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Review Article

An Investigation of Electromyographic Activity of Trapezius and Serratus Anterior Muscles in Individuals with Scapular Dyskinesis during Different Types of Push-ups: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: The use of push-ups has been suggested to strengthen the scapular stabilizers, while incorporating unstable surfaces is recommended to enhance the involvement of the neuromuscular system. However, the impact of this instability on electromyography (EMG) activity in the periscapular muscles during push-ups in individuals with Scapular dyskinesis remains uncertain. Consequently, the objective of the current study was to assess the influence of unstable surfaces on EMG activity in the trapezius and Serratus anterior muscles among individuals with scapular dyskinesis during push-ups.

Methods: A comprehensive search was conducted in Web of Science, PubMed, and Scopus databases, covering articles published from the inception of these databases until September 25, 2021. The search strategy utilized three main keyword categories: Scapular dyskinesis, electromyography, and push-up. Initially, 5,249 articles were identified through this search process. After a thorough assessment of the full text of these articles, four studies were deemed suitable for inclusion in the final review. Data extraction and evaluation of methodological quality were carried out as part of the review process. The Standardized Mean Difference (SMD) and corresponding 95% Confidence Interval (CI) were calculated to perform the meta-analysis using Comprehensive Meta-Analysis (CMA) Software, Version 3. Statistical significance was determined by a P value less than 0.05.

Results: The findings of the study revealed that the utilization of unstable surfaces among individuals with scapular dyskinesis led to an increase in the activity of the upper trapezius (P=0.011; SMD=0.807 [95%CI 0.188, 1.427]). Conversely, it reduced the Serratus anterior's activity (P=0.000; SMD=-0.665 [95%CI -1.023, -0.307]). However, the electromyography activity of the Lower trapezius was not significantly affected (P=0.176).

Conclusion: Due to the imbalance between the upper trapezius and serratus anterior muscles in individuals with scapular dyskinesis, caution should be exercised when using unstable surfaces. Incorrect utilization of unstable surfaces may worsen these individuals' muscle imbalance. Therefore, it is advisable to approach unstable surfaces with heightened caution in individuals with scapular dyskinesis.

Background

Scapular dyskinesis, or scapular dysfunction, refers to abnormal alterations in scapular motion or position,

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characterized by protrusions of the inferior angle and medial border towards the thorax in static and dynamic states. Additional symptoms of this condition include early shrugging of the scapular during shoulder elevation and inadequate upward and downward rotation of the scapular during shoulder movements [1]. In athletes engaged in overhead sports such as volleyball, baseball, handball, and swimming, the prevalence of scapular dyskinesis has been reported as 54.5%. In contrast, in non-overhead sports like rugby, disabled table tennis, and Amputee soccer, the prevalence is 33.3% [2]. When scapular dyskinesis is accompanied by muscular imbalances, strategies involving scapular stabilization exercises, particularly targeting the serratus anterior (SA) and lower trapezius (LT) muscles, can be implemented [3].

Several researchers have recommended using push-up (PU) exercises to strengthen the scapular stabilizers and incorporate unstable surfaces to enhance neuromuscular system engagement [3-6]. PU exercises evaluate the strength and endurance of various upper limb and torso muscles and are also utilized as strengthening exercises [7]. Based on the literature review, push-up plus (PUP) exercises involving full scapular protraction are more beneficial than traditional PUs. PUP exercises enhance the activity of the SA muscle while reducing the activity of the upper trapezius (UT) muscle [6, 8]. Furthermore, modifications to standard PUP are often recommended, such as performing PUP exercises on the knees, elbows, or against walls. These modifications are believed to limit the amount of weight-bearing during exercise, particularly in the initial phase of rehabilitation programs. They are suggested when individuals may have difficulty performing standard PUP exercises consistently [9].

Previous research has examined electromyography (EMG) activity during PU exercises, employing various factors and methodologies [3, 10-12]. Kang et al. (2019) conducted a systematic review and meta-analysis investigating EMG analysis of the SA muscle and UT muscle during PUP exercises. Their analysis included 19 studies with a total of 356 participants, demonstrating that hand position (such as arm distance, elbow flexion angle, and shoulder flexion angle) and lower limb position had variable effects on the activation of both the SA and UT muscles during PUP exercises. Furthermore, the study revealed a 2.74% increase in UT muscle activity when PUP exercises were performed on unstable surfaces compared to stable surfaces [13].

De Araujo et al. (2020) conducted a systematic review and meta-analysis of EMG studies, investigating the impact of using unstable surfaces on periscapular muscle activity across 33 studies. The meta-analysis indicated a minimal increase in UT muscle EMG activity when using an unstable surface. In contrast, the activity of the middle trapezius (MT) and LT muscles did not significantly change. Additionally, a small effect size was observed, indicating a decrease in EMG activity of the SA muscle when an unstable surface was utilized [14].

It is worth noting that the majority of studies investigating the effects of different types of PU and PUP exercises on stable and unstable surfaces have focused on individuals without scapular dyskinesis (healthy subjects). However, some experts advocate for a rehabilitative approach that emphasizes strengthening the SA and LT muscles while minimizing UT muscle activity [15]. Nevertheless, there are conflicting results regarding the benefits of performing these exercises on unstable surfaces for individuals with scapular dyskinesis. With many scattered articles exploring different types of PU and PUP exercises, it becomes challenging for readers to summarize and draw definitive conclusions. In such circumstances, a systematic review and meta-analysis can help consolidate data from previous studies, address ambiguities, and provide integrated results.

Considering the existing studies in this field, the objective of this study is to gather and synthesize results regarding the EMG activity of the trapezius and SA muscles during various types of PU and PUP exercises performed on both stable and unstable surfaces in individuals with scapular dyskinesis. The study aims to answer whether using an unstable surface is suitable for restoring muscular balance and improving scapular dyskinesis in individuals with this condition. By conducting a systematic review and meta-analysis, this study aims to provide a comprehensive understanding of the effects of these exercises in individuals with scapular dyskinesis.

Methods

The research method employed in this study was a systematic review and meta-analysis. The study adhered to the guidelines outlined by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [16]. Furthermore, the study protocol was registered in the PROSPERO database, ensuring transparency and accountability in the research process.

Search Strategy

In this study, a systematic search was conducted in electronic databases, including Web of Science (WOS), PubMed, and Scopus, to identify relevant articles in English. The search encompassed articles with no time limit until September 25, 2021. The Google Scholar database was also used to search for studies not indexed in the databases mentioned earlier. Furthermore, the reference lists of the selected articles were thoroughly examined to identify additional relevant information.

The search strategy involved three main categories of keywords and their synonyms, combined using Boolean operators. The main keywords within each category were merged using the Boolean operator “and”, while the synonymous keywords within each category were combined using the Boolean operator “or”. The three main categories and their respective keywords were as follows:

1. Scapul* OR shoulder OR glenohumeral OR scapulothoracic OR orientation OR protraction OR malposition OR rhythm OR dysrhythmia OR dyskines* OR dysfunction OR “sick scapul*” OR wing* OR floating OR tipp* OR tilt* OR “scapul* downward rotation syndrome” OR muscle OR muscular
2. Electromyograph* OR “EMG” OR electromyogram

OR "root mean square" OR "root-mean-square" OR "RMS" OR pattern OR recruitment OR activ* OR coactiv* OR co-activ* OR cocontract* OR co-contract* OR timing OR onset OR offset

3. Push*-up* OR "push*up*" OR "Push* up*" OR press*-up* OR "press*up*" OR "press* up*" OR "Close* kinetic chain" OR "close* kinematic chain" OR "Close* chain"

Selection of Articles

Research Inclusion Criteria

The study specifically included full-text studies published in peer-reviewed journals in English without any time limit until September 25, 2021. The articles considered for inclusion either reported the mean and standard deviation of EMG activity of the SA and trapezius muscles or provided sufficient data to calculate the effect size.

Exclusion Criteria

The authors excluded review and meta-analysis articles, case reports, and conference papers with only an abstract.

The PICO model, a search strategy development tool, formulated the research question and identified studies relevant to the research subject [17]. The PICO elements used in this study were:

● Population: Participants without a history of trauma, fracture, surgery, pain, or limited mobility in the shoulder joint and classified under at least one of the three Kibler classifications for scapular dyskinesis.

● Interventions: Different types of PU and PUP exercises performed on unstable surfaces.

● Comparators: Various PU and PUP exercises were performed on stable surfaces.

● Outcomes: EMG activity of the SA and trapezius muscles.

The articles were reviewed by two independent authors (R.A and P.S). Duplicate articles were eliminated, and each author screened the remaining articles' titles and abstracts. Articles that met the inclusion and exclusion criteria were retained. In the second phase, the authors thoroughly reviewed the full texts of the selected articles to evaluate their eligibility. Any conflicts or disagreements regarding the eligibility and exclusion criteria were resolved through discussion and consensus between the two authors or by seeking the input of a third author if needed (R.SHH).

The Extraction of Data

The two authors, R.A and P.S, conducted an independent and thorough review of the articles that met the eligibility criteria. The following data were extracted using a predefined form:

1. Name of the first author and publication year.
2.Gender, sample size, and age of the participants.
3. Type of PU exercise.
4. Muscles under evaluation.
5.Main findings of the study.

When the data was unclear, or the published articles were not accessible or downloadable, the authors contacted the first author or corresponding author via email to obtain the missing or additional data.

This rigorous data extraction process ensured that relevant information from the selected studies was collected consistently.

The Assessment of the Methodological Quality of Studies

The methodological quality of the included articles was independently assessed by the two authors, R.A and P.S. They used a modified version of the standardized quality evaluation form provided by Siegfried et al., which is based on the Newcastle Ottawa Scale (NOS) for observational research [18]. The Cochrane Handbook recommends using this tool for Systematic Reviews to assess various aspects of internal and external validity in research [19]. Hootman et al. (2011) reported moderate to good inter-rater reliability for the NOS [20].

The chosen form, developed by Siegfried et al., allows for individually assessing each validity aspect of observational studies rather than providing a summarized final score. This approach was preferred because it provides a detailed evaluation of the quality of the included studies. Modified versions of this form, specifically designed for systematic research on EMG activities of shoulder and scapular muscles during rehabilitation exercises, were employed in this study based on previous systematic reviews conducted in this area [19, 21-24].

Statistical Analysis

The present study compared the EMG activities of the SA and trapezius muscles on both stable and unstable surfaces. The mean values, along with their corresponding standard deviations, were used. The standardized mean difference (SMD) and the corresponding 95% confidence intervals (CI) were computed to conduct the meta-analysis [25].

The random-effects model was employed to derive overall estimates for all meta-analyses. The Cochran's Q test and I^2 statistics were utilized to evaluate the heterogeneity between the studies [26]. According to Higgins and Green's classification, I^2 values were categorized as low (0 to 30%), moderate (31 to 50%), high (51 to 75%), and very high (76 to 100%) to determine the level of heterogeneity [27].

Additionally, publication bias was evaluated using Begg's funnel plot and asymmetry tests, including Egger's and Begg's tests [28, 29]. These tests help to identify any potential bias introduced by publication bias in the included studies.

All statistical analyses were performed using Comprehensive Meta-Analysis (CMA) version 3. A P value lower than 0.05 was considered statistically significant, indicating a significant difference or association in the results.

Results

Selection of Articles

The search strategy initially identified a total of 5,249 studies across multiple databases. Additionally, one article was found through the Google Scholar database. These studies were subjected to the screening process for inclusion in the meta-analysis.

Upon reviewing the full texts of the identified studies, 51 articles were selected for further evaluation. After careful assessment against the eligibility criteria, four studies met the inclusion criteria and were included in the final review.

It is worth noting that no additional relevant articles were identified through the reference lists of the final included articles.

Figure 1 illustrates the screening process, outlining the number of articles at each stage and the reasons for excluding specific studies during the selection process.

Characteristics of Articles

All the articles included in the research were observational studies that examined the EMG activities of the periscapular muscles during exercises performed on both stable and unstable surfaces [3, 30-32]. It is important to note that all four studies included in the research had exclusively male participants, and two included a control group [30, 31]. It should be highlighted that none of the study subjects reported experiencing pain.

Table 1 provides comprehensive details of each study, including information on the participants, exercise types, and the tools used to create instability.

The included studies utilized three types of exercises: PU, PUP, and knee PUP. Various unstable tools, such as wobble boards, proprioceptive boards, balance discs, and slings, were employed during the exercises.

Regarding EMG analysis, the normalization process was performed using two different methods across the studies. Three studies normalized the EMG data based on maximal voluntary isometric contractions (MVICs) [30-32], while one study utilized maximal voluntary contractions (MVCs) for normalization [3].

Quality Assessment

The quality of the included studies was assessed using the form provided by Siegfried et al., based on the NOS [18]. It is important to note that all the studies included in the research had exclusively male participants, which may limit the generalizability of the findings to the broader population. Additionally, no dropouts were reported, indicating that all participants completed the interventions as intended.

In terms of blinding, none of the articles mentioned tester blinding during the measurement and recording of EMG activities. This issue could be considered a potential risk factor for increasing bias. However, given the observational nature of the analysis of EMG activity, it may not have been feasible to blind the testers.

All four studies involved a physical examination performed by two clinicians to assess scapular dyskinesis. All studies used Random sequences to perform various PU exercises and data normalization.

One study did not include a specific training session to familiarize participants with the different types of PU exercises, stable and unstable surfaces, range of motion, body posture, and pace of PU [31]. However, in all studies, participant height was used to standardize the training technique and determine the location of the arms and legs. In some studies, a metronome was employed to control the speed of PU exercises.

Table 2 provides an overview of the quality evaluation of all the included studies, including information on various aspects assessed by the NOS-based form.

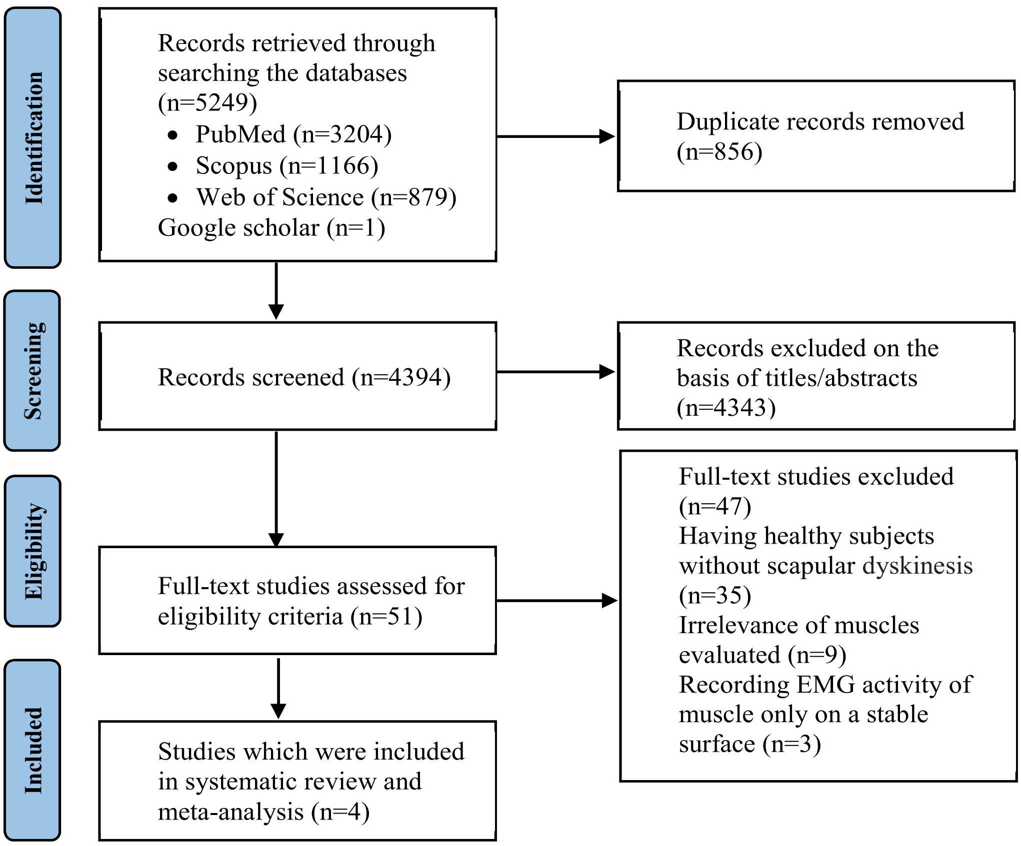

Figure 1: Flow diagram showing the selection process of studies.

Table 1: The key features of the research included in the meta-analysis

Author	Participants (Male/Female)	Age (years)	Intervention(s) (Type of PU)	Muscles assessed	Main Outcomes
De Faria et al. (2021)	CG=14 (all male) DG=13 (all male)	CG=24.57±4.30 DG=24.53±2.43	PU on stable and unstable (HI, HFI) proprioceptive board and balance disc	SA, UT, MT, and LT	Using the unstable surfaces could improve MT activity in the CG only. The MT activity of CG was higher than that of DG under unstable surfaces.
de Araújo et al. (2018)	CG=18 (all male) DG=18 (all male)	CG=21.50±2.60 DG=21.89±2.95	PU on stable and unstable (HI) wobble board	MSA, LSA, UT, and LT	Using the unstable surface increased the activity of UT and LSA for the CG and decreased the activity of MSA and LSA for DG.
Lee et al. (2017)	Dyskinesis=18 (all male)	27.7	SPUP, KPUP on stable and unstable (HI) sling	UT, LT, and LSA	UT activity: (both exercises) with sling>without sling LSA activity: without sling> with a sling and SPUP>KPUP UT/LSA and UT/LT ratios: SPUP (without sling) <other PUP exercises.
Pirauá et al. (2014)	Dyskinesis=30 (all male)	21.7±2.5	PU on stable and unstable (HI) wobble board	MSA, LSA, UT, and LT	Using unstable surfaces could reduce the activity of the SA and enhance the activity of the trapezius. UT/MSA and UT/LSA ratios were higher during unstable PU.

CG (Control group), DG (Dyskinesis group), PU (Push-up), PUP (push-up plus), SPUP (Standard push-up plus), KPUP (Knee push-up plus), HI (Hand instability), HFI (Hand and feet instability), M, L (Middle, Lower) SA (Serratus anterior), UT (Upper trapezius), MT (Middle trapezius), LT (Lower trapezius)

Table 2: Quality evaluation of all included studies

Study	External validity		Internal validity							
			Performance	Detection		Selection bias and control of confounding				
Author	Representative sample	Participation rate	Direct observation	Blind rater	Physical examination	Randomization of exercises	Familiarization of exercises	Standardization of exercise technique	Randomization of $MVIC_s$	Appropriate normalization	Appropriate statistical tests
De Faria et al. (2021)	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes
de Araújo et al. (2018)	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lee et al. (2017)	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pirauá et al. (2014)	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Qualitative Analysis

In the present study, a total of 111 male participants were included. Among them, 79 participants had scapular dyskinesis, while 32 were in the control group without it.

The systematic review included closed kinetic chain exercises, specifically PU, PUP, and knee PUP exercises.

Various muscles were assessed in the included studies. The UT muscle was evaluated in four studies, the MT muscle in one study, the LT muscle in four studies, the middle SA muscle in two studies, and the lower SA muscle in three studies. It is important to note that one study did not specifically identify the middle or lower fibers of the SA muscles.

Quantitative Analysis

The studies included in the meta-analysis focused on quantitatively analyzing the effects of using unstable surfaces on the activities of the periscapular muscles during standard PU exercises. The meta-analysis considered a standardized PU exercise as the baseline for comparison. This standard PU exercise involved specific positioning and movement parameters:

1. Positioning: The head, hip joints, and spine were neutral, ensuring proper alignment.
2. Arm and leg spacing: The arms and legs were spaced shoulder-width apart.
3. Up phase: During the upward movement, the upper limbs were perpendicular to the ground, with the elbows fully extended. The forearms and wrists were in a pronated position.
4. Down phase: During the downward movement, the forearms and wrists were maintained in a pronated position, with the elbows flexed at approximately 90°. The shoulders were abducted at approximately 45° [33].

These standardized parameters for the PU exercise provided a consistent reference point for evaluating the effects of using unstable surfaces on periscapular muscle activities.

UT Muscle

The meta-analysis results (as shown in Figure 2) indicated a statistically significant difference in the activity of the UT muscle in individuals with scapular dyskinesis when performing PU exercises on stable versus unstable surfaces (P=0.011). However, it is important to note that very high heterogeneity was observed among the included studies (P=0.001; I^2=80.98%).

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
De Faria et al. (2021)	0.517	0.295	0.087	-0.062	1.096	1.751	0.080
de Araujo et al. (2018)	0.362	0.243	0.059	-0.115	0.839	1.488	0.137
Lee et al. (2017)	2.299	0.450	0.202	1.417	3.181	5.111	0.000
Piraua et al. (2014)	0.467	0.192	0.037	0.090	0.844	2.430	0.015
	0.807	0.316	0.100	0.188	1.427	2.553	0.011

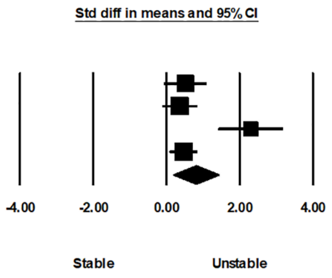

Figure 2: Forest plot of UT activity on both stable and unstable surfaces.

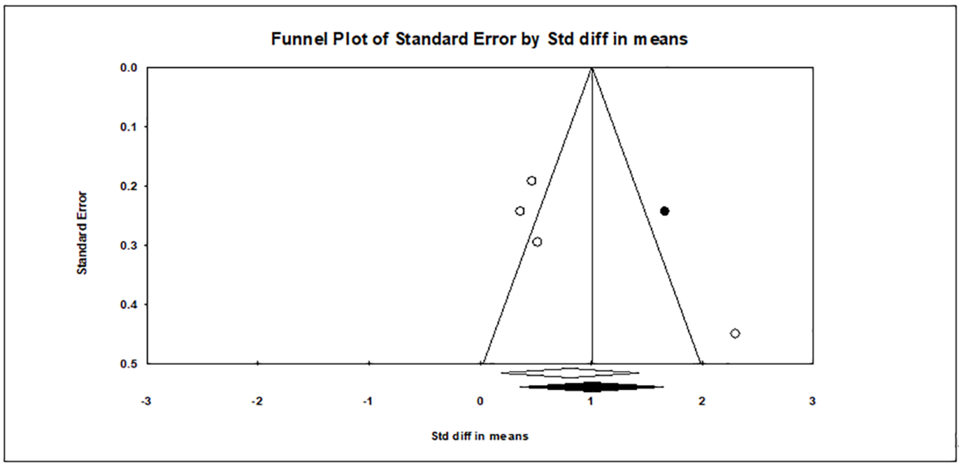

Figure 3: Funnel plot of UT activity on both stable and unstable surfaces.

Given the high level of heterogeneity, the random-effects model was employed in the meta-analysis. This model considers the variability between studies and provides more conservative estimates, aiming to reduce the potential impact of data heterogeneity on the study's findings. Using the random-effects model minimizes heterogeneity's influence on the overall effect estimate, and a more cautious interpretation of the results can be made.

The asymmetrical distribution of studies around the funnel plot's main (vertical) axis (Figure 3) suggests the possibility of visual publication bias. The "trim and fill" method used the random-effects model to assess and address this bias. This method involves adding a hypothetical study to the right side of the funnel plot to account for potential missing studies due to publication bias.

However, the analysis using the "trim and fill" method indicated that even with the inclusion of a hypothetical study, the final result and conclusion remained unchanged. This finding suggests that the publication bias, if present, does not significantly impact the overall findings of the meta-analysis.

Furthermore, Begg's test yielded a significance level of P=0.308, indicating no evidence of publication bias in the included studies. Similarly, the results of Egger's test (P=0.156) also suggested the absence of publication bias in this meta-analysis.

LT Muscle

The meta-analysis results (as shown in Figure 4) indicate that there is no significant difference in the activity of the LT muscle among individuals with scapular dyskinesis when performing PU exercises on both stable and unstable surfaces (P=0.176). The statistical analysis showed no significant heterogeneity between the included studies (P=0.465; I^2=0.00%).

These findings suggest that the activity of the LT muscle does not significantly differ when performing PU exercises on stable versus unstable surfaces in individuals with scapular dyskinesis. The lack of heterogeneity among the studies further supports the consistency of the results.

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
De Faria et al. (2021)	0.078	0.278	0.077	-0.466	0.622	0.281	0.779
de Araujo et al. (2018)	0.394	0.245	0.060	-0.086	0.873	1.609	0.108
Lee et al. (2017)	-0.125	0.237	0.056	-0.588	0.339	-0.527	0.598
Piraua et al. (2014)	0.222	0.185	0.034	-0.140	0.585	1.204	0.229
	0.155	0.114	0.013	-0.069	0.378	1.355	0.176

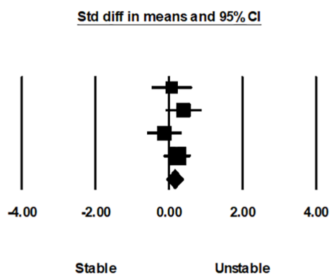

Figure 4: Forest plot of LT activity on both stable and unstable surfaces.

The asymmetrical distribution of studies around the funnel plot's main (vertical) axis (Figure 5) suggests the possibility of visual publication bias. The "trim and fill" method used the random-effects model to assess and address this bias. This action involved adding two hypothetical studies to the right side of the funnel plot to account for potential missing studies due to publication bias.

The "trim and fill" analysis indicated that including these hypothetical studies influenced the final result and conclusion. This finding suggests that publication bias, if present, could potentially impact the overall findings of the meta-analysis.

Additionally, the results of Begg's test yielded a significance level of P=1.000, indicating no evidence of publication bias in the included studies. Similarly, the results of Egger's test (P=0.770) suggested the absence of publication bias in this meta-analysis.

SA Muscle

The meta-analysis results (as shown in Figure 6) indicate a significant difference in the activity of the SA muscle among individuals with scapular dyskinesis when performing PU exercises on stable versus unstable surfaces (P=0.000). The statistical analysis reveals moderate heterogeneity between the included studies (P=0.115; I^2=49.50%).

The asymmetrical distribution of studies around the funnel plot's main (vertical) axis (Figure 7) suggests the possibility of visual publication bias. The "trim and fill" method used the random-effects model to assess and address this bias. The analysis with the "trim and fill" method indicated that even with the inclusion of

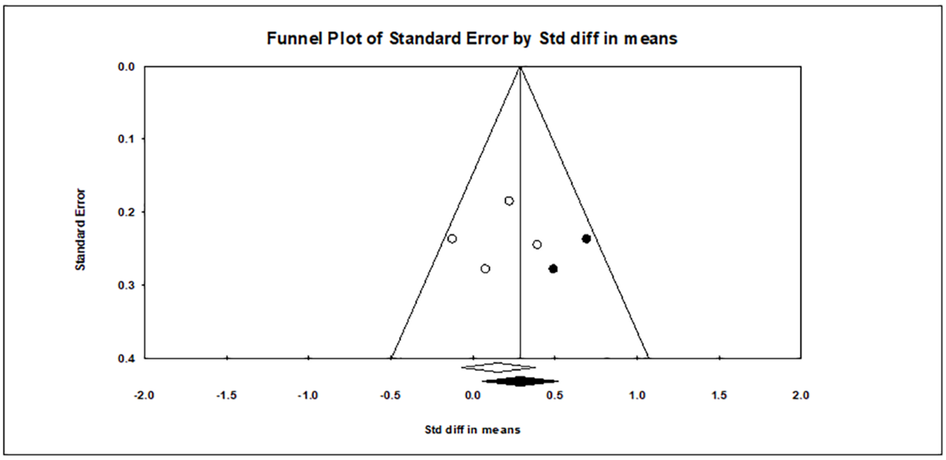

Figure 5: Funnel plot of LT activity on both stable and unstable surfaces.

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
De Faria et al. (2021)	-0.224	0.281	0.079	-0.774	0.326	-0.797	0.425
de Araujo et al. (2018)	-1.175	0.306	0.094	-1.776	-0.574	-3.834	0.000
Lee et al. (2017)	-0.817	0.272	0.074	-1.351	-0.284	-3.002	0.003
Piraua et al. (2014)	-0.538	0.195	0.038	-0.920	-0.155	-2.753	0.006
	-0.665	0.183	0.033	-1.023	-0.307	-3.644	0.000

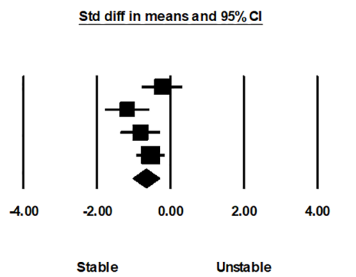

Figure 6: Forest plot of SA activity on both stable and unstable surfaces.

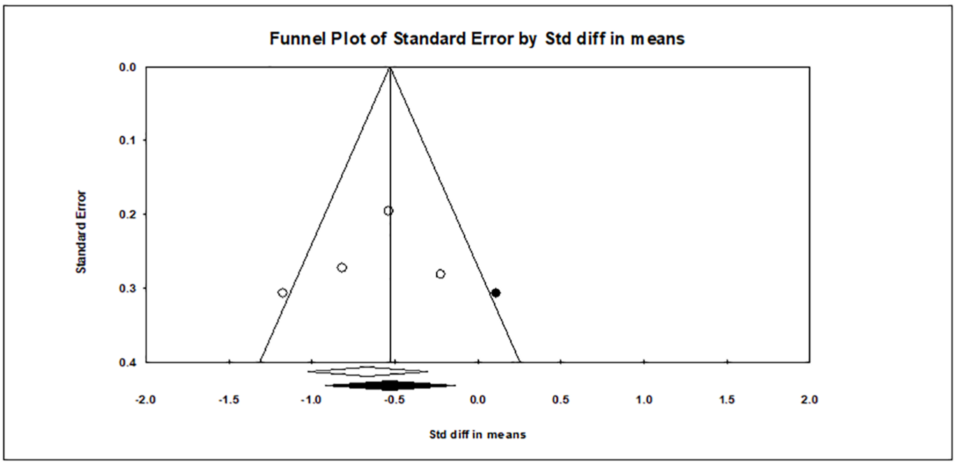

Figure 7: Funnel plot of SA activity on both stable and unstable surfaces.

a hypothetical study, the final result and conclusion remained unchanged. This finding suggests that the publication bias, if present, does not significantly impact the overall findings of the meta-analysis.

Furthermore, the results of Begg's test yielded a significance level of P=0.734, indicating no evidence of publication bias in the included studies. Similarly, the results of Egger's test (P=0.592) demonstrated the absence of publication bias in this meta-analysis.

Discussion

After analyzing the included studies, our systematic review revealed that the use of unstable surfaces led to an increase in the EMG activity of the UT muscle and a decrease in the EMG activity of the SA muscle in individuals with scapular dyskinesis. However, there was no significant impact on the EMG activity of the LT muscle. It is important to discuss the specific characteristics of each muscle to understand the reasons behind these observations with unstable surfaces.

Regarding the increased EMG activity of the UT muscle, it is likely due to the heightened motor control required when using unstable surfaces within the kinetic chain. However, it is worth noting that this result may have been influenced by the study conducted by Lee et al. (2017), where the UT muscle activity during the standard PUP on the sling was increased. In contrast to the other three studies, Lee et al. did not observe any change in the height of the feet from the ground after introducing the unstable surface under the participant's hands [32]. Consequently, raising the arms off the ground (in this case, using tool handles to perform the PUP) while keeping the legs in a normal position causes greater flexion in the glenohumeral (GH) joint, leading to scapular elevation through increased UT muscle activity [13].

Furthermore, it has been reported that the activity of the UT muscle during the PUP with lumbar support on the sling is significantly lower than during the standard PUP on the sling. The presence of lumbar support provides a stable condition for easier implementation of the PUP exercise, making it less influenced by the unstable surface compared to the standard PUP on the sling [32].

Considering these findings and the objective of minimizing UT muscle activity in exercise and rehabilitation programs for individuals with scapular dyskinesis, it is recommended to prioritize the PUP with lumbar support over the standard PUP when using a sling as an unstable surface.

Regarding the LT muscle, no significant impact was found on the EMG activity when using an unstable surface. However, based on the reviewed literature, some authors have reported increased activity in the LT muscle during PU on an unstable surface. They argue that this response may be an alternative neuromuscular strategy for scapular control, compensating for the reduced activity of the SA muscle [30]. Therefore, it was expected to observe increased LT muscle activity for neuromuscular control or improved balance during exercise, considering the reduced activity of the SA muscle in the meta-analysis.

These findings support a recent theoretical hypothesis proposed by McQuade et al. (2016), where they question the term "scapular stability" and suggest that the scapular should possess specific strength to transmit forces between the limbs and upper body, regardless of the adopted neuromuscular strategy [34]. Thus, the LT muscle appears to play a "secondary" role during PU exercises and is only required when the SA muscle function is impaired. Additionally, individuals with scapular dyskinesis, who experience deficiencies in scapular external rotation and posterior tilt, rely on the LT muscles to assist in these movements during arm elevation [35]. However, the LT muscle's effectiveness seems more pronounced in dynamic tasks performed in an open kinetic chain. In closed kinetic chain exercises like PU, which prioritize static stabilization, the LT muscle's role as a stabilizer is diminished, while more action is needed based on the sports biomechanics [6].

Furthermore, the argument presented by Horsak et al. (2017) can be used to justify the limited impact of unstable surfaces on the EMG activity of the LT muscles. They suggest that muscles in both the elbow and GH joints may increase activity levels to preserve upper limb stability and body balance during exercise, making significant periscapular muscle activity unnecessary [36].

The findings obtained from the relevant studies indicate that the EMG responses of the SA muscle vary when unstable surfaces are utilized during different types of PU. Therefore, a comprehensive analysis is necessary to understand these outcomes better. Generally, studies measuring SA muscle activity during PU at various surfaces can be categorized as follows: studies reporting no difference [5, 7], studies reporting reduced activity [37-39], and studies reporting increased activity [3, 6]. It is essential to categorize the studies and clarify the three factors influencing the findings to facilitate comprehension of the results.

The first factor to consider is that studies reporting reduced EMG activity on unstable surfaces did not account for adjusting the leg height to maintain trunk alignment [37-39]. Placing an unstable surface under the hands raises the upper body and causes a slope in the torso. As a result, more body mass is shifted to the lower limbs, increasing the load applied to the legs and reducing the demand on the upper limbs. Ignoring this biomechanical aspect likely introduced bias in the results of SA muscle activity on unstable surfaces [30].

The second factor is related to the implementation of the exercise used in studies that reported no difference in SA muscle activity [5, 7]. In studies measuring PU isometrically, the unstable surfaces employed may not provide sufficient stimulus for a significant increase in SA muscle activity.

The third factor is associated with different parts of the SA muscle, such as the upper and lower fibers, which may have distinct and complementary roles. Inman et al. (1996) reported that the upper fibers of the SA muscle have greater motor function for scapular rotation, while the lower fibers play a more stabilizing role and attach the scapular to the thorax, contributing to posterior tilt [40]. This argument is supported by studies reporting an increase in lower SA muscle activity during PU on unstable surfaces [3, 6].

Based on the explanations provided and the results of the meta-analysis concerning the SA muscle, reduced activity of this muscle was reported in all studies included in our work, except for the study conducted by De Faria et al. (2021). Their study indicated that using unstable surfaces did not influence the EMG activities of the SA muscles. To justify the ineffectiveness of using unstable surfaces on SA muscle EMG activities in De Faria et al.'s study, it should be noted that scapular dyskinesis can exhibit different alteration patterns. In their study, only type II scapular dyskinesis was considered [41], while the other three studies reporting a reduction in SA muscle activities encompassed various types of scapular dyskinesis (except for type III scapular dyskinesis in Piraua et al.'s study). These studies were categorized as follows: Types I to III and combined patterns in the "Yes" category (scapular dyskinesis) and type IV in the "No" category (normal scapular motion) [42].

It is worth mentioning that the tools used to create instability in De Faria et al.'s study provide mediolateral instability, as type II dyskinesis may contribute to altering the control of both internal and external rotational scapular motions [42, 43]. In addition to the explanations above, the main argument put forward by the researchers to justify the reduced activity of the SA muscle is that different neuromuscular control strategies are stimulated in scapular dyskinesis due to the increased demand imposed by PU on unstable surfaces. Unstable surfaces may exacerbate differences in neuromuscular control during the execution of PU, and it is believed that the presence of scapular dyskinesis is associated with a specific disorder in the EMG activities of the SA muscles [3, 30].

This systematic review and meta-analysis are the first to investigate the effectiveness of using unstable surfaces on the EMG activities of the trapezius and SA muscles, the main muscles involved in individuals with scapular dyskinesis. Despite the high quality of the studies included in the analysis based on the quality assessment form, the study encountered some methodological limitations:

1. Including only English-language research may have omitted studies published in other languages. However, the impact of language bias is debatable, and its effects have not been definitively proven [44, 45].

2. The statistical sample of studies consisted exclusively of men.

3. The results are limited to individuals with painless scapular dyskinesis. Therefore, it is impossible to generalize the findings to women or individuals with painful shoulder dysfunction, such as Subacromial impingement syndrome.

4. The review did not specify the motor control aspects during PU and PUP exercises.

Considering the above limitations, this review offers therapists and sports professionals an EMG-based framework to prescribe different types of PU based on their goals related to the neuromuscular demands of individuals with scapular dyskinesis. This framework can help restore muscle imbalance and address specific muscle engagement.

Conclusion

Using unstable surfaces in individuals with scapular dyskinesis can lead to an increase in EMG activity in the UT muscles and a decrease in EMG activity in the SA muscles. However, the EMG activity of the LT muscles is not significantly affected by the use of unstable surfaces. Therefore, it is important to exercise caution when using unstable surfaces in individuals with scapular dyskinesis, as it may exacerbate the muscle imbalance between the UT and SA muscles. Improper use of unstable surfaces can potentially worsen the muscle imbalance in these individuals.

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