Original Article

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The bench press prime mover muscles firing frequency changes according to sticking region during maximal and submaximal effort

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Abstract: The bench press (BP) is a widely used exercise in strength training. Despite numerous studies on muscle activation during BP, little is known about individual muscle frequency changes during the sticking region (SR). This study aimed to evaluate muscle activation during 1 repetition maximum (RM) and 4RM BP in 24 male participants experienced with BP exercise. Electromyography was used to measure muscle activity in various muscles during pre-sticking, sticking, and post-sticking phases, with kinematic data aiding in phase differentiation. Our findings revealed a significant decrease in muscle activation frequency as participants moved from the pre-sticking to the sticking and then to the post-sticking phases ($p<0.01$). This decline was evident in both 1RM and 4RM conditions, indicating muscle exhaustion that persisted even after the SR. The SR of the BP is the most challenging part of the exercise, resulting in a decrease in muscle frequency during this phase in both 1RM and 4RM repetitions. It indicates exhaustion of the muscles which persisted even in the post-sticking phase, highlighting the challenging nature of the exercise. This study presents insights into muscle activity during the BP, which can help understanding the impact of each exercise phase on muscle frequency.

Keywords: bench press EMG; sticking region muscle activation; firing frequency bench press

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INTRODUCTION

Barbell bench press is a popular strength-training exercise that primarily targets the chest, shoulders, triceps muscles, and trunk stabilizers. It is commonly performed using a barbell and is a fundamental exercise in many strength training programs for both recreational and professional athletes [1,2]. Strengthening of individual muscle groups can increase the bench press performance and alternate muscle activation patterns.

The bench press exercise is divided into three phases: pre-sticking, sticking and post-sticking [3]. The most challenging part to overcome, which determines about success of the attempt, is sticking region (SR) [4]. During SR the velocity of the movement is the lowest, and after the sticking region the velocity of the barbell increases [5]. There have been numerous theories proposed about the sticking region; however, several authors support Van Den Tillaar's and Ettema's [6] statement that the sticking region is not solely due to insufficient force generated to overcome the load, as some researchers suggest. Instead, it is attributed to the delay in transitioning from maximal triceps contraction to maximal activation of the chest muscles and front deltoids [7,8]. Other theory indicate that SR occurrence is defined by the work of the muscle in a biomechanically disadvantageous position in terms of muscle length and moment of force [9-11], where triceps brachii long head was identify as major muscle contributing to overcome the SR [5]. However, this is in contrary with finding that SR is not accompanied by muscle activity increase in bench press, squat and deadlift [5,7]. Moreover, Van den Tillaar suggests that this sticking region is often caused by a decrease in peak acceleration and peak bar velocity. Specifically, as an individual approaches the sticking region, their ability to accelerate the movement decreases, leading to a decrease in peak bar velocity. This decrease in peak bar velocity can then cause the individual to get "stuck" in the sticking region, as they are unable to generate enough force to overcome the resistance of the weight [5]. Additionally, based on Larsen study grip width also affects the sticking region and indicates that when recreationally trained males aim to maximize their weight lifting in 1RM bench press attempts, utilizing a wide or medium grip width on the bench press may prove advantageous when compared to narrow grip [12].

While SR are more frequently observed in lifts with near-maximal loads such as 1RM [13, 14], 4RM [15] and 6RM [10], they can also occur in sub-maximal lifts as a result of accumulated fatigue. Studies have shown that the mean bar velocity in sub-maximal lifts decreases with increasing repetitions, and that peak bar velocity can decline significantly during sub-maximal lifts until exhaustion. This decrease in bar velocity can serve as an indicator of neuromuscular fatigue [16]. In addition, Duffey and Challis [17] demonstrated that the kinematic profile of the last repetition during sub-maximal bench pressing until exhaustion resembled that of a maximal 1-RM bench press, suggesting that fatigue has a significant impact on an individual's ability to generate force. Acute fatigue mechanisms, such as excitation-contraction coupling failure, can lead to breakdown during exercise [14].

In their research, van den Tillaar et al. [5,18,19], employed surface electromyography (sEMG) to analyze muscle activity during the bench press, particularly focusing on the pre- and post-sticking regions. Their objective was to identify the muscles that aid in overcoming the sticking region. Van den Tillar [10] examined the effect of the fatigue and sEMG during a 6-RM barbell bench press, where grip width was self-adjusted by participants. Interestingly, the triceps brachii long head showed similar activity levels in both the pre- and post-sticking regions. This finding suggests that the triceps brachii long head does not play a major role in overcoming the sticking region. Contrastingly, other studies [18, 19] utilizing maximal loads demonstrated that the deltoid and pectoralis major muscles were more critical in assisting lifters through the sticking phase of the bench press. These insights highlight the importance of specific muscle activation patterns in successful bench press execution.

However, the literature has not extensively explored the differentiation of bench press phases during a 4RM, a common method to boost strength in athletes [20] discovered variations in sEMG readings between the two sides of the body. Notably, they observed higher sEMG activity on the dominant side in muscles such as the pectoralis major, anterior deltoid, and the long head of the triceps brachii. Muscle activation is subject to influence from six key factors, with intensity being the most significant [21,22]. An increase in intensity correlates with heightened muscle activation. Additionally, factors such as mental focus, movement velocity, and fatigue [23] also impact sEMG results.

In a separate study, Golas et al. [24] observed varying activity patterns between men and women during barbell bench press exercises with loads from 55% to 100% of their 1RM. In this context, men exhibited higher activation in the triceps brachii's long head, whereas women experienced an increase in deltoid muscle activity as the load increased. This further underscores the gender-specific differences in muscle activation during the bench press.

Since there is a lack of information about individual muscle frequency change during SR and controversial finding about the mechanism of overcoming the sticking region, the aim of this study is to evaluate the muscle activation frequency during 1RM and 4RM bench press exercise. Our hypothesis proposes that the firing frequency of the measured muscles is anticipated to decrease during the sticking phase, given that this is the most challenging phase. Additionally, we expect a decrease in firing frequency with an increasing number of repetitions, indicative of progressive exhaustion.

MATERIAL AND METHODS

Participants

24 male participants (age 23.3 ± 2.5 years; height 181.9 ± 5.0 cm; weight 84.8 ± 8.9 kg, 1RM 107 ± 27). All had several years of experience in strength training in a gym environment and therefore have experience with a barbell bench-press. For the duration of the testing, none of the probands suffered from any medical conditions that would limit their bench press performance. Ethics committee approval was granted prior to testing (approval no.: 146/2015) and the entire research was conducted according to the ethical standards for research in sport.

Procedure

Prior to the start of the research, each proband was familiarized with the testing procedure, and completed a questionnaire regarding their current physical and mental state. This was followed by a warm-up consisting of a body warm-up (running in place, etc.), a light workout using resistance bands (exercises for: external rotators of the arm, triceps, back and chest muscles), finished with stretching. After warming up, electromyography electrodes were attached to the proband's body to record muscle activity during movement. Before testing began, a maximal free isometric contraction test was performed.

Maximum Repetition measurements

The self-reported one-repetition maximum (1RM) was established based on the information provided by the participants about their maximal lifts executed in the preceding six months. If the participant successfully completed the lift at their self-reported 1RM, they attempted a subsequent lift with an additional 2.5 to 5 kilograms. Conversely, if the initial attempt at the self-reported 1RM was unsuccessful, the weight was reduced by 2.5 to 5 kilograms. To mitigate the potential impact of fatigue, rest periods of at least 5 minutes were mandated between each attempt [24]. All participants executed a bench press exercise with a 3 second eccentric lowering phase, followed by a minimal pause during the transition phase, and then engaged in the concentric lifting phase, performed as rapidly as possible with maximum effort [24, 25]. Following the estimation of their 1RM, participants were given a 48-hour break. After this rest period, they proceeded to estimate their 4RM. Subsequently, the 4RM was assessed, utilizing the same methodology as applied for the 1RM measurement.

Warm-up

Upon arrival at the sports laboratory, each participant was briefed on the research process. This introduction was followed by a multi-stage warm-up routine. Initially, the subjects engaged in brief exercises such as jumping jacks and running on the spot, progressing to exercises that mobilized the upper body. Subsequently, they performed 10 repetitions of various exercises using a rubber expander, including forearm presses, upright presses, chest-to-forearm presses, and standing extensions from forearm to shoulder press.

After these general warm-up exercises, participants moved on to a specific warm-up using the Olympic bar, based on a pre-calculated percentage of their 1RM. The first set involved lifting a 20 kg bar for an unspecified number of repetitions. This was followed by a second set of 8 repetitions with 40% of their 1RM, and a third set of 5 repetitions with 70% of their 1RM. This phase of the warm-up was intentionally kept brief to largely maintain the body's prepared state from the initial exercises while aiming to conserve energy reserves and avoid affecting maximum performance capabilities.

Bench press performance

All testing was performed on a straight bench 110 cm long, 25 cm wide and 60 cm high, with an Eleiko IPF powerlifting competition bar weighting 20 kg. Bench-press was performed according to modified IPF rules. The grip width was set at 81 cm - measured between the little fingers. During the research, bar could touch the chest, however no thrusting away from the chest was allowed. At least two assistants were present during testing to operate the laboratory equipment and to assist in the event of a failed attempt. The load for the first experiment was chosen based on the proband's personal assumptions. If the experiment was successful and fast enough, after discussion with the subject, the weight was either increased or kept. Conversely, if the attempt was unsuccessful and there was a failure, the weight was reduced. There was a 3-min rest interval between each trial. Any trial that did not meet the 1RM was not included in the study.

sEMG

A surface electromyograph was used to collect muscle activity data. EMG activity was recorded using Musclelab 6000 (Ergotest Technology AS, Langesund, Norway). Electrodes (ECG Bluesensor NF-50-K/W/1) were placed according to SENIAM guidelines to selected muscles of the left side of the proband's body. After warming up the proband was shaved and degreased with alcohol gasoline. The electrodes were attached to the midpoints of the muscle bellies, with interelectrode distance 1 cm, of the: Rectus Abdominis (RA), Obliquus Abdominis (OA), Triceps Brachii, caput longum (TB), Latissimus Dorsi (LD), Anterior Deltoideus (AD), Deltoideus Posterior (DP), Pectoralis Major, pars sternalis (PMS), Pectoralis Major, pars clavicularis (PMC). The electrodes functionality was checked in Spyke software 6.3, where they were individual electrodes were assigned to muscles and the scanning was set to 2000 Hz for optimum range, data accuracy and hardware requirements. The raw EMG signals were transformed to the square root of the mean (RMS) value by a hardware peripheral network (frequency response 20-500 kHz, averaging constant 100 ms, total error ± 0.5%). Data were sampled at 200 Hz.

Kinematics

Three-dimensional motion recording (Qualisys, Sweden) was used for data collection. All motion was recorded on nine cameras with a sampling rate of 200 Hz. Eight cameras recorded the motion of markers placed on the proband and the equipment, one camera recorded a video for control in case of any ambiguity about the progress of the current experiment.

The markers, three were fixed on the bar (one at the centre, two at the ends of the bar), one fixed on the upper half of the sternum to avoid contact with the bar. Another marker was attached to the elbow (olecranon axis). In addition, two clusters with more markers were attached on the forearm and upper arm.

After the analysis of the individual data from the Qualisys track manager, the obtained values were divided into individual stages and transferred to Excel for further statistical processing (Table 1). The resulting times of the individual phases of the lift were calculated according to the change in velocity of the bar as follows:

a) pre-sticking region = tV2 max - tV3 min (time of 2nd highest speed - time of 3rd highest speed)
b) sticking region = tV4 min - tV2 max (time of 4th lowest speed - time of 2nd highest speed)
c) post-sticking region = tV5 min - tV4 min (time of 5th lowest speed - time of 4th lowest speed)

Data analysis

The measured EMG signal was filtered in Matlab using a bandpass filter 70-500 Hz with stop frequencies of 65 Hz and 550 Hz. Attenuation in the border band (70-65 and 500-550) was 60 dB/octave, the gain in the passband was not applied. The frequency analysis method chosen was fast Fourier Transformation (DFT), for individual repetitions of the bench press. On their base, the median frequency spectrum for each repetition and its phase was calculated.

Statistics

A three way ANOVA was used to calculate the differences between repetitions, phases, and muscle activation for 4RM and for differences between the muscles and withing the phases in 4RM followed by Tukey post hoc. For 1RM two way repeated measures ANOVA was used with Bonferroni post hoc. If the sphericity assumption was violated, p-values of the Greenhouse-Geisser adjustment were reported. Results are calculated from median and standard deviation using IBM SPSS Statistics Version 29.0. Significant level was set on 0.05.

RESULTS

There were significant differences in 4RM measurement between the repetition $F = 30.03$, $p < 0.001$, phase $F = 418.67$, $p < 0.001$ and muscle $F = 846.82$, $p < 0.001$. Two-Way interaction effect indicates significant interactions between repetition and muscle $F = 4.14$, $p < 0.001$, however no main interactions between repetition and phase $F = 0.48$, $p = 0.83$, and phase and muscle $F = 0.34$, $p = 0.988$. Three-Way interaction effect (Repetition x Phase x Muscle) was not statistically significant $F = 0.37$, $p > 0.999$. These results suggest that while individual factors like the number of repetitions, phase of the exercise, and the muscle involved significantly affect EMG activity, their combined interactions (except for the interaction between Repetition and Muscle) do not significantly influence EMG activity.

The post hoc analysis was performed using Tukey's Honestly Significant Difference (HSD) test to explore pairwise comparisons within the significant factors identified in the 3-way ANOVA. The Tukey HSD test for “Repetition” indicates that all pairs of repetitions (1 vs. 2, 1 vs. 3, 1 vs. 4, 2 vs. 3, 2 vs. 4, 3 vs. 4) are significantly different from each other $p < 0.001$. Additionally, all pairs of phases are significantly different from each other. For muscles significant difference occurred between deltoid anterior and obliquus abdominis, deltoid posterior and pectoralis pars sternalis, deltoid posterior and obliquus abdominis,

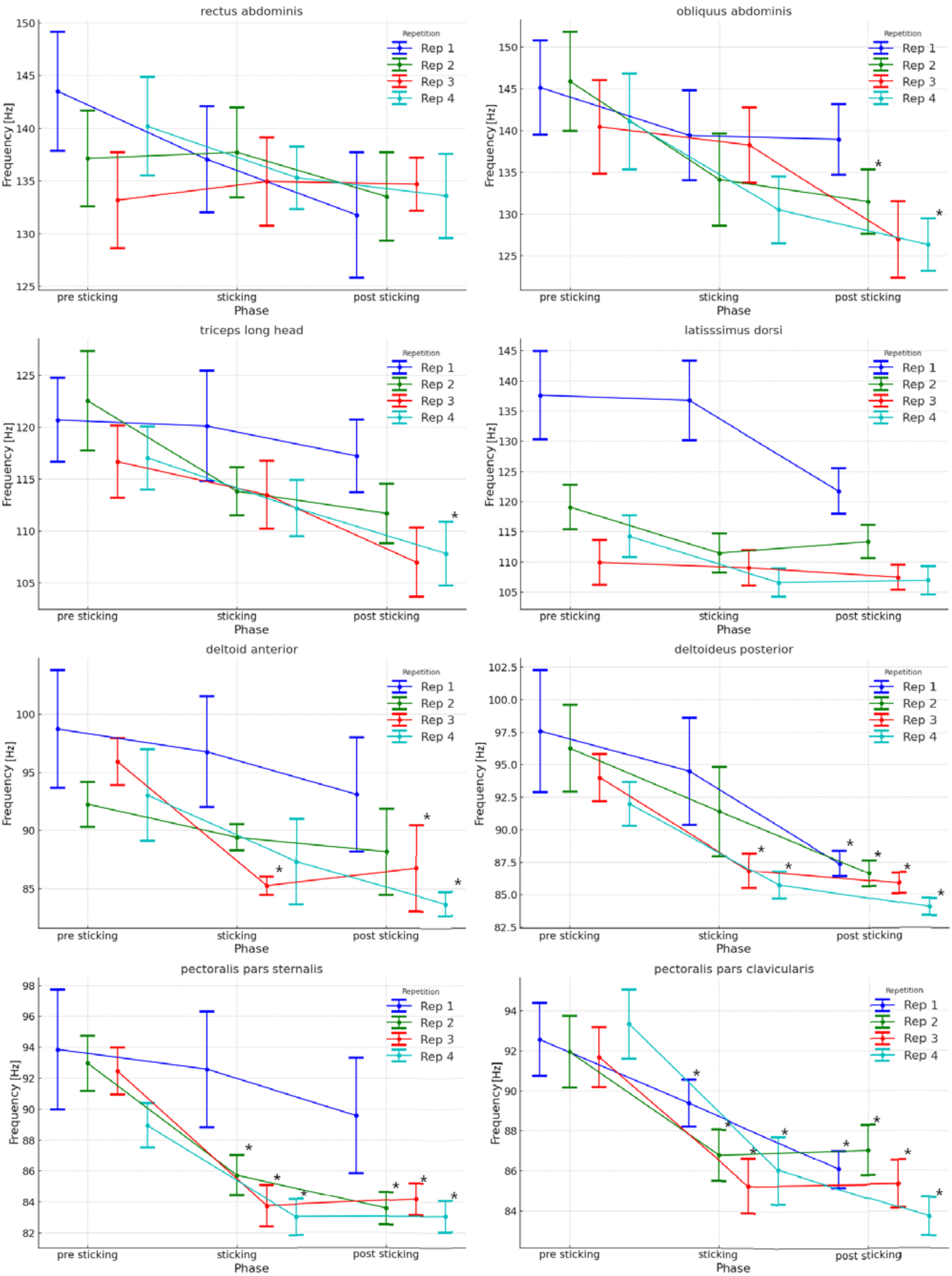

Figure 1. Median frequency of discharge of individual muscles in each part of the movement phases in each repetition of 4RM. *significant differences between the phases of the movement when comparing to pre-sticking phase.

deltoid posterior and triceps long head, pectoralis pars clavicularis and obliquus abdominis, pectoralis pars sternalis and obliquus abdominis, latissimus dorsi and obliquus abdominis, obliquus abdominis and rectus abdominis, obliquus abdominis and triceps long head. Effect Sizes (Partial Eta Squared) for Repetition is $\eta^2 = 0.0496$ for Phase is $\eta^2 = 0.0211$ for 'Muscle' is $\eta^2 = 0.7743$. This is a large effect, implying that about 77.43% of the variance in EMG activity can be explained by the difference in muscles involved. Pairwise t-test was used to find significant difference for each muscle group between different phases, using a threshold of 0.05 for significance. For the obliquus abdominis muscle, significant differences were found between the "pre sticking" and "sticking" phases, and between the "pre sticking" and "post sticking" phases. The triceps long head showed a significant difference between the "pre sticking" and "post sticking" phases. Similar patterns of significance were observed in other muscles like the deltoideus posterior and pectoralis pars clavicularis. Significant dropping in muscle activation between the repetitions was observed in Obliquus Abdominis where significant difference was between repetitions 1 and 4. Triceps caput longum, significant difference between repetitions 1 and 3 and between repetitions 1 and 4. Latissimus Dorsi with significant differences between repetitions 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4. Deltoideus Anterior, significant differences between repetitions 1 and 2, 1 and 3, 1 and 4. Deltoideus Posterior significant difference between repetitions 1 and 4, 2 and 4. And Pectoralis Pars Sternalis with significant differences between repetitions 1 and 3, 1 and 4. Pectoralis Pars Clavicularis and Rectus Abdominis didn't show significant differences between the repetitions (Figure 1).

For 1RM there was no significant difference between the muscle's activation and phases of the movement $F = 1.34$, $p = 0.195$. There was significant difference between the phases $F = 88.44$, $p < 0.001$ (Figure 2). Bonferroni post hoc revealed significant differences between all the phases, with the highest mean difference between pre sticking phase when compared to post sticking 14.6 and sticking 11.26. Barbell kinematic results shows increasing time in sticking region with repetitions (Table 1).

Table 1. The mean and SD for duration of each phase of 4 RM in seconds

Phase	Duration of each phase of 4 RM (s)			
	1st Repetition Mean ± SD	2nd Repetition Mean ± SD	3rd Repetition Mean ± SD	4th Repetition Mean ± SD
Pre sticking	0.35 ± 0.22	0.31 ± 0.14	0.27 ± 0.11	0.28 ± 0.14
Sticking	0.53 ± 0.3	0.6 ± 0.42	0.87 ± 0.75	1.14 ± 0.59
Post sticking	1.17 ± 1.66	0.86 ± 0.26	0.96 ± 0.29	1.6 ± 0.87

SD - standard deviation

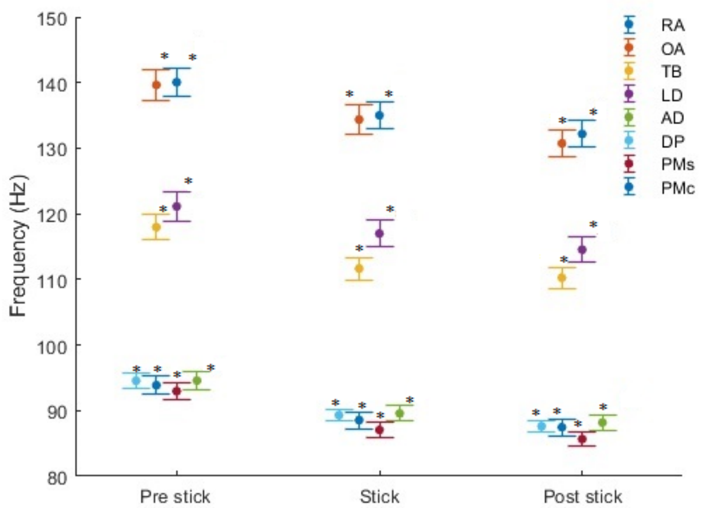

Figure 2. Median frequency of discharge of individual muscles in each part of the movement phases in 1RM. *significant differences between the phases of the movement.

DISCUSSION

The findings of this study contribute significantly to the understanding of muscle activation patterns during the bench press, particularly in the context of varying repetitions and the distinct phases of the exercise. Our research provides a nuanced view of how specific muscles respond during the pre-sticking, sticking, and post-sticking regions, both in 1RM and 4RM bench press exercises. The notable absence of significant differences in muscle activation across the phases in the 1RM trials suggests that, during a maximal single lift, the muscles may be uniformly engaged throughout the exercise. However, the observation of a significant difference between the phases in terms of duration, particularly with increasing time in the sticking region, underscores the unique challenges posed by this phase in maximal lifts [5,13].

In contrast, the 4RM trials exhibited significant differences in muscle activation across repetitions and muscles, highlighting the impact of fatigue and repeated exertions on muscle behaviour. The decrease in muscle activation in muscles like the Obliquus Abdominis and Triceps Brachii Long Head across repetitions indicates that fatigue plays a critical role in muscle performance during repeated sub-maximal lifts. This aligns with the concept of neuromuscular fatigue impacting the ability to generate force, as indicated by Duffey and Challis [17].

Our study also sheds light on the influence of grip width, as indicated by Larsen's findings [12], and its impact on overcoming the sticking region. This suggests that grip width adjustments could be a strategic consideration in training programs, particularly for recreational athletes aiming to optimize their bench press performance.

In previous studies evaluating sEMG during barbell bench press, the pre sticking region was not characterized in all muscles by maximum activation compared to other phases. In a study made by Tillaar [5], only in the triceps caput longum and biceps muscles was activation higher before the pre sticking phase compared to the post sticking phase and decreased with the number of repetitions. Several studies have reported that, at 100% 1RM compared to submaximal loads (70%, 80%, 90% 1RM), there is a reduction in pectoralis major activity and a greater activation of the anterior deltoid and TB at the start of the concentric phase of the bench press movement [26,27]. These findings suggest that as external loads increase, muscle recruitment shifts towards the anterior deltoid, and the pectoralis major assumes a more supportive role as a prime mover [7, 28]. However, our results show higher activation of TB during all phases in both 1RM and in 4RM, where it remained highest during all repetitions. Those differences in the neuromuscular activity of primary movers are not solely dependent on their own coactivation, but also on the activity of their antagonist muscles, which serve as stabilizers [21]. Nevertheless, our results agree with Dunnick [29] where was a significant increase in the surface electromyography activity of the latissimus dorsi muscle with heavier loads (80% 1RM) compared to lighter loads (60% 1RM) during the bench press exercise.

The highest frequency for both 1 RM and 4 RM was found in the pre-sticking phase, followed by a significant decrease in the sticking phase. This finding corresponds with the study of van den Tillaar [13] who concluded that one of the reasons for the existence of the critical phase of the movement is poor mechanical positioning. He states that the greatest force exerted was observed in the pre-sticking phase followed by a significant decrease in force at the beginning of the sticking phase, where in the post-sticking phase the force remained relatively the same. Subsequently, there is a decrease in electromyography (EMG) frequency and exerted force, which may indicate that muscle fatigue is one of the reasons for the existence of the critical phase of the movement.

The decrease in median frequency occurring after the pre-sticking phase indicates that muscle fibers become fatigued and produce less force, which is related to exhaustion caused by exceeding the most demanding region during the bench press. When muscles become fatigued, the median and upper quartile frequency of the power spectral density in the EMG signal decreases. This reduction in frequency is typically seen as an indication of compression of the frequency spectrum. The compression occurs because the muscle fiber conduction velocity slows down, leading to longer duration and lower frequency content in the recorded action potentials [30]. This agrees with the results of Walker et al. [31] who examined neuromuscular fatigue during maximal and submaximal efforts in leg press exercises where he observed decrease in median frequency. According to Bigland-Ritchie et al. [32] when individuals exert maximum effort, there is a reduction in the median frequency of muscle activity. However, even as muscle performance declines due to fatigue, the electrical signals reaching the muscle remain strong enough to engage all the available motor units and enable them to generate maximum force during the exhausting contraction. As a result, participants of our study were able to successfully push through the challenging phase of the movement, referred to as the "sticking region," in subsequent repetitions, despite the decrease in median frequency.

This study has some limitations that need to be considered. First, participants were randomly selected from a diverse population, who have varying sport specializations, resulting in a diverse training background. To obtain more accurate results, it would be more appropriate to select participants from the same specialization, preferably those with a focus on strength training. Additionally, the placement of EMG electrode cables may lead to overlapping and create movement artifacts during the exercise. Moreover, there are other factors that may influence the results, such as lack of sleep, fatigue, low motivation, and nervousness among the participants.

Sticking region is the most mechanically demanding part to surpass during a bench press exercise. Therefore, a decrease in muscle activity indicates exhaustion caused by overcoming this point which is observed in each of the 4RM repetitions and 1RM. This exhaustion also remained in the post sticking phase.

CONCLUSION

The study offers insights into the firing frequency of muscles during repetitions performed at 4RM. This information contributes to a clearer comprehension of the demanding characteristics of different phases within this exercise. Observing exhaustion emphasises the challenging nature of the sticking phase. The findings also contribute to our understanding of the mechanism of overcoming the sticking region.

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