32.3 ± 12.8	159.5 ± 7.3	58.2 ± 14.7	22.7 ± 4.2

sophisticated equipment and highly trained personnel. Manual muscle testing of the diaphragm is insufficient when evaluating for postural muscular competency, and standard procedures for such testing are not available.

One rehabilitation method focusing on clinical postural analysis is Dynamic Neuromuscular Stabilization (DNS) (Kobesova et al., 2016; Kobesova et al., 2014; Kolar et al., n.d.). According to DNS, the functional tests are based on neurophysiological and developmental kinesiology principles, in which core stability is assessed in various pediatric developmental positions (Kobesova et al., 2016; Kobesova et al., 2014; Kolar et al., n.d.). DNS includes practical manual tests to assess postural diaphragmatic function (Kobesova et al., 2020a). The diaphragm plays a key role in postural stabilization, and its dysfunction can be related to back pain (Kolar et al., 2012) and neck pain (Wallden, 2017). Therefore, the DNS diaphragm test may prove to be important in the clinical assessment of back pain and neck pain patients.

The DNS diaphragm test and its variation, the intra-abdominal pressure regulation test (IAPRT) (Kobesova et al., 2020a) assess an individual's capability to voluntarily activate the diaphragm in coordination with abdominal wall. The reliability of DNS tests was previously studied by Jacisko et al. (2021) on a cohort of 25 asymptomatic individuals reporting moderate reliability both in palpation and observation measures for the diaphragm test and IAPRT when performed by certified DNS instructors. The primary outcome of this study was intended to determine the inter-rater reliability of the diaphragm test and IAPRT between physiotherapists, one DNS-trained (experienced) and the other with minimal training in the DNS testing procedures (novice), among non-specific low back pain (LBP) and neck pain participants. The secondary outcomes aimed to investigate whether reliability varied between participants with low back pain (LBP) and those with neck pain, as well as if reliability differed based on the level of pain reported by the participants. Since the diaphragm test and IAPRT are easy to perform and have been described in detail in several publications (Jacisko et al., 2021; Kobesova et al., 2016, 2020a; Kolar et al., n.d.), we expected good inter-examiner reliability even between an experienced therapist and a beginner.

2. Methods

Before commencement of the study, ethical clearance was obtained from an Institutional Review Board. Data were gathered from individuals who had been referred to an outpatient musculoskeletal physical therapy department for low back pain and/or neck pain. The inclusion criteria consisted of non-specific LBP and/or neck pain with a minimum numeric pain rating scale (NPRS) (Hartrick et al., 2003; Hjermstad et al., 2011) score of 3, and age ranging between 18 and 60 years. Exclusion criteria included LBP associated with sciatica, cervical radiculopathy, a recent history of thoracic/abdominal surgery, neurological or any other diseases affecting muscle and respiratory function, spinal deformities that hindered the ability to assume the initial test position, pregnancy, and any serious spinal pathologies.

2.1. Participants

Written informed consent was obtained from all 50 participants who met the eligibility criteria and volunteered to participate in the study. Participants were recruited from a physiotherapy out-patient department at a medical college hospital. Table 1 displays the demographic characteristics of the study group. The first tester (#1) was an experienced therapist with more than 20 years in the field of musculoskeletal physiotherapy, who had completed four DNS courses that included training in the application of the diaphragm test and IAPRT. The second tester (#2) was a novice qualified physiotherapist who had undergone training and practice of DNS diaphragm test and IAPRT test on several models before the actual study started. This short training of the novice tester #2 was performed by the experienced tester #1. The tests were performed in random order by the testers with a gap of 2 min between the tests. Each test was conducted twice: the initial run ensured the participant understood the instructions, with corrections made as needed. The second attempt was then used for data collection and evaluation in the study. Both testers were blinded from each other and were blinded from knowing what type of pain each patient reported.

Fig. 1. Diaphragm test assessment
Participants were instructed to establish and maintain a seated upright posture on the examination table, feet dangling, with non-weight-bearing hands supinated with open palms during the entire test. The tester placed forefingers in the lower intercostal spaces, and additional fingers along the lateral abdominal wall, with thumb pads on the posterior abdominal wall near the spine to palpate diaphragm movement during inhalation and diaphragm activation. Participants were instructed to push against the tester's fingers, which included deep breathing into the abdomen, followed by full exhalation. Testers assessed lower rib separation, side-to-side activation symmetry in the superior lumbar triangle, upright spinal posture, thoracic elevation, and shoulder or scapula movement. Correct activation involves symmetrical expansion of the superior lumbar triangle, widened lower intercostal spaces, balanced abdominal muscle activity, upright spine, and no thoracic elevation during inhalation. Incorrect activation was indicated by uneven abdominal expansion, insufficient intercostal widening, shoulder or scapula elevation, and spinal flexion or extension.

2.2. Procedures

2.2.1. Diaphragm test

Fig. 1 illustrates the execution of the test, while the caption for Fig. 1 provides detailed instructions given to participants and describes the signs of correct and incorrect activation (Kobesova et al., 2020a). Observations related to the quality of performance were marked on a 100 mm Visual Analog Scale (VAS) for each component including: 1. symmetrical expansion of the abdominal wall in superior lumbar triangle area, 2. widening of lower intercostal spaces, 3. balanced activity of back musculature, 4. maintain IAP while exhaling, 5. spine upright (elongated and neutral) and 6. overall performance. The higher the VAS number the better the quality of stabilization.

Fig. 2. Intra-abdominal Pressure Regulation Test (IAPRT)
Participants were instructed to establish and maintain a seated upright posture on the examination table, feet dangling, with non-weight-bearing hands supinated with palms open during the entire test. The tester faced each participant and palpated the lower abdomen proximal to the groin, directing the participant to activate intra-abdominal pressure against the tester's fingers above the inguinal ligaments. Symmetry and degree of activation were assessed, along with visual observation of abdominal contour and umbilicus movement. No instruction regarding maintaining neutral chest or umbilical posture was provided, as these observations helped define pressurization quality. Proper activation involved symmetrical pressure maintenance, balanced abdominal muscle activity, a neutral chest position, widened lower chest, stable pelvis, and an upright spine. Incorrect activation included insufficient or asymmetrical lower abdominal activation, umbilical inward/upward movement due to rectus abdominis hyperactivation, rib cage elevation, pressure maintenance failure, and spine or pelvis instability indicated by pelvic tilt.

2.2.2. *Intra-abdominal pressure regulation test*

Fig. 2 illustrates the execution of the test, while the caption for Fig. 2 provides detailed instructions given to participants and describes the signs of correct and incorrect activation (Kobesova et al., 2020a). The quality of performance was marked on a 100 mm VAS for each component that included: 1. Symmetrical activation of lower abdominal wall, 2. Umbilicus remains in neutral position, 3. Proportional activation of abdominal musculature, 4. Chest in neutral position and 5. Overall performance including spinal and pelvic stability during the test.

2.3. *Statistical analysis*

All components within the diaphragm test and IAPRT were averaged and combined into single VAS values for each test. Descriptive statistics were calculated for all variables. Data are mean ± standard deviation, unless otherwise noted. All variables were normally distributed, as assessed by using z-score kurtosis and skewness values. Inter-rater reliability was determined using intraclass correlation coefficients ($ICC_{2,1}$) and their 95% confidence intervals (CI) between the trained DNS rater and the untrained novice rater in their observation measures of the diaphragm test and IAPRT test, based on a single-rater (k = 1), absolute agreement, 2-way random model. Reliability was defined as poor (ICC <0.50), moderate (ICC 0.50–0.75), good (ICC 0.75–0.90), and excellent (>0.90) (Koo and Li, 2016). Pearson's correlations were used to analyze the relationship between the different DNS assessors VAS measures. The strength of correlations were interpreted as weak (<0.3), moderate (0.4–0.6), or strong (>0.7), as reported by (Akoglu, 2018). The standard error of measurement (SEM) was calculated as ($SEM = SD\sqrt{1\text{-ICC}}$) to provide an indication of the score precision (Weir, 2005). Power analysis, using G*Power 3.1, indicated and 80% chance of detecting a moderate correlation of 0.5 in 29 participants with statistical significance determined *a priori* at $p < 0.05$ (two-tailed). All data was analyzed using the Statistical Package for the Social Sciences (SPSS v28 for Mac; IBM Corp, Armonk, NY).

3. Results

All tests were completed in 48 participants, yet three had incomplete data recorded, therefore resulting in 45 participants with complete data for each DNS assessment. The primary outcome of this study demonstrated moderate reliability exists between an experienced DNS clinician and a novice clinician when assessing LBP and neck pain patients in the diaphragm test and IAPRT ($p < 0.001$). Table 2 includes all inter-rater reliability, reported as intra-class correlation coefficients (ICC) for both the diaphragm test and IAPRT with their 95% confidence intervals. The secondary outcomes of this study demonstrated moderate reliability exists when assessing only LBP ($p < 0.001$) or neck pain ($p = 0.002$, $p = 0.009$) patients independently. When patients were stratified according to the severity of their LBP or neck pain according to the NPRS, patients with lower overall pain scores (NPRS score of 5 or <) demonstrated lower ICC's, yet still considered moderate reliability ($p = 0.004$, $p = 0.001$). However, patients who reported higher NPRS scores (NPRS score of 6 or >) demonstrated the greatest ICC's ($p < 0.001$), with the

Table 2
Inter-rater reliability of DNS tests (mm) between expert and novice clinician using a single-rating, absolute-agreement, 2-way random-effects model ($ICC_{2,1}$) for LBP and Neck Pain patients.

			95% Confidence Interval			F Test With True Value 0		
Patients	DNS Test	ICC	Lower Bound	Upper Bound	SEM	Value	*df*1	Sig
LBP & Neck Pain	Diaphragm	0.731[a]	0.560	0.843	9.87	6.39	44	<0.001
	IAPRT	0.669[a]	0.326	0.832	12.69	6.70	44	<0.001
LBP	Diaphragm	0.735[a]	0.525	0.860	10.05	6.38	32	<0.001
	IAPRT	0.672[a]	0.332	0.839	13.26	6.56	34	<0.001
Neck Pain	Diaphragm	0.721[a]	0.304	0.909	9.09	6.32	11	0.002
	IAPRT	0.604[a]	0.023	0.884	10.66	5.54	9	0.009
NPRS Score 5 or <	Diaphragm	0.590[a]	0.194	0.823	9.82	3.89	17	0.004
	IAPRT	0.561[a]	0.115	0.896	13.39	4.59	18	0.001
NPRS Score 6 or >	Diaphragm	0.777[b]	0.567	0.892	9.89	7.73	26	<0.001
	IAPRT	0.726[a]	0.377	0.880	12.41	8.21	25	<0.001

Note: ICC = Intraclass Correlation Coefficient.
SEM = Standard Error of Measurement.
IAPRT = Intra-Abdominal Pressure Regulation Test.
Correlation coefficients using absolute agreement.
[a] Denotes: Moderate reliability.
[b] Denotes: Good reliability.

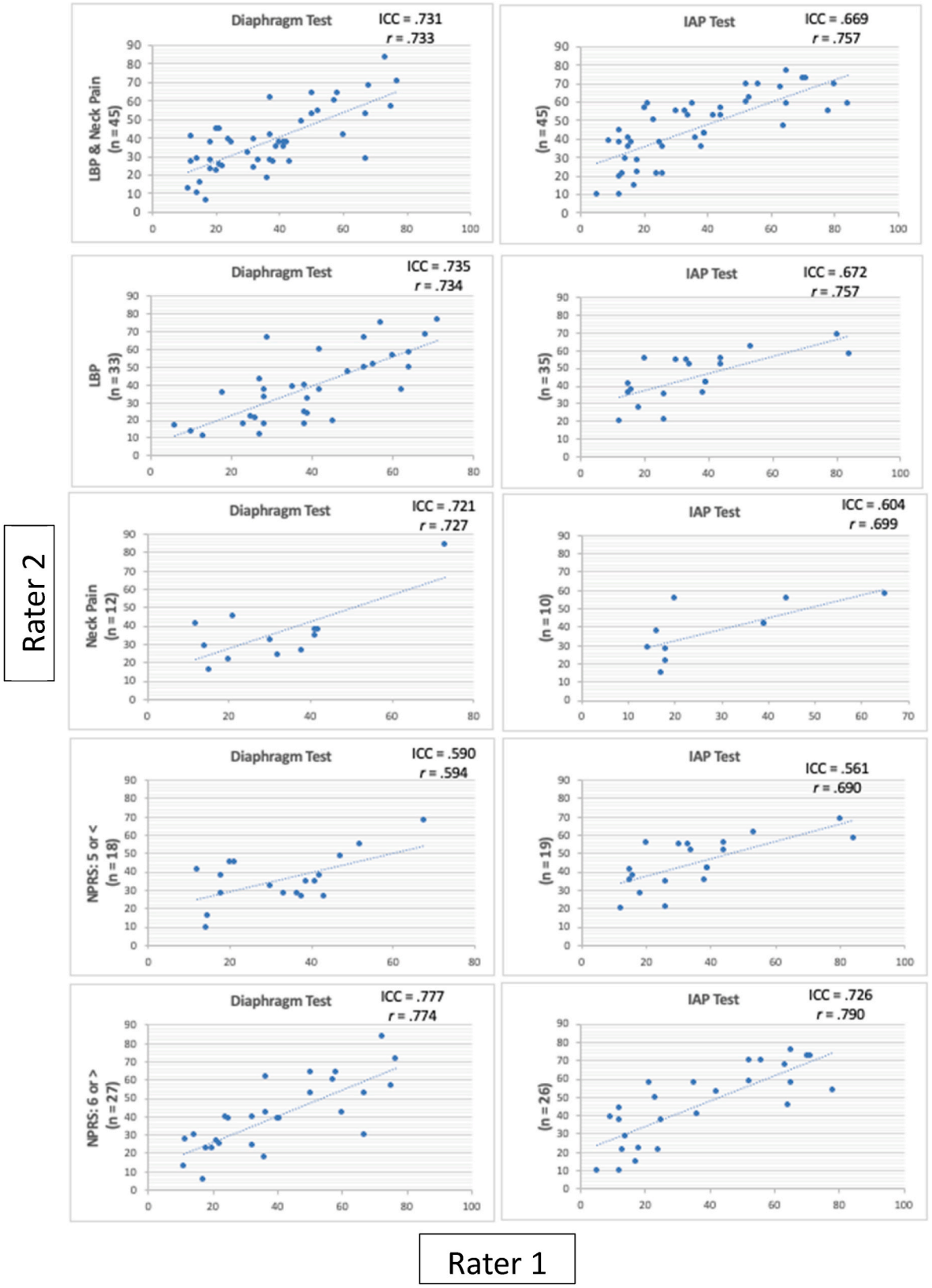


Fig. .3. Scatter plots of correlation between inter-rater VAS measurements for Diaphragm and IAPRT tests in patients with LBP and neck pain, with intraclass correlation coefficient (ICC) and Pearson correlation coefficient (*r*) included in each graph.

diaphragm test indicating good reliability. The scatterplots in Fig. 3 illustrate moderate or strong correlations exist between raters along with the ICC values.

4. Discussion

This study presents two clinical tests assessing dual postural-respiratory function in which the diaphragm plays a key role. Both the diaphragm test and the IAPRT proved moderate reliability between an experienced DNS clinician and a novice clinician when evaluating LBP and neck pain patients, with increased reliability among those reporting elevated pain.

The diaphragm performs a major role in respiration and postural stability, as it stabilizes the spine during weight-bearing, balancing and postural activities (Bordoni and Zanier, 2013). Therefore, examination of the diaphragm function and the ability to maintain and regulate IAP can be important in LBP patients (Beeckmans et al., 2016; Janssens et al., 2013; Kolar et al., 2012), neck pain patients (Tatsios et al., 2022), and also in gastroesophageal reflux disease, (Bitnar et al., 2015, 2021; Moffa et al., 2020), urinary stress incontinence (Abidi et al., 2022), defecation disorders (Brusciano et al., 2007), neurological diseases (Son et al., 2017; Yoon et al., 2020) or orthopedic problems (Acar et al., 2019; Lam and Mehdian, 1999). Currently, this testing may also become important among post-COVID patients with respiratory muscle dysfunction who also have a greater risk of back pain (Shallan et al., 2022; Yadav et al., 2022).

Although postural stabilization is a vital function and a basic prerequisite for movement, there is currently no uniform examination protocol (gold standard) for postural assessment with sufficiently proven reliability. The advantage of the DNS diaphragm test and IAPRT tests is they evaluate both the respiratory pattern and the concurrent ability to modify IAP (Novak et al., 2021). Additionally, DNS does not evaluate the tests with just one number overall, but examines various aspects within the test, for example the position of the shoulder blades, head or chest, pelvic stability, straightening of the spine, position of the supporting segments, etc. This enables a detailed evaluation and thus more precise targeting of therapy. In this research we utilized evaluation of each test component on 100 mm VAS for detailed analysis, however for practical application, a numerical recording on a scale of 1–4 for each component may perhaps be more convenient and sufficient (Kobesova et al., 2020a).

At the time of this writing, very few studies have evaluated the reliability of DNS tests. Jacisko et al. (2021) investigated the correlation between clinical DNS postural examinations and instrumental examination. The patient was examined by two experienced therapists (licensed DNS instructors) performing five DNS functional tests and by the DNS Brace device. This device measures the pressure exerted by the abdominal wall and thus indirectly the change in IAP through four sensors placed on the trunk orthosis (Novak et al., 2021). The study demonstrated good inter-rater reliability and good correlations between clinical and instrumental examination for three evaluated tests including: Hip flexion test, diaphragm test and IAPRT. In our current research, the experienced therapist was trained by DNS expert instructors and the novice was trained by experienced, non-expert DNS clinicians. Therefore, we presume that reliability might further improve if the tests were conducted by two therapists who were trained by DNS expert instructors, or perhaps by the instructors themselves as indicated by Jacisko et al. (2021). The work of Cha et al. (2017) monitored the reliability of the "DNS heel sliding test". The authors found excellent intra-rater reliability when the test was performed by the same rater within 24 h (ICC = 0.953). Good agreement (ICC = 0.869) was also reported when comparing postural stabilization assessment using the DNS Heel sliding test with the Bilateral Straight Leg Lowering Test, which the authors consider to be a routine way of testing postural stabilization (Cha et al., 2017). The new contribution of our study lies in comparing inter-examiner reliability between experienced and novice examiners and in the analysis of the effect of pain level on the reliability of the tests. Also, the reliability of the DNS postural-respiratory tests in relation to pain intensity has not been previously reported.

This study does have some limitations: The examiner, while experienced in DNS assessment, was not a certified DNS therapist or instructor. Reliability was assessed only for patients with LBP and neck pain; not other diagnoses affecting postural stabilization and respiratory patterns. Additionally, of the 11 postural tests in the DNS protocol (Kobesova et al., 2020a), only two were analyzed, so these results cannot be applied to the other DNS postural tests.

5. Conclusions

The DNS diaphragm and intra-abdominal pressure regulation tests can be utilized by clinicians for the assessment of diaphragm dysfunction among non-specific neck pain and LBP patients with moderate reliability, with a greater degree of reliability noted in patients suffering from stronger pain.

Funding

This study was supported by the foundation Movement without Help and by the grant Erasmus+ The movement activity enhancement after the COVID19 pandemics No. 2021-1-SK01-KA220-HED-000023008.

CRediT authorship contribution statement

Rajasekar Sannasi: Supervision, Methodology, Data curation. **Craig E. Morris:** Writing – review & editing, Conceptualization. **Andrew Busch:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Thrishala Noronha:** Writing – review & editing, Investigation, Data curation. **Vidhya Krishna P:** Writing – review & editing, Investigation, Data curation. **Martin Stribrny:** Writing – review & editing, Conceptualization. **Alena Kobesova:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

None.

References

Abidi, S., Ghram, A., Ghroubi, S., Ahmaidi, S., Elleuch, M.H., Girard, O., Papasavvas, T., Laukkanen, J., Ben Saad, H., Knechtle, B., Weiss, K., Chlif, M., 2022. Impact of urinary incontinence on physical function and respiratory muscle strength in incontinent Women: a Comparative study between urinary incontinent and Apparently Healthy Women. JCM 11, 7344. https://doi.org/10.3390/jcm11247344.

Acar, Y., Ilçin, N., Gürpinar, B., Can, G., 2019. Core stability and balance in patients with ankylosing spondylitis. Rheumatol. Int. 39, 1389–1396. https://doi.org/10.1007/s00296-019-04341-5.

Akoglu, H., 2018. User's guide to correlation coefficients. Turkish Journal of Emergency Medicine 18, 91–93. https://doi.org/10.1016/j.tjem.2018.08.001.

Beeckmans, N., Vermeersch, A., Lysens, R., Van Wambeke, P., Goossens, N., Thys, T., Brumagne, S., Janssens, L., 2016. The presence of respiratory disorders in individuals with low back pain: a systematic review. Man. Ther. 26, 77–86. https://doi.org/10.1016/j.math.2016.07.011.

Bitnar, P., Stovicek, J., Andel, R., Arlt, J., Arltova, M., Smejkal, M., Kolar, P., Kobesova, A., 2015. Leg raise increases pressure in lower and upper esophageal sphincter among patients with gastroesophageal reflux disease. J. Bodyw. Mov. Ther. https://doi.org/10.1016/j.jbmt.2015.12.002.

Bitnar, P., Stovicek, J., Hlava, S., Kolar, P., Arlt, J., Arltova, M., Madle, K., Busch, A., Kobesova, A., 2021. Manual cervical Traction and trunk stabilization Cause significant changes in upper and lower esophageal sphincter: a randomized trial. J. Manip. Physiol. Ther. 44, 344–351. https://doi.org/10.1016/j.jmpt.2021.01.004.

Bordoni, B., Zanier, 2013. Anatomic connections of the diaphragm influence of respiration on the body system. JMDH 281. https://doi.org/10.2147/JMDH.S45443.

Brusciano, L., Limongelli, P., Del Genio, G., Sansone, S., Rossetti, G., Maffettone, V., Napoletano, V., Sagnelli, C., Amoroso, A., Russo, G., Pizza, F., Del Genio, A., 2007. Useful parameters helping proctologists to identify patients with defaecatory disorders that may be treated with pelvic floor rehabilitation. Tech. Coloproctol. 11, 45–50. https://doi.org/10.1007/s10151-007-0324-3.

Cha, Y.J., Lee, J.J., Kim, D.H., You, J.S.H., 2017. The validity and reliability of a dynamic neuromuscular stabilization-heel sliding test for core stability. Technol. Health Care 25, 981–988. https://doi.org/10.3233/THC-170929.

Cholewicki, J., Juluru, K., McGill, S.M., 1999. Intra-abdominal pressure mechanism for stabilizing the lumbar spine. J. Biomech. 32, 13–17. https://doi.org/10.1016/S0021-9290(98)00129-8.

Guo, J., Guo, W., Ren, G., 2021. Embodiment of intra-abdominal pressure in a flexible multibody model of the trunk and the spinal unloading effects during static lifting tasks. Biomech. Model. Mechanobiol. 20, 1599–1626. https://doi.org/10.1007/s10237-021-01465-1.

Hartrick, C.T., Kovan, J.P., Shapiro, S., 2003. The numeric rating scale for clinical pain measurement: a Ratio measure? Pain Pract. 3, 310–316. https://doi.org/10.1111/j.1530-7085.2003.03034.x.

Hjermstad, M.J., Fayers, P.M., Haugen, D.F., Caraceni, A., Hanks, G.W., Loge, J.H., Fainsinger, R., Aass, N., Kaasa, S., 2011. Studies comparing numerical rating scales, Verbal rating scales, and visual Analogue scales for assessment of pain intensity in Adults: a systematic Literature review. J. Pain Symptom Manag. 41, 1073–1093. https://doi.org/10.1016/j.jpainsymman.2010.08.016.

Jacisko, J., Stribrny, M., Novak, J., Busch, A., Cerny, P., Kolar, P., Kobesova, A., 2021. Correlation between palpatory assessment and pressure sensors in response to postural trunk tests. Isokinet. Exerc. Sci. 29, 299–308. https://doi.org/10.3233/IES-205238.

Janssens, L., Brumagne, S., McConnell, A.K., Hermans, G., Troosters, T., Gayan-Ramirez, G., 2013. Greater diaphragm fatigability in individuals with recurrent low back pain. Respir. Physiol. Neurobiol. 188, 119–123. https://doi.org/10.1016/j.resp.2013.05.028.

Kobesova, A., Davidek, P., Morris, C.E., Andel, R., Maxwell, M., Oplatkova, L., Safarova, M., Kumagai, K., Kolar, P., 2020a. Functional postural-stabilization tests according to Dynamic Neuromuscular Stabilization approach: Proposal of novel examination protocol. J. Bodyw. Mov. Ther. 24, 84–95. https://doi.org/10.1016/j.jbmt.2020.01.009.

Kobesova, A., Kolar, P., Andel, R., Kyncl, M., Stulik, J., Davidek, P., Lardner, R., 2020b. Dynamic magnetic resonance imaging Assisted Diagnosis of Occult spinal instability—a new useful approach. J. Med. Imaging Health Inform. 10, 2649–2653. https://doi.org/10.1166/jmihi.2020.3219.

Kobesova, A., Safarova, Marcela, Kolar, Pavel, 2016. Dynamic neuromuscular stabilization: exercise in developmental positions to achieve spinal stability and functional joint centration. In: Textbook of Musculoskeletal Medicine. Oxford University Press, Oxford.

Kobesova, Alena, Valouchova, Petra, Kolar, Pavel, 2014. Dynamic Neuromuscular Stabilization: Exercises based on developmental kinesiology models. In: Functional Training Handbook. Wolters Kluwer Health/Lippincott Williams & Wilkins, Philadelphia, pp. 25–51.

Kolar, P., Kobesova, A., Valouchova, P., Bitnar, P., n.d. Dynamic neuromuscular stabilization: assessment methods, in: Recognizing and Treating Breathing Disorders: A Multidisciplinary Approach..

Kolar, P., Sulc, J., Kyncl, M., Sanda, J., Cakrt, O., Andel, R., Kumagai, K., Kobesova, A., 2012. Postural function of the diaphragm in persons with and without chronic low back pain. J. Orthop. Sports Phys. Ther. 42, 352–362. https://doi.org/10.2519/jospt.2012.3830.

Koo, T.K., Li, M.Y., 2016. A Guideline of Selecting and reporting intraclass correlation coefficients for reliability research. Journal of Chiropractic Medicine 15, 155–163. https://doi.org/10.1016/j.jcm.2016.02.012.

Laghi, F.A., Saad, M., Shaikh, H., 2021. Ultrasound and non-ultrasound imaging techniques in the assessment of diaphragmatic dysfunction. BMC Pulm. Med. 21, 85. https://doi.org/10.1186/s12890-021-01441-6.

Lam, K.S., Mehdian, H., 1999. The importance of an Intact abdominal musculature mechanism in maintaining spinal Sagittal balance: Case illustration in Prune-Belly Syndrome. Spine 24, 719–722. https://doi.org/10.1097/00007632-199904010-00022.

Moffa, A., Oliveto, G., Matteo, F.D., Baptista, P., Cárdenas, A., Cassano, M., Casale, M., 2020. Modified inspiratory muscle training (m-IMT) as promising treatment for gastro-oesophageal reflux disease (GERD). Acta Otorrinolaringol. Esp. 71, 65–69. https://doi.org/10.1016/j.otorri.2019.01.003.

Novak, J., Jacisko, J., Busch, A., Cerny, P., Stribrny, M., Kovari, M., Podskalska, P., Kolar, P., Kobesova, A., 2021. Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests. Clin. Biomech. 88, 105426 https://doi.org/10.1016/j.clinbiomech.2021.105426.

Shallan, A., Al-Nassan, S., Hawamdeh, M., Alshammari, F., Muhsen, A., Al-Malty, A.M., 2022. The potential of short and long term health consequences of COVID-19 on back pain among COVID-19 survivors. Fiz Pol 22, 26–30. https://doi.org/10.56984/8ZG0DE8mY.

Son, M.S., Jung, D.H., You, J.S.H., Yi, C.H., Jeon, H.S., Cha, Y.J., 2017. Effects of dynamic neuromuscular stabilization on diaphragm movement, postural control, balance and gait performance in cerebral palsy. NeuroRehabilitation 41, 739–746. https://doi.org/10.3233/NRE-172155.

Tatsios, P.I., Grammatopoulou, E., Dimitriadis, Z., Papandreou, M., Paraskevopoulos, E., Spanos, S., Karakasidou, P., Koumantakis, G.A., 2022. The Effectiveness of spinal, diaphragmatic, and specific stabilization exercise manual therapy and respiratory-related Interventions in patients with chronic Nonspecific neck pain: systematic review and Meta-analysis. Diagnostics 12, 1598. https://doi.org/10.3390/diagnostics12071598.

Wallden, M., 2017. The diaphragm – more than an inspired design. J. Bodyw. Mov. Ther. 21, 342–349. https://doi.org/10.1016/j.jbmt.2017.03.013.

Weir, J.P., 2005. Quantifying test-Retest reliability using the intraclass correlation coefficient and the SEM. J. Strength Condit Res. 19, 231. https://doi.org/10.1519/15184.1.

Yadav, U., Yadav, C., Jain, H., Antil, P., Seth, A., Devgun, R., Sheoran, A., Devgun, A., 2022. A study of musculoskeletal Manifestations among post COVID patients at a Tertiary Care Centre. Int J Med Rev Case Rep 1. https://doi.org/10.5455/IJMRCR.172-1657109329.

Yoon, H.S., Cha, Y.J., You, J.S.H., 2020. 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. NeuroRehabilitation 46, 381–389. https://doi.org/10.3233/NRE-192983.