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EFFECTS OF CORE STABILIZATION EXERCISE ON MUSCLE ACTIVITY DURING HORIZONTAL SHOULDER ADDUCTION WITH LOADS IN HEALTHY ADULTS: A RANDOMIZED CONTROLLED STUDY

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The importance of core stabilization exercises for extremities associated with dynamic spinal stabilization prior to movement has been demonstrated. However, no previous studies have investigated the muscle-coordinated effects on the upper trapezius (UT), anterior deltoid (AD), pectoralis major (PM), bilateral transverse abdominis (TrA), bilateral internal oblique (IO), and bilateral external oblique (EO) in healthy adults. The purpose of this study was to compare the effects of the dynamic neuromuscular stabilization (DNS) breathing technique and the abdominal bracing (AB) technique on UT, AD, PM, bilateral IO/TrA, and bilateral EO motor control in healthy participants during horizontal shoulder adduction. Thirty-six participants, eight of whom were female, were randomized into an AB and a DNS group and performed horizontal shoulder adduction with loads (8 and 17 lb). The clinical outcomes were UT, AD, and PM muscle activation and TrA/IO and EO muscle activation. Paired t-tests were used to analyze electromyography (EMG) data to determine statistically significant differences in muscle activity between the two techniques. For the EMG analysis, the maximal voluntary isometric contraction was measured for normalization and then divided by the EMG amplitude value. The results showed that UT, AD, and PM muscle amplitudes were lower and TrA/IO and EO muscle amplitudes were higher with DNS than with AB ($P < 0.05$). Our findings provide clinical evidence that core exercise with DNS is more effective in lessening UT, AD, and PM muscle activation and improving bilateral TrA/IO motor control than with AB.

Keywords: Core exercise; shoulder; dynamic neuromuscular stabilization; pectoralis major; upper trapezius.

1. Introduction

Various core stabilization exercises, such as dynamic neuromuscular stabilization (DNS), abdominal bracing (AB), and abdominal draw-in maneuver (ADIM), have been used to strengthen and stabilize the paraspinal muscles. Previous studies have demonstrated the positive effects of various exercises on upper extremity kinematics.[1] Recent studies have also found that core stabilization exercises improve whole-body balance and, independently, upper extremity function.[2–4] Core muscles are key to utilizing all the power and mobility of the body and maintaining centralization while the body moves.[2,5] Centralization is important because the proximal stability of the trunk is essential for controlling the functional movement of the distal parts.[6,7] Moreover, if the spine is not stabilized and repeatedly performs movements that place strain on the joints, musculoskeletal disease may develop.[8] Excessive activation of the upper trapezius (UT) and pectoralis major (PM) causes an upper cross syndrome, weakening the lower trapezius and serratus anterior. This could result in excessive scapular elevation, along with a reduction in scapular upward rotation and posterior tilt, which can lead to impingement syndrome, narrowing the subacromial space.[9–11] Further, if the trapezius continues to be overactivated due to repetitive work, soreness may occur, resulting in tension-type headaches.[12] Previous core stabilization studies have focused on the pre-activation of the abdominal wall muscles as a major factor.[3,5] This strategy has been shown to increase spine stiffness, thus reducing unwanted spinal fluctuations and minimizing the risk of injury while lifting objects.[13,14] Co-activation of abdominal muscles, which is essential for dynamic motor control and sports performance,[15] functionally produces abdominal pressure and associated dynamic spinal stabilization prior to movement.[4,8]

Strengthening the core muscles stabilizes the spine, leads to corrective electromyography (EMG) changes,[16] and can prevent musculoskeletal disease.[17] The DNS breathing technique is a core exercise that can support limb movements with correct kinematics by giving the core muscles, which constitute the core of spinal alignment, a central role in the functional oblique chain. A previous study reported that DNS exercise provides greater improvement in trunk stability (2.4%) and balance (68.7%) than neurodevelopmental therapy in acute stroke patients.[18] In another study, 15 patients with cerebral palsy showed gross motor function measure improvement (7.86%) after DNS exercise.[19] A functional magnetic resonance imaging (MRI) study showed that ADIM activates the cortical primary motor cortex–somatomotor cortex–supplementary motor area network, whereas DNS activates both these cortical areas and the subcortical cerebellum–basal ganglia–thalamus–cingulate cortex network.[20]

The DNS breathing technique provides dynamic stabilization of the spine by providing optimal intra-abdominal pressure (IAP), which is achieved by simultaneously adjusting the circular stabilization belt with the diaphragm and the internal oblique (IO), transverse abdominis (TrA), pelvic floor, external oblique (EO), rectus abdominis, multifidus, and thoracic muscles.[21,22] The technique optimizes the exercise system based on the scientific principles of developmental kinesiology and is a core exercise designed to induce limb movement with correct kinematics, thus preventing damage during sports or tasks involving frequent lifting of heavy loads.[22] However, no previous studies have investigated the muscle-coordinated effects on the upper trapezius (UT), anterior deltoid (AD), pectoralis major (PM), bilateral transverse abdominis (TrA), bilateral internal oblique (IO), and bilateral external oblique (EO) in healthy adults. Therefore, the purpose of this study was to compare the effects of the DNS breathing technique and the AB technique on UT, anterior deltoid (AD), PM, bilateral IO/TrA, and bilateral EO motor control during horizontal shoulder adduction with loads in healthy participants. We hypothesized that DNS and AB would result in different EMG amplitudes of the PM, AD, bilateral IO/TrA, and EO muscles.

2. Materials and Methods

2.1. *Participants*

A power analysis using G-Power software version 3.1.9.4 (Franz Faul, University of Kiel, Germany) was performed to determine the minimum sample size requirement. The results showed that a sample size of 33 participants was required to achieve a medium effect size of $\eta^2 = 0.6$, with a power of $1 - \beta = 0.8$ and a level of 0.05 in the pilot study.

A convenience sample of 36 adults (8 females; mean age: 24.16 ± 3.63 years) was used in this study. The study was approved by the Institutional Review Board of University (IRB No. 1041849-201812-BM-120-01) and was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants prior to the study. Participants with (i) a known history of neurological or back surgery, (ii) rotator cuff tendinitis, (iii) hypertension or diabetes, and (iv) limited shoulder range of motion were excluded from the study.

2.2. *Experimental procedures*

This study employed a randomized, single-blinded experimental design. The participants were randomly assigned to a DNS and an AB group using the "Flip a coin" tool in Google Search. To minimize experimental biases related to participants' expectations, the participants were blinded to study information that may have influenced them until the completion of the experiment. A consistent experimental procedure was implemented using standardized tests, including muscle activity measurements.

2.3. *Dynamic neuromuscular stabilization*

A therapist initially introduced the core stabilization exercise steps to the participants as follows: (i) The therapist neutralized the participant's thorax and rib cage in the quadruped position, allowing the participant to breathe into the diaphragm naturally. (ii) The therapist maintained this alignment and asked the participant to inhale into the diaphragm and coactivate the TRA/IO. (iii) The participant was asked to correct the DNS movement surrounding the 10th–12th ribs, confirming that the cylinder barrel shape extended from the midline forward and laterally. The corrective movement by the therapist ensured that the rib cage was not extended from the participant's transverse section to the head.[7,22–24] During core stabilization training, EMG was used to provide accurate visual feedback on the target muscle activation and thickness of the TrA, IO, and EO. EMG data were collected using TeleMyo DTS (Noraxon Inc., Scottsdale, AZ, USA), bandpass-filtered (20–450 Hz) and notch-filtered (60 Hz) and analyzed using MyoResearch software (Noraxon Inc.). The sampling rate was 1000 Hz.

2.4. *Abdominal bracing*

Each participant was asked to contract all abdominal muscles without abdominal expansion and pelvic movement. In the training session, an examiner familiar with abdominal bracing visually checked the lumbar spine angle and the movement of the lower abdomen of the participants and corrected them if necessary. During the training task, the participants were asked to maximally co-contract their abdominal muscles without hollowing the lower abdomen or changing the upper body position.[13,25] The contraction of the rectus abdominis and EO muscles was checked by palpation. IO muscle activation was examined to detect breath holding during AB.

2.5. *Surface electromyography*

EMG (Noraxon Inc., Scottsdale, AZ, USA) was used to determine the TrA/IO, EO, PM, UT, and AD muscle amplitudes during core stabilization. To ensure optimal electrical conductance, each location was shaved using a gel and then cleaned with an alcohol wipe. An investigator prepared the electrode sites by shaving excessive hair off the muscle belly and cleaning the skin using isopropyl alcohol with a sterile gauze pad to reduce the impedance of the EMG signal. Disposable Ag/AgCl surface electrodes were then fixed to the target sites. The electrodes were placed in pairs parallel to the muscular fibers. The TrA and IO electrodes were placed approximately 2 cm medially and inferiorly from the anterior superior iliac spine (ASIS). For the EO, the electrodes were placed on the side of the abdominal at 2-cm intervals, at a slight angle between the crest and rib directly above the ASIS, halfway between the crest and the ribs at a slightly oblique angle. For the UT, the electrodes were placed on the ridge of the shoulder, with a slight transverse distance from the cervical spine at C7 and the acromion. For the AD, the electrodes were placed on the anterior aspect of the arm approximately 4 cm below the clavicle. For the PM, the electrodes were placed on the chest wall at an oblique angle to the clavicle approximately 2 cm below it.[26] To normalize the data, the root mean square of a 5-s maximal voluntary isometric contraction (MVIC) for each muscle was calculated three times. While lying down, the participants horizontally adducted their shoulder to 90 degrees holding 8- and 17-lb weights to maintain core stabilization using DNS. All participants performed horizontal adduction three times, during which their EMG activity was measured. The muscle amplitude was compared between core stabilization and AB conditions using 8- and 17-lb weights.

2.6. *Intervention*

The DNS and AB core stabilization techniques were practiced 30 min per day, five times a week for two weeks. The same investigator performed the EMG activity tests during the intervention. For the AB technique, each participant was asked to lie in the supine position with one hand on the abdominal area and perform an inward abdominal movement during expiration and inspiration while horizontally adducting the other shoulder, holding a kettlebell for 5 s. For the DNS technique, each participant was asked to exhale and centralize on the thorax and rib cage in a caudal position. Subsequently, maintaining a neutral caudal alignment, the participant was asked to inhale to enable the diaphragm to descend and allow co-activation of the TrA and pelvic floor muscles.[21,24,27] while horizontally adducting the shoulder holding a kettlebell for 5 s. Real-time ultrasound (X8, Medison Co., Ltd., Republic of Korea) images were acquired to provide the participants with visual feedback (Fig. 1).

2.7. *Statistical analysis*

The data were expressed as means ± standard deviations. All continuous variables were analyzed using the Kolmogorov–Smirnov test to test the assumption of normal distribution. An independent t-test was used to determine statistically significant differences in the EMG amplitudes of TrA/IO, EO, UT, AD, and PM contractions

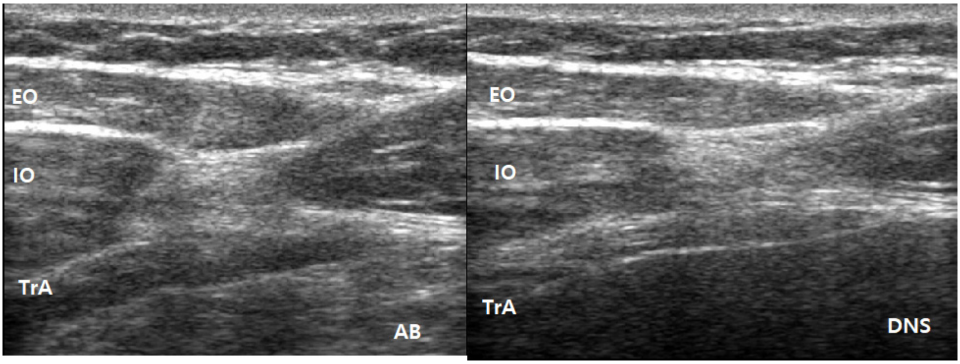

Fig. 1. Ultrasound imaging during dynamic neuromuscular stabilization (DNS) and abdominal bracing (AB). EO, external oblique; IO, internal oblique; TrA: transverse abdominis.

between AB and DNS. The level of statistical significance was set to $\alpha = 0.05$. The statistical analysis was performed using IBM SPSS Statistics version 25.0 (IBM, Armonk, NY, USA) for Windows.

3. Results

Thirty-six participants who successfully performed AB and DNS stabilization were included in the analysis. Table 1 shows the gender, age, height, weight, and dominant side of the participants. The independent t-test showed that right EO and left IO/TrA muscle activity was significantly higher during DNS than during AB, while AD and PM muscle activity was significantly lower during DNS than during AB ($P < 0.05$) (Table 2). Furthermore, bilateral IO/TrA muscle activity was significantly higher, and UT and PM muscle activity was significantly lower during DNS than during AB ($P < 0.05$) (Table 3). Conversely, bilateral EO muscle activity was significantly higher during AB than during DNS. These findings indicated high abdominal stabilization muscle activity and low activation of the muscles around the shoulder (PM and AD) during DNS.

Table 1. Demographic characteristics of the participants ($N = 36$).

Characteristic	AB ($n = 18$)	DNS ($n = 18$)
Age (years), mean ± SD	23.14 ± 2.64	25.18 ± 4.61
Sex, male/female	14/4	14/4
Height (cm), mean ± SD	168.14 ± 7.10	166.28 ± 3.45
Weight (kg), mean ± SD	65.00 ± 7.43	69.14 ± 10.33
Dominant side, left/right	0/15	0/15

Notes: AB, abdominal bracing; DNS, dynamic neuromuscular stabilization; SD, standard deviation.

Table 2. EMG activity of the UT, AD, PM, bilateral EO, and bilateral IO/TrA in 8-lb conditions.

Muscle	AB (% MVIC) mean ± SD	DNS (% MVIC) mean ± SD	P-value
UT	12.6 ± 8.7	12.5 ± 4.2	0.07
AD	24.4 ± 6.6	23.1 ± 3.3	0.04*
PM	11.8 ± 6.9	11.1 ± 5.2	0.02*
Left EO	16.1 ± 4.2	18.1 ± 5.1	0.07
Right EO	15.3 ± 2.7	13.3 ± 3.6	0.01*
Left IO/TrA	17.1 ± 4.8	19.9 ± 2.1	0.04*
Right IO/TrA	18.1 ± 3.8	20.7 ± 2.6	0.23

Notes: Unit: μV. AB, abdominal bracing; DNS, dynamic neuromuscular stabilization; MVIC, maximal voluntary isometric contraction; SD, standard deviation; UT, upper trapezius; AD, anterior deltoid; PM, pectoralis major; EO, external oblique; IO, internal oblique; TrA, transverse abdominis. *Statistically significant.

Table 3. EMG activity of the UT, AD, PM, bilateral EO, and bilateral IO/TrA in 17-lb conditions (Unit: μV).

Muscles	AB (% MVIC) mean ± SD	DNS (% MVIC) mean ± SD	P-value
UT	38.2 ± 6.3	36.5 ± 8.7	0.04*
AD	46.1 ± 4.1	46.3 ± 2.8	0.23
PM	34.7 ± 2.3	31.4 ± 3.5	0.02*
Left EO	20.2 ± 5.7	18.2 ± 3.4	0.03*
Right EO	18.8 ± 4.1	14.7 ± 5.3	0.01*
Left IO/TrA	14.7 ± 4.1	21.2 ± 6.7	0.01*
Right IO/TrA	11.4 ± 2.9	17.4 ± 4.1	0.02*

Notes: NUnit: μV. AB, abdominal bracing; DNS, dynamic neuromuscular stabilization; MVIC, maximal voluntary isometric contraction; SD, standard deviation; UT, upper trapezius; AD, anterior deltoid; PM, pectoralis major; EO, external oblique; IO, internal oblique; TrA, transverse abdominis. * Statistically significant.

4. Discussion

To our knowledge, this is the first study to demonstrate the effects of DNS on the EMG amplitudes of the UT, AD, PM, bilateral IO/TrA, and bilateral EO muscles during horizontal shoulder adduction. As hypothesized, DNS promoted IO/TrA activation while reducing UT, AD, and PM activation. Because in a literature review we found only an EMG study comparing the effects of DNS exercise on muscle activation in the lower extremity and the cervical, thoracic, and lumbar spine,[24] it was not possible to compare our results to previous findings. However, our results support previous reports of significant differences in PM, UT, and AD activity between DNS and AB.

The EMG analysis of muscle activation in horizontal shoulder adduction showed that the PM and UT were the least activated during DNS. Trunk stability analysis showed significantly higher left and right IO/TrA activation during DNS (16.6% and 19.3% of MVIC, respectively) than during AB (16.2% and 13.1% of MVIC, respectively).

Previous clinical evidence has shown that the UT and PM were overactive, whereas the AD and trunk muscles were underactive, which caused muscle imbalance and associated shoulder instability, resulting in limited flexion of the glenohumeral joints. However, the UT and PM muscles were under-activated due to AD and trunk muscle hyperactivation using the DNS technique. Therefore, DNS could be a novel intervention for restoring shoulder movement. Sidebottom demonstrated that DNS reduced pain while performing shoulder flexion and reaching behind the back and behind the head.[28]

Recent research has shown that breathing pattern dysfunction (BPD) can affect the musculoskeletal system, suggesting that it should be managed first when treating musculoskeletal disorders.[22] BPD is often ignored in clinical practice due to a lack of time or knowledge.[29] If breathing patterns are not normalized, this can affect more distal movement systems in the kinetic chain, causing dysfunction and pain.[22] The distal extremities require proximal stability to move optimally.[30]

Neuromechanically, the differential effects observed in our study may have resulted from extremity movement control activation by DNS, which promotes core chain dynamic stabilization and movement control,[19,24] whereas other core exercises promote selective activation of the TrA or co-activation of the deep and superficial abdominal muscles. It has been theorized that DNS reflexively activates the first oblique core chain as soon as the shoulder-supporting zone is connected to the floor surface, which provides the punctum fixum (stable basis) for the PM–AD–UT–ipsilateral EO–RA–contralateral IO contacting the TrA connected by the thoracolumbar fascia, while the second oblique chain is facilitated when the ipsilateral hip-supporting zone comes into contact with the surface, activating the opposite oblique chain muscle.[19,21,31] These anterior oblique chains could be balanced by the dorsal chain muscles, thus being held upright and stabilizing, thereby generating an external (negative) stabilizing force, as in the horizontal shoulder adduction test. IAP is internally generated by the diaphragm–TrA–pelvic floor–multifidus proximal core chain during breathing, which then requires a force to reinforce the oblique muscle chain.[32] This synchronized coupling action of the internal and external pressure force chains provides muscle stabilization.[22,23]

In this study, we found that DNS changed PM, AD, and UT muscle activation in the cervical–thoracic–lumbar musculature. This is because DNS involves IAP generation via the oblique chain. Previous studies have demonstrated that motor control recruitment, motor control improvement, and muscle-coordinated activation can be achieved by restoring core stability and increasing IAP.[14,23]

Our study has some limitations that could be addressed by future studies. One limitation is that it investigated only horizontal shoulder adduction. Another limitation is that the superficial and deep chain muscles and IAP were not measured. Further research is needed to develop an MRI technique for accurately measuring basic chain muscle motor control during dynamic shoulder movements.

5. Conclusion

This study examined the effect of core exercises on muscle activity during horizontal shoulder adduction in healthy adults. DNS was found to effectively promote deep muscle activation and superficial muscle deactivation, resulting in minimal PM, AD, and UT activation. Moreover, it was significantly more effective than AB in facilitating deep abdominal muscle activation and inhibiting UT and PM activation. This research provides important insights into the core stabilization and motor control mechanisms and has clinical implications for the development of therapeutic exercises for treating shoulder pain.

Ethical Compliance

The experiments conducted in this study were approved by the ethics committee and responsible authorities of our research organizations and followed all guidelines, regulations, laws, and ethical standards required for experiments involving humans.

Conflict of Interest

There are no conflicts of interest to declare.

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