

Electromyographic analysis of core muscle activity during variations of abdominal exercises

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Published online: January 31, 2025

Accepted for publication: January 15, 2025

DOI:10.7752/jpes.2025.01020

Abstract:

Problem Statement: Core stability is crucial for athletic performance and injury prevention. However, a comprehensive understanding of the specific activation patterns of core muscles during various abdominal exercises is lacking. This study aims to elucidate these activation patterns, focusing on the rectus abdominis, internal obliques, external obliques, and erector spinae. **Purpose:** The primary objective of this study was to evaluate the activation patterns of core muscles during abdominal exercises and to identify any asymmetries in muscle engagement that could inform exercise prescription and rehabilitation strategies. **Approach:** This study involved a detailed analysis of muscle activation using electromyographic (EMG) technology within a sample group of ten jumpers from Mangalore University's Department of Physical Education, each with a training history of around 7.0 ± 3.5 years. The primary objective was to evaluate the electromyographic activity of core muscles during various abdominal exercises, which included sit-ups, back extensions, and planks. **Materials and Methods:** EMG electrodes were strategically placed on the rectus abdominis, internal obliques, external obliques, and erector spinae. Participants underwent a series of exercises while their muscle activity was recorded, allowing for a comprehensive analysis of muscle engagement during each exercise. **Results:** The findings revealed that the rectus abdominis consistently exhibited dominant activation across all exercises, accounting for a significant proportion of overall muscle engagement. During planks, the rectus abdominis, external obliques, and internal obliques collectively contributed to over 87% of muscle activation. Notably, asymmetries were observed in muscle activation between the right and left sides of the rectus abdominis and internal obliques, potentially linked to individual differences in muscle recruitment patterns or handedness. **Conclusions:** These results underscore the importance of balanced muscle activation for effective core stability and highlight the need for personalized training approaches to address individual muscular imbalances. The insights gained from this research can inform the development of tailored core-strengthening programs and rehabilitation strategies, ultimately enhancing performance and preventing injuries in both athletic and general populations. This study advances understanding of core muscle dynamics and sets the stage for future research on muscle activation patterns in diverse populations.

Key Words: Electromyography, Core stability, Muscle activation, Maximum voluntary contractions (MVC), Abdominal exercise, Injury prevention.

Introduction

Electromyography (EMG) emerges as a pivotal discipline that elucidates the intricate dynamics of muscular activity at the intersection of biology and technology. EMG is a sophisticated tool for capturing and interpreting the electrical signals produced during muscle contractions, playing a crucial role in clinical diagnostics and sports science applications (Pazos & Garcia, 2020). Decoding these electrical patterns is essential for diagnosing neuromuscular disorders, assessing muscle performance, and refining physical training regimens. The versatility of EMG extends beyond medical diagnostics, significantly impacting athletic performance enhancement, where customized training protocols can markedly improve an athlete's capabilities (Priego-Quesada et al., 2022). The foundational work in electromyography can be traced back to pioneering studies that established that core power generation is fundamental to all physical activities (Muceli et al., 2022). The significance of core muscle function is particularly evident in various physical activities, where the core acts as the body's stabilizer and power generator.

Core stability is defined as the ability of the lumbopelvic-hip complex to return to equilibrium following a perturbation without compromising the integrity of the vertebral column (Laveneziana et al., 2019). The growing recognition of trunk or core muscle training's importance for enhancing health, rehabilitation, and athletic performance underscores its relevance in contemporary fitness paradigms (Chandolias et al., 2022). Research indicates that abdominal muscles are critical contributors to virtually all physical activities, whether in competitive sports or everyday tasks such as lifting heavy objects (Borysiuk, 2008). The recruitment of these

muscles is essential for developing athletic ability and functional movement, as effective muscle recruitment enhances core stability and provides proximal stability to facilitate distal mobility (Huang et al., 2020). For optimal core stability, both the smaller, deeper core muscles and the larger, superficial core muscles must contract in a coordinated manner, with appropriate timing and tension (Martinek et al., 2021). This coordinated contraction is vital for maintaining balance and stability during dynamic movements. Among the various core muscles, this study focuses on four key muscles: the Rectus Abdominis (RA), External Obliques (EO), Internal Obliques (IO), and the Erector Spinae (ES) from the posterior chain.

The initial phase of the research involves measuring the Maximum Voluntary Isometric Contraction (MVIC) of these muscles on both the anterior and posterior sides, providing a comprehensive understanding of their activation patterns (Jonkman et al., 2024). The research journey delves into the dynamic realm of jumpers, where EMG serves as a navigational tool, guiding the exploration of subtle nuances in muscle activation. This investigation resides at the confluence of scientific inquiry and athletic performance, promising to illuminate the intricate engagement of core muscles during explosive movements. The ability to analyze EMG data allows for a deeper understanding of how core muscle activation influences overall athletic performance, particularly in activities that require rapid and powerful movements (Priego-Quesada et al., 2022). The relevance of EMG in understanding muscle function is further underscored by studies that compare muscle activation patterns during exercises performed on stable versus unstable surfaces. Such investigations reveal that core muscles, including the rectus abdominis, transversus abdominis, and erector spinae, exhibit varying levels of activation depending on the stability of the surface during exercise (Huang et al., 2020). This variability highlights the adaptability of core muscles and their critical role in maintaining stability and balance during dynamic activities. Moreover, the relationship between core muscle strength and overall athletic performance has been extensively documented. Research indicates that enhanced core stability improves athletic performance and reduces the risk of injury by providing a stable base for movement (Chandolias et al., 2022). The importance of core stability is particularly pronounced in sports requiring rapid changes in direction, jumping, and landing, where maintaining balance and control is paramount. Consequently, tailored training programs focusing on core muscle activation can significantly enhance an athlete's performance and resilience (Priego-Quesada et al., 2022). In addition to athletic applications, EMG is instrumental in clinical settings, where it aids in the diagnosis and rehabilitation of neuromuscular disorders.

The ability to assess muscle activation patterns provides valuable insights into the functional capabilities of patients with conditions such as spinal muscular atrophy (SMA) and other neuromuscular diseases (Pazos & Garcia, 2020). Studies have shown that individuals with SMA exhibit reduced muscle strength and altered activation patterns, underscoring the importance of targeted rehabilitation strategies incorporating core muscle training (Muceli et al., 2022). Exploring core muscle activation through EMG also extends to understanding the effects of various training modalities on muscle performance. For instance, concurrent strength and endurance training has been shown to elicit distinct neuromuscular adaptations, influencing muscle activation patterns during subsequent physical activities (Huang et al., 2020). This highlights the necessity of considering training specificity when designing programs to enhance core stability and overall athletic performance. Furthermore, the normalization of EMG data is a critical aspect of accurately interpreting muscle activation levels. Various normalization techniques, such as using the Maximum Voluntary Isometric Contraction (MVIC) as a reference, have been employed to standardize EMG readings across different studies (Martinek et al., 2021). However, discrepancies in normalization methods can lead to variations in reported muscle activation levels, emphasizing the need for consistency in research methodologies. The interplay between muscle activation and functional movement is further illustrated by studies examining the effects of core stability exercises on muscle activity and trunk impairment in populations with specific needs, such as stroke patients. These investigations reveal that targeted core stability training can enhance muscle activation and improve functional outcomes, reinforcing the therapeutic potential of EMG in rehabilitation settings (Chandolias et al., 2022). The exploration of electromyography as a tool for studying muscle function reveals its multifaceted applications in both clinical and athletic contexts. The intricate relationship between core muscle activation, stability, and overall performance underscores the importance of continued research in this dynamic field. By harnessing the insights gained from EMG studies, practitioners can develop more effective training and rehabilitation protocols that optimize muscle function and enhance athletic performance.

Material & methods

Selection of Tool

Electromyography (EMG) is the recording of electrical activity in muscle, the recording of the electrical activity of muscle tissue, or its representation as a visual display or audible signal, using electrodes attached to the skin or inserted into the muscle (Saito et al., 2018). The test was performed with non-invasive surface EMG electrodes placed on the Rectus Abdominals (RA), External Obliques (EO), Internal Obliques (IO), and Erector spinae - longissimus dorsi (ES).

Participants

Ten Jumpers of Mangalore University, Department of Physical Education fraternity, with 7.0 ± 3.5 years of training experience, were chosen between 20 - 25 years of age. Subjects are participating in

intercollegiate and state-level competitions and athletic championships. All the subjects were healthy and free from musculoskeletal or neuromuscular injuries, pain, or illness. Subjects who completed an informed consent form before data collection were advised to refrain from training their core for 48 hours before testing to ensure accurate muscle activation readings.

Table 1. Demographic details of the subjects

N	Weight (Kgs)	Height (cms)	BMI
10	62 ± 4.77	172.75 ± 5.14	20.85 ± 2.06

Skin preparation

Proper skin preparation is crucial to ensure accurate and artefact-free signals. The alcohol was used to wipe off the dirt, and the area of electrode placement was shaved in case the subject had more body hair, which would impede the electrode signal sEMG.



Fig 1. Recording of MVC

Electrode placement

Measurements were done with surface electrodes placed on the skin over the muscle belly longitudinally to muscle fibres using SENIAM (Surface Electromyography for the Non-invasive Assessment of Muscles) guidelines.



Fig 2. External oblique electrode placement

(EO) Midway between the ASIS and rib cage parallel to the muscle fibre. The external oblique was placed 13 cm lateral to the umbilicus.



Fig 3. Internal Oblique electrode placement

(IO) For internal oblique 3 cm medial and inferior to the right Anterior Superior Iliac Spine (ASIS).

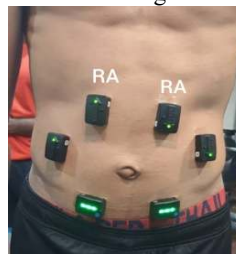


Fig 4. Rectus Abdomens electrode placement

(RA) 3cm lateral & 3cm superior to the umbilicus.



Fig. 5. Erector spinae - longissimus dorsi electrode placement

(ES) – The electrode must be placed at two finger width lateral from the proc—Spin of L1.

Procedure

An important aspect is the level of muscle contraction, which is related to muscle force; it determines both amplitude and frequency metrics (Roman-Liu & Bartuzi, 2018). Firstly, the anterior chain's maximum voluntary contraction (MVC) was measured using EMG. The subject was asked to lie down in a supine position with knees bent. To record the MVC of the anterior muscle (RA, IO, and EO), external resistance was applied over the shoulders so that the subject reached his maximum voluntary contraction while trying to get up from the starting position. This was similar to studies by Vera-Garcia et al. (2010), Escamilla et al. (2006), Oliva-Lozano & Muyor (2020).

After recording the MVC, the individual was requested to perform three sit-ups, elevating his upper body to 45 degrees and returning to the starting position (laid down). The participant was requested to wait for five seconds before returning to the previous position, and a window gap of three seconds was taken to indicate the maximum activation for further investigation.

The MVC of the posterior muscle was also recorded. When the person was instructed to lie down in a prone position with his hands locked behind his neck and elevate his upper body above the ground or beginning position while an external force was applied. After the MVC for the posterior (erector spinae – longissimus dorsi) muscle was recorded, the individual was requested to execute three repetitions of back extension for five seconds each, with a window gap of three seconds recorded for analysis.

Allowing one minute of rest between exercises ensured the person was not too tired to do the next activity. After a minute of rest, the participant was requested to hold the plank posture for 10 seconds as the activation of all eight muscles was monitored. All eight muscles' EMGs were recorded for subsequent study.

Instruments

The electrical activity of six lower extremity muscles was monitored with pre-amplified Ag/AgCl surface electrodes. The Delsys system, which involves cordless electromyographic equipment, was used to detect muscle activation and interfaced with an amplifier/ processor module (CMRR 87 dB at 60 Hz; input impedance. 15 megohms at 100 Hz; 20–4000 Hz band-pass). The bilateral (right & left) eight muscles analyzed were Rectus abdominis (RRA) & (LRA), External Obliques (REO) & (LEO), Internal Obliques (RIO) & (LIO) and Erector spinae (RES) & (LES). After standard skin preparation, the electrodes were placed distal to the approximate motor point of each muscle. Amplification of each EMG signal was set to maximize resolution. EMG channels were sampled for the duration of the exercise (approximately 15 mins) and 1 min recovery for a total of three repetitions.

Statistical analysis

The data was streamed via USB to the computer system (Lenovo ThinkPad, P14s) and analyzed using LabChart 8, Ad Instruments, USA software. The data was converted to RMS value in the software. The data was shown in graphs and tables to make a meaningful comparison between the muscle activation of each muscle during different repetitions.

Descriptive statistics were calculated for selected EMG-dependent variables. The data was analyzed using advanced Excel and SPSS Software.

Data analysis

The EMG signals generated during both MVICs testing and while performing exercises were analyzed and filtered using the root-mean-square (RMS) technique (LabChart 8.0, Ad Instruments, USA) (Chan et al., 2020). The sEMG data was acquired using Trigno Wireless System, Delsys, Natick, MA, United States and used to quantify muscle activity (Torres-Banduc et al., 2021).

The MVIC for each muscle was determined by calculating the EMG signal throughout the 5-s period of MVIC. The MVIC was performed on the selected muscles: Rectus Abdominus, External Obliques, Internal Obliques on the anterior aspect and Longissimus Dorsi on the posterior aspect of the body.

Results

The study assessed core muscles' electromyographic (EMG) activity during various abdominal exercises, specifically sit-ups, back extensions, and planks.

Muscle Activation During Sit-Ups

The root mean square (RMS) values and percentage activations of the anterior core muscles during sit-ups are summarized in Table 2. Among these, the right rectus abdominis (RRA) exhibited the highest RMS value (0.584 ± 0.12 mV), followed by the left rectus abdominis (LRA, 0.493 ± 0.09 mV).

Table 2. RMS & Percentage activation of sit-ups for anterior muscles.

Muscles	RMS	% Activation
RRA	0.584 ± 0.12	140.10 ± 22.49
LRA	0.493 ± 0.09	131.71 ± 29.48
REO	0.263 ± 0.12	186.28 ± 45.42
LEO	0.325 ± 0.20	202.56 ± 47.81
RIO	0.148 ± 0.3	127.14 ± 23.52
LIO	0.115 ± 0.03	229.01 ± 58.89

Note. The values represent the Mean $\pm$ Standard Deviation of muscle activation for ten samples and are expressed in RMS of mV and percentage activation while performing sit-ups.

Figure 6 illustrates these RMS values graphically. The external oblique muscles also showed significant activation, with the right external oblique (REO) recording an RMS value of 0.263 ± 0.12 mV and the left external oblique (LEO) at 0.325 ± 0.20 mV. In contrast, the left internal oblique (LIO) demonstrated the lowest RMS activation at 0.115 ± 0.03 mV, indicating a lesser role in this exercise than the rectus abdominis and external obliques.

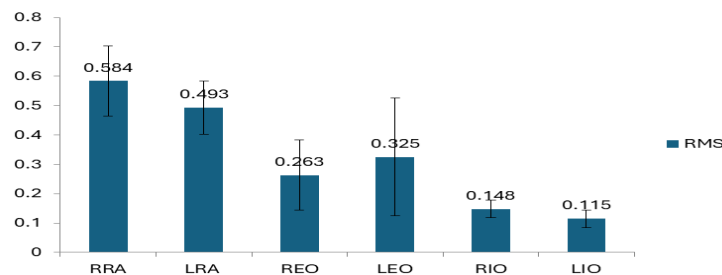


Figure 6. Muscle activation graphical representation of anterior core muscles while performing sit-ups expressed in RMS of mV.

Percentage activation analysis of each muscle during sit-ups (Figure 7) highlights that the left internal oblique (LIO) exhibits the highest percentage activation (229.01%), indicating greater recruitment of muscle fibers compared to other anterior muscles (Farina et al., 2004). The right rectus abdominis (RRA) and left rectus abdominis (LRA) also showed substantial contributions, with percentage activations of 140.10% and 131.71%, respectively. The external obliques also contributed significantly, with REO at 186.28% and LEO at 202.56%. These findings highlight the dominant role of the rectus abdominis and external obliques in trunk flexion during sit-ups while also indicating the compensatory activation of the internal obliques.

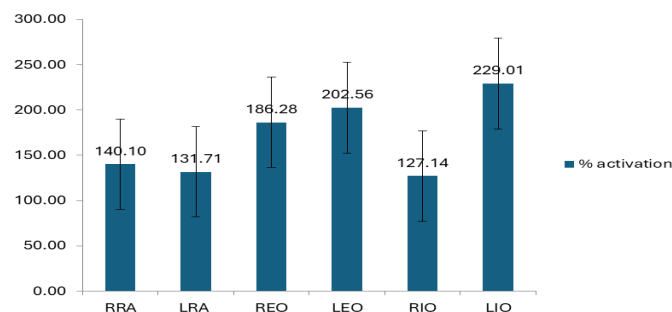


Figure 7. Percentage activation of each muscle during performing sit-ups.

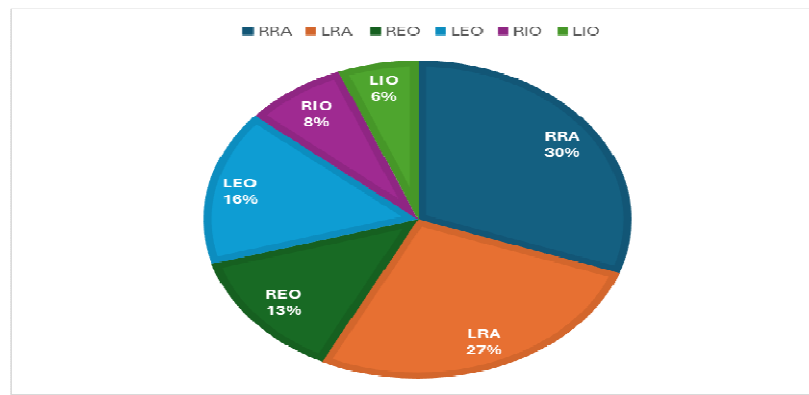


Fig 8. Percentage contribution of all eight selected anterior muscles during sit-ups.

The data (Fig. 8) shows an asymmetric contribution of the rectus abdominis (RRA and LRA) muscles, with the right side being more active by approximately 3.63%. The external oblique muscles (REO and LEO) exhibit a relatively balanced contribution, with only a slight difference of about 2.68%. Notably, the rectus abdominis and external oblique muscles account for a large proportion (approximately 86.29%) of muscle activation during sit-ups. In contrast, the internal oblique muscles (RIO and LIO) have a combined contribution of approximately 13.72%.

Muscle activation during back extensions

For posterior core muscles, Table 3 shows that the right erector spinae (RES) exhibited slightly higher RMS activation (0.136 ± 0.05 mV) compared to the left erector spinae (LES, 0.119 ± 0.02 mV). Figure 8 graphically represents this data, while Figure 9 confirms these muscles' nearly symmetrical percentage contribution during back extensions, with only a 4% difference.

Table 3. Muscle activation and percentage contribution of posterior muscles for back extension

Muscles	RMS	% Activation
RES	0.136 ± 0.05	64.30 ± 18.39
LES	0.119 ± 0.02	60.19 ± 7.44

Note. The values represent the Mean $\pm$ Standard Deviation of muscle activation for ten samples and are expressed in RMS of mV and percentage activation while performing back extension.

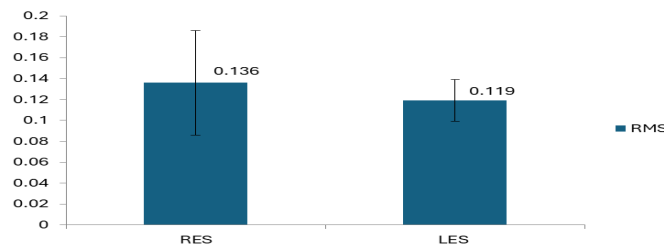


Figure 9. Muscle activation graphical representation of erector spinae muscles while performing back extension expressed in RMS of mV.

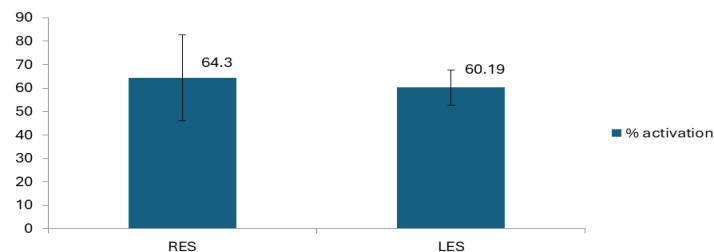


Figure 10. Percentage activation of RES and LES

When executing back extensions, the percentage contribution of RES and LES is nearly identical, with only a 4% difference in activation. When executing back extensions, the percentage contribution of the right erector spinae - (RES) and the left erector spinae - (LES) is remarkably similar, with only a marginal 4% difference in muscle activation. RES and LES exhibit similar activation patterns during trunk flexion and extension exercises (Vera-Garcia et al., 2000).

The percentage contribution of the right erector spinae (RES) and the left erector spinae (LES) was measured during back extension exercises. The results show a relatively balanced contribution between these two muscles, with RES contributing 52.15% and LES contributing 47.85% to the overall muscle activation during the exercise. This data indicates that both sides of the lower back actively support the spine during back extensions.

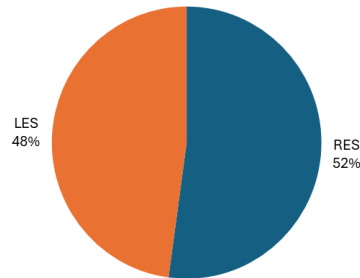


Figure 11. Percentage contribution of two posterior muscles during back extension.

Muscle activation during planks

Table 4 shows RMS and percentage activations for eight bilateral muscles during planks. The RRA exhibited the highest RMS value (0.211 ± 0.11 mV), while the LES recorded the lowest (0.022 ± 0.02 mV). Figure 10 presents the graphical RMS representation, while Figure 11 reveals that the external oblique muscles (LEO, 107.68%) exhibited the highest activation percentage, followed by the rectus abdominis and internal obliques.

Table 4. Muscle activation and percentage contribution of eight bilateral muscles while performing planks.

Muscles	RMS	% Activation
RRA	0.211 ± 0.11	53.23 ± 26.76
LRA	0.09 ± 0.01	26.40 ± 12.28
REO	0.151 ± 0.08	99.22 ± 21.73
LEO	0.134 ± 0.55	107.68 ± 29.90
RIO	0.083 ± 0.01	76.46 ± 16.90
LIO	0.044 ± 0.12	85.92 ± 24.20
RES	0.058 ± 0.03	30.52 ± 9.82
LES	0.022 ± 0.02	16.24 ± 5.48

Note. The values represent the Mean $\pm$ Standard Deviation of muscle activation for ten samples and are expressed in RMS of mV and percentage activation while performing planks.

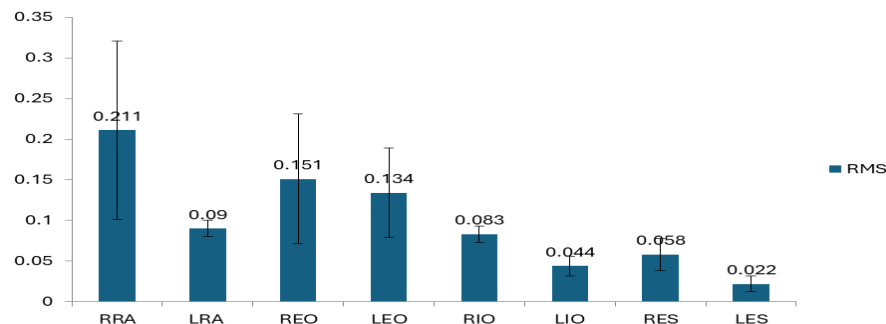


Figure 12. Muscle activation graphical representation of eight bilateral muscles while performing planks

During planks, the primary activators are RRA (0.211 ± 0.11) and LEO (0.134 ± 0.55). The divergence in RRA & LEO is more significant than in other muscles.

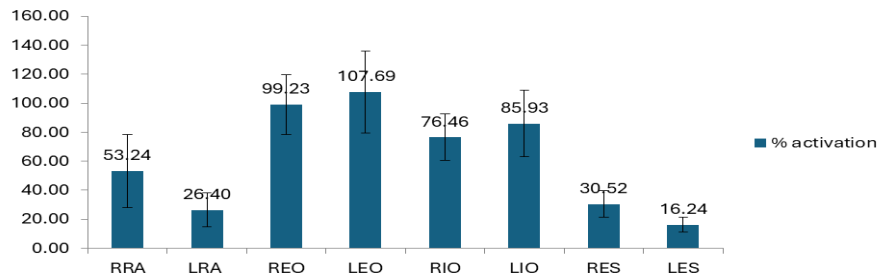


Figure 13. Percentage activation of each selected muscle during performing planks.

The rectus abdominis muscles collectively contribute significantly to core activation during planks (Figure 14), with a total activation of 37.17%. The right rectus abdominis (RRA) demonstrates a more active role than the left rectus abdominis (LRA), indicating a possible side dominance or handedness effect (Behm et al., 2010). The external oblique muscles show a substantial combined contribution of 33.77%, highlighting their role in maintaining lateral stability and resisting rotation in the plank position. The balanced activation of the right external oblique (REO) and left external oblique (LEO) prevents excessive rotation and ensures a stable plank position (Behm et al., 2010). The internal oblique muscles jointly contribute 16.62%, aiding in core stabilization and minimizing excessive lateral movement during the plank. The erector spinae muscles contribute a combined total of 12.44%, indicating a more minor role in this exercise. With a combined contribution of 12.44%, the erector spinae muscles play a more minor role in planks.

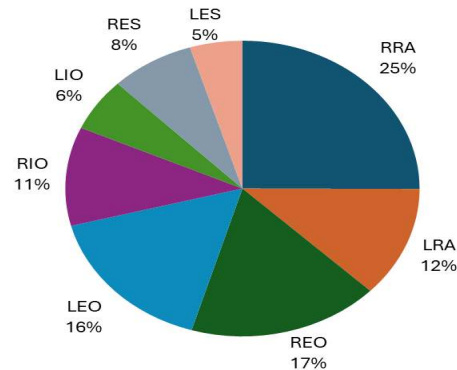


Figure 14. Percentage contribution of all eight bilateral anterior and posterior muscles during performing planks.

Overall percentage contribution

Table 5 summarizes the percentage contributions during all three exercises. The rectus abdominis muscles (RRA and LRA) contributed the most (30.50% and 26.87%, respectively) for sit-ups. The erector spinae muscles dominated back extensions, with the RES contributing 52.15%. During planks, the rectus abdominis contributed significantly (RRA: 25.04%, LRA: 12.13%), with external obliques also playing a critical role.

Table 5. Percentage contribution of eight bilateral muscles during sit-ups, back extension and planks.

Sit-ups		Back Extension		Planks	
Muscles	% Contribution	Muscles	% Contribution	Muscles	% Contribution
RRA	30.50	RES	52.15	RRA	25.04
LRA	26.87	LES	47.85	LRA	12.13
REO	13.12			REO	17.47
LEO	15.80			LEO	16.30
RIO	7.68			RIO	10.80
LIO	6.04			LIO	5.82
RES	NA			RES	7.66
LES	NA			LES	4.78

Note. The values represent the percentage contribution of eight muscles for ten subjects.

The analysis demonstrated that the rectus abdominis exhibited significantly higher activation levels during sit-ups compared to the other muscles tested. Given that EMG analysis has been shown to reflect not only muscle activation, research has also proven that muscle fatigue over extended periods of exertion (Agostinho et al., 2024), but the recorded activation patterns may also serve as an early indicator of muscular fatigue, necessitating further investigation into the temporal dynamics of fatigue relative to exercise intensity.

Discussion

Muscle recruitment during sit-ups

The results indicate that the rectus abdominis muscles, particularly the right rectus abdominis (RRA), are the primary contributors during sit-ups, which aligns with their known role in trunk flexion. The high percentage activation of the left internal oblique (LIO) suggests its compensatory role in providing rotational stability during this exercise. The observed asymmetry in activation between the RRA and the left rectus abdominis (LRA), approximately 3.63%, may be attributed to handedness or a dominant side, as some individuals tend to recruit one side more than the other during exercises. This disparity underscores the importance of evaluating the implications of such asymmetry on muscle growth and potential muscular imbalances, as highlighted in previous research (Cram, 2003). In contrast, the relatively balanced activation of the external oblique muscles indicates that individuals can effectively engage both the right external oblique (REO) and left external oblique (LEO), essential for maintaining core stability. While the internal oblique muscles play a necessary role in trunk rotation and stability, their proportional contribution during sit-ups is minimal compared to the rectus abdominis and external obliques. The significant contributions of the rectus abdominis and external obliques during core exercises underscore their essential roles in core strengthening. Notably, research, such as the study comparing muscular electrical activity during bent-knee sit-ups and using a Five-minute Shaper device (Guerrero-Mendez et al., 2021), provides further insight into optimizing muscle activation. This study used surface electromyography (sEMG) to analyze how these exercises engage the rectus abdominis, internal obliques, external obliques, and erector spinae muscles.

Posterior muscle activation in back extensions

The balanced activation of the erector spinae muscles (RES and LES) during back extensions during back extensions is essential for maintaining spinal stability and reducing the risk of lower back injuries. Research indicates that bilateral symmetry in muscle activation contributes significantly to postural stability and effective spinal extension during physical activities (Speirs et al., 2016). This symmetry is crucial for enhancing performance in exercises like back extensions and preventing injuries that may arise from imbalances in muscle activation (Amirova et al., 2021). The role of the erector spinae muscles in maintaining an upright posture and facilitating controlled trunk extension is underscored by their anatomical arrangement and muscle fiber composition. Studies have shown that the erector spinae muscles consist predominantly of type I fibers, which are well-suited for endurance activities such as maintaining posture over extended periods (Zhang et al., 2020). This composition allows for sustained muscle contractions necessary for stability-related activities, such as back extensions. Furthermore, muscle activity patterns in the erector spinae can vary based on the type of exercise performed. This suggests that exercise prescriptions to strengthen these muscles should consider the specific demands of different movements (Chin et al., 2017). Understanding these dynamics of erector spinae activation during exercises can inform effective exercise prescriptions that not only aim to strengthen the lower back but also promote overall spinal health and functional performance (Darçın et al., 2023; Saeterbakken & Fimland, 2012).

Core muscle engagement in planks

The plank exercise demonstrates a significant contribution from the rectus abdominis (37.17%) and external obliques (33.77%), highlighting their critical role in stabilization. The substantial activation of both the left external oblique (LEO) and right external oblique (REO) underscores their importance in resisting rotation and maintaining core stability during the static plank position. The relatively lower contribution of the erector spinae muscles (12.44%) is expected, as their role in planks is secondary to anterior core muscles (Behm et al., 2010). Notably, the analysis reveals that the LEO exhibits higher activation than all other muscles, indicating greater recruitment of the muscle fibers during the exercise. Existing research suggests variations in muscle fiber recruitment patterns may occur under different task intensities. Specifically, slow-twitch fibers are predominantly activated at lower intensities, resulting in lower root mean square (RMS) values. At the same time, high-intensity tasks recruit fast-twitch fibers, leading to higher activation percentages. Additionally, the temporal patterns of muscle activation can change with muscle fatigue, potentially reducing the rate of motor unit recruitment (decreasing RMS) while maintaining force production through increased motor unit synchronization (De Luca et al., 2006; Enoka & Duchateau, 2016; Farina et al., 2004).

The significant contribution of the rectus abdominis aligns with its established role in stabilizing the core and maintaining a strong straight body position during planks. The observed dominance of the RRA over the LRA suggests that side dominance or handedness may influence muscle activation patterns, which is crucial for understanding individual variations in exercise performance (Behm et al., 2010).

Furthermore, the external oblique muscles' substantial contribution emphasises their importance in maintaining lateral stability and resisting rotation, which is essential for effective plank execution. The balanced activation of the REO and LEO prevents excessive rotation. It plays a supportive role in core stabilization, further enhancing the overall effectiveness of the plank exercise. Although the erector spinae muscles contribute less significantly during planks, their activation remains essential for providing support and stability to the lower back and spine, which is crucial for maintaining proper form during exercise. This finding aligns with the work of Vera-Garcia et al. (2000), which emphasizes that while the erector spinae are not the primary focus during planks, their engagement is necessary for overall spinal stability.

Implications for exercise prescription

The findings from this study offer valuable insights for designing exercise programs that effectively target specific core muscle groups. The significant activation of the rectus abdominis and external obliques during sit-ups and planks underscore their critical roles in core strengthening. However, the observed asymmetries in muscle activation highlight the need for careful consideration to prevent potential muscle imbalances which could lead to injuries over time. To address these discrepancies, incorporating exercises emphasising unilateral activation may be beneficial, allowing for balanced development of both sides of the core. Additionally, the high activation levels of the posterior muscles during back extensions indicate their effectiveness in strengthening the lower back, an area crucial for maintaining proper posture and preventing injuries. This finding supports the implementation of tailored approaches to core training that consider individual needs, fitness levels, and specific exercise goals. By customizing exercise programs to address each individual's strengths and weaknesses, practitioners can enhance overall core stability and functional performance while minimizing the risk of injury. Moreover, the use of EMG analysis within our study revealed activation patterns among core muscles and holds potential as a reliable indicator of muscle fatigue. As documented by Agostinho et al. (2024), changes in EMG signal characteristics can reflect muscle fatigue, which is essential for developing personalized training regimens to improve endurance and performance while minimizing the risk of injury.

Conclusions

This study has elucidated the intricate interactions among various muscles engaged in planks and other core-strengthening exercises, underscoring the critical importance of balanced muscle activation for maintaining a stable and effective plank posture. The findings reveal that the rectus abdominis, external obliques, and internal obliques collectively account for over 87% of muscle activation during planks, highlighting their essential roles in core stability. Notably, the observed differences in activation between the right and left sides of certain muscle groups, particularly the rectus abdominis and internal obliques, suggest that individual variations in muscle recruitment patterns or handedness may influence exercise performance. Understanding these activation patterns is vital for designing effective core-strengthening exercises and preventing injuries. The insights from this research can inform the development of customized training programs that address individual muscular imbalances, ensuring a more balanced approach to core development. Moreover, this study emphasizes the need for further research to explore how these muscle activation patterns impact plank performance across diverse populations, including athletes, individuals in rehabilitation, and the general public. By advancing our understanding of core muscle engagement, we can enhance fitness and rehabilitation programs, ultimately leading to more effective training strategies and improved injury prevention.

The findings of this study not only contribute to our knowledge of core muscle dynamics but pave the way for innovative approaches to exercise prescription. By prioritizing balanced muscle activation and addressing individual differences, we can foster a more holistic understanding of core training, promoting better outcomes for all individuals seeking to enhance their physical fitness and overall well-being.

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