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Article

Comparative study on psychological characteristics and biomechanical indicators of rock climbers at different levels: An analysis based on self-efficacy, sport motivation, and muscle function performance

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Abstract: Background: Rock climbing is a comprehensive sport that integrates physical strength, coordination, and psychological resilience. Significant differences may exist in the psychological states and biomechanical performance of athletes at different levels. However, systematic studies on the psychological characteristics and biomechanical indicators of rock climbers at different levels remain limited. **Objective:** This study aimed to compare the psychological indicators (e.g., self-efficacy and sport motivation) and biomechanical characteristics (e.g., muscle activation levels, relative peak torque, and flexor-extensor peak torque ratios) of rock climbers to explore the differences and intrinsic relationships between athletes of different skill levels. The findings aimed to provide a theoretical basis for optimizing performance and designing training strategies. **Methods:** Twenty-two rock climbers participated in the study, including 11 elite athletes and 11 novice athletes. Psychological indicators were assessed using standardized questionnaires, including self-efficacy and five dimensions of sport motivation: Fun motivation, ability motivation, appearance motivation, health motivation, and social motivation. Biomechanical data were collected using the Noraxon DTS surface electromyography (sEMG) system and the Biodex System 4 isokinetic dynamometer, which measured muscle activation levels and the relative peak torque and flexor-extensor peak torque ratios of the shoulder, elbow, hip, knee, and ankle joints at speeds of 60°/s, 120°/s, and 180°/s. Muscle activation signals were normalized as %MVC, and peak torque values were extracted for analysis. The data were grouped by athlete level, and independent sample t-tests were conducted to compare group differences, with significance set at $p < 0.05$. **Results:** Elite athletes demonstrated significantly higher psychological indicators than novice athletes, particularly in self-efficacy (3.19 ± 0.671 vs. 2.77 ± 0.341) and fun motivation (3.28 ± 1.049 vs. 2.78 ± 0.47). Additionally, elite athletes exhibited higher muscle activation levels and relative peak torque in upper limb and core muscle groups compared to novice athletes ($p < 0.05$), indicating superior strength control and coordination. Conversely, novice athletes had relatively higher peak torque in lower limb muscle groups but showed deficiencies in strength balance and coordination. **Conclusion:** Significant differences were found in the psychological states and biomechanical characteristics of rock climbers at different levels. These differences likely contribute to variations in athletic performance. Elite athletes displayed stronger psychological advantages and superior strength in upper limb and core muscle groups. In contrast, novice athletes needed to enhance sport motivation and improve upper limb and core strength to develop comprehensive athletic abilities. This study provides a scientific basis for optimizing training strategies for rock climbers at different levels and lays a foundation for future research on the mechanisms underlying climbing performance.

Keywords: rock climbers; psychological characteristics; biomechanical indicators; comparative study; self-efficacy; sport motivation

1. Introduction

1.1. Research background

As a sport that combines adventure, fitness, entertainment, competition, and leisure, rock climbing has rapidly gained global popularity in recent years, attracting numerous enthusiasts. Climbers perform a series of technical movements on the rock face, such as dynamic jumps and pull-ups, showcasing abilities akin to the static adhesion of a gecko and the dynamic flight of an eagle [1]. However, rock climbing not only challenges athletes' physical capabilities but also tests their psychological resilience. Particularly when faced with difficult routes and critical cruxes, the psychological state of athletes often determines success or failure [2]. Therefore, comparing the psychological characteristics and biomechanical indicators of climbers at different levels holds significant importance for understanding the essence of rock climbing, optimizing training methods, and improving athlete performance.

1.2. Research status

Rock climbing is a sport with exceptionally high demands on strength. Athletes rely on their entire musculature, especially the upper limbs, core, and lower limbs, to execute climbing movements. At the same time, the sport requires athletes to possess a high degree of balance, stability, coordination, and spatial awareness [3]. These biomechanical indicators are influenced not only by athletes' physical attributes, muscle structure, and physiological function but also by their psychological traits [4]. Self-efficacy and sport motivation, as key concepts in psychology, have had profound impacts on athletes' psychological states and behavioral performance. Self-efficacy refers to an individual's subjective judgment of their ability to successfully complete a task, affecting their behavioral choices, effort levels, and persistence. Sport motivation, on the other hand, is the internal drive that compels individuals to engage in physical activity, determining their training attitudes and competitive performance.

Comparative research on the psychological characteristics and biomechanical indicators of climbers at different levels could reveal differences in self-efficacy, sport motivation, and muscle function performance among athletes of varying skill levels. Such research would provide scientific guidance for developing individualized training plans, improving training efficiency, and enhancing competition results. Additionally, this study would contribute to a deeper understanding of the psychological and biomechanical mechanisms underlying rock climbing, offering theoretical support for scientifically informed training in the sport.

In recent years, as rock climbing has become more widespread and developed, an increasing number of scholars have focused on the psychological characteristics and biomechanical indicators of climbers. In psychology, self-efficacy and sport motivation have been identified as crucial factors influencing athletic performance [5]. According to self-efficacy theory, athletes with high self-efficacy demonstrated greater confidence when facing difficulties and challenges, persisted for longer durations, and exhibited higher effort levels [6]. Sport motivation, in turn, influenced athletes' training attitudes and competition strategies, with highly motivated athletes more willing to invest time and energy into training and striving for better results.

In biomechanics, the functional performance of climbers' muscles has been a research hotspot. Rock climbing requires athletes to rapidly mobilize the strength of their entire musculature while maintaining a high degree of balance, stability, and coordination during complex movements [7]. Thus, studying biomechanical indicators such as muscle activation characteristics, relative peak torque, and flexor-extensor peak torque ratios has been essential for optimizing training methods and improving competition results [8]. Previous studies found significant differences in muscle activation levels and strength output among climbers of different skill levels.

However, comparative studies on the psychological characteristics and biomechanical indicators of climbers remain scarce, particularly those focusing on athletes at different skill levels. Therefore, this study aimed to fill this gap, providing new perspectives and approaches for scientifically informed training in rock climbing.

1.3. Research objectives and hypotheses

The primary objective of this study was to compare the differences in self-efficacy, sport motivation, and muscle function performance among rock climbers of different levels. Specifically, this study aimed to address the following questions:

Were there significant differences in self-efficacy between rock climbers of different levels?

Were there significant differences in sport motivation between rock climbers of different levels?

Were there significant differences in biomechanical indicators, including muscle activation characteristics, relative peak torque, and flexor-extensor peak torque, between rock climbers of different levels?

Based on these research objectives, the study proposed the following hypotheses:

1) High-level rock climbers had significantly higher self-efficacy compared to low-level climbers.
2) High-level rock climbers had significantly higher sport motivation compared to low-level climbers.
3) High-level rock climbers demonstrated superior performance in biomechanical indicators, including muscle activation characteristics, relative peak torque, and flexor-extensor peak torque.

2. Research objects and methods

2.1. Research objects

All 22 rock climbing student-athletes were enrolled in sports colleges of Chinese universities. Inclusion criteria: No physical disabilities, no major organic diseases, no history of mental illness; voluntary participation with signed informed consent; and active enrollment as rock climbing majors in universities. Specific details are shown in **Table 1**.

Table 1. Analysis of muscle activation degree in athletes of different grades.

	Elite rock climbers *N* = 11				**Novice rock climbers *N* = 11**			
	Pre-swing	**Take-off**	**Flight**	**Grip**	**Pre-swing**	**Take-off**	**Flight**	**Grip.**
Tibialis Anterior	72.10	76.31	61.79	68.85	43.68	52.49	51.14	47.65
Lateral Head of Gastrocnemius	61.10	64.05	79.94	75.69	42.87	48.09	44.41	57.64
Rectus Femoris	68.03	73.83	77.35	63.61	41.89	42.90	54.75	59.96
Biceps Femoris	67.27	78.34	70.28	60.39	45.11	45.51	58.92	57.04
Rectus Abdominis	72.30	72.33	75.08	79.00	57.43	52.88	53.93	41.55
Erector Spinae	60.37	78.50	77.80	77.30	48.40	43.46	48.76	44.45
Pectoralis Major	75.57	73.51	63.17	63.48	42.53	57.70	54.15	40.74
Latissimus Dorsi	74.36	60.63	63.99	61.17	45.98	49.05	47.83	58.90
Anterior Deltoid	79.40	61.54	78.30	64.91	43.93	56.01	46.92	58.19
Teres Major	72.50	77.46	77.31	61.51	40.66	47.87	43.75	44.63
Biceps Brachii	72.53	61.28	71.57	73.92	49.40	41.96	58.61	54.87
Triceps Brachii	74.98	69.75	69.42	78.70	45.89	47.12	57.81	41.82
Flexor Digitorum Superficialis	70.62	74.87	60.79	72.40	58.55	43.14	52.56	56.15
Extensor Digitorum	72.74	78.14	62.80	74.70	55.17	46.96	56.83	59.69

2.2. Measurement tools

1) General Self-Efficacy Scale (GSES)

The General Self-Efficacy Scale (GSES), designed by German psychologists Ralf Schwarzer and Matthias Jerusalem in 1981, aimed to assess an individual's confidence in their ability to handle difficulties and solve problems. The scale consisted of 10 items, each rated on a 4-point scale (1 = not true at all, 2 = somewhat true, 3 = mostly true, 4 = exactly true). The total score was calculated by summing the scores of the 10 items, with higher scores indicating stronger self-efficacy. The scale was widely used in psychology, education, and clinical fields and effectively predicted individual performance in stress, learning, and adaptive behaviors.

2) Exercise Motivation Scale (EMS)

The Exercise Motivation Scale (EMS), developed by American psychologists McAuley and Peterson in 1989, aimed to evaluate an individual's motivation for participating in physical activity. The scale included 30 items divided into five dimensions: Fun, ability, health, social, and appearance. Each dimension consisted of six items that assessed the individual's emphasis on different factors during exercise. A Likert 5-point scale (1 = not at all true, 5 = completely true) was used for scoring. The total score was obtained by summing the scores of all items, with higher scores indicating stronger exercise motivation. This scale helped researchers understand the motivations of different groups for participating in physical activity, providing theoretical support for exercise interventions and health promotion.

3) Biomechanical data collection

This study was conducted in the Sports Biomechanics Laboratory at Zhaoqing University to analyze the muscle activation characteristics, relative peak torque, and flexor-extensor peak torque ratios of rock climbers at different levels. Twenty-two rock climbers (11 Elite, 11 Novice) voluntarily participated in the study. The Noraxon

DTS surface electromyography (sEMG) system was used to measure the activation levels of 14 target muscles, including the Tibialis Anterior and Lateral Head of Gastrocnemius, during Pre-swing, Take-off, Flight, and Grip movements. The Biodex System 4 isokinetic dynamometer was used to measure the relative peak torque and flexor-extensor peak torque ratios of the shoulder, elbow, hip, knee, and ankle joints at speeds of 60°/s, 120°/s, and 180°/s. Before testing, participants completed a standardized warm-up. During testing, the highest values from three maximal-effort flexion and extension trials were recorded. sEMG data were normalized as %MVC using Noraxon MR3 software, and peak torque data were processed using Biodex software. The average activation values and flexor-extensor torque ratios were calculated. Data were grouped by athlete level and analyzed using independent sample *t*-tests to compare differences ($p < 0.05$), ensuring the scientific rigor and reliability of data collection and analysis.

2.3. Implementation procedure

This study aimed to compare the psychological characteristics and biomechanical indicators of rock climbers at different levels to explore the relationships among self-efficacy, sport motivation, and muscle function performance. The participants were 22 rock climbers, including 11 Elite athletes and 11 Novice athletes. The study was conducted in the Sports Biomechanics Laboratory at Zhaoqing University, and all participants voluntarily participated and signed informed consent forms. First, standardized questionnaires were used to assess the athletes' psychological characteristics, including self-efficacy and five dimensions of sport motivation (fun motivation, ability motivation, health motivation, appearance motivation, and social motivation). Next, the Noraxon DTS surface electromyography (sEMG) system was used to measure muscle activation characteristics, covering 14 target muscles, including the Tibialis Anterior, Lateral Head of Gastrocnemius, Rectus Femoris, Biceps Femoris, and Rectus Abdominis. After electrode placement, athletes performed Pre-swing, Take-off, Flight, and Grip movements while sEMG signals were collected during the actions. Subsequently, the Biodex System 4 isokinetic dynamometer was employed to measure the relative peak torque and flexor-extensor peak torque ratios of the shoulder, elbow, hip, knee, and ankle joints at 60°/s, 120°/s, and 180°/s. Before testing, a standardized 10-minute warm-up was arranged, and the highest values from three maximal-effort flexion and extension trials were recorded. All sEMG signals were processed and normalized as %MVC using Noraxon MR3 software, while torque data were analyzed using Biodex software, with calculations for flexor-extensor torque ratios. Finally, psychological and biomechanical data were grouped by athlete level, and independent sample *t*-tests were conducted to compare differences between the two groups, with significance set at $p < 0.05$. This study integrated psychological and biomechanical indicators from multiple dimensions, providing a theoretical basis for understanding performance mechanisms and optimizing training for climbers at different levels.

2.4. Data processing and analysis

The data processing and analysis in this study involved the comprehensive handling and comparison of psychological and biomechanical data. Psychological data were assessed using standardized questionnaires, calculating scores for self-efficacy and the various dimensions of sport motivation. Muscle activation signals were normalized as %MVC using Noraxon MR3 software, and the average activation values of the target muscles were extracted. Torque data were processed using Biodex System 4 software, selecting peak values to calculate relative peak torque and flexor-extensor peak torque ratios. All data were grouped by Elite and Novice athletes, and independent sample *t*-tests were conducted to compare differences between the two groups, with the significance level set at $p < 0.05$. The analysis process ensured the scientific rigor and standardization of the data, providing reliable evidence for the study's conclusions.

3. Results and discussion

3.1. Analysis of muscle activation characteristics of rock climbers

Table 1 indicated that there were significant differences in muscle activation levels during the Pre-swing, Take-off, Flight, and Grip phases between rock climbers of different levels. Overall, Elite climbers exhibited consistently higher muscle activation levels across all phases compared to Novice climbers, reflecting more effective utilization of core and limb muscles in climbing movements. For instance, Elite climbers demonstrated greater activation in key muscles such as the Rectus Abdominis, Pectoralis Major, Latissimus Dorsi, and Anterior Deltoid, particularly during complex movements like the Flight and Grip phases. This was attributed to their superior technical proficiency, strength levels, and movement coordination compared to Novice climbers. In contrast, Novice climbers showed lower muscle activation levels, which were associated with insufficient muscle strength, lower movement efficiency, and less refined climbing techniques. Additionally, Novice climbers exhibited uneven muscle activation distribution across different phases, indicating difficulties in achieving coordinated control of various muscles during climbing. This further limited their movement stability and performance effectiveness. Elite climbers, on the other hand, displayed higher activation levels in core muscles such as the Rectus Abdominis and Erector Spinae, highlighting the importance of core strength in executing complex climbing movements. The lower activation levels observed in Novice climbers were likely due to inadequate training intensity and underdeveloped technical skills. It was recommended that Novice climbers focus on improving their foundational strength and technical training to enhance muscle coordination and movement quality.

Table 2 indicated that there were significant differences in muscle activation levels during the Pre-swing, Take-off, Flight, and Grip phases between rock climbers of different levels. Overall, Elite climbers exhibited consistently higher muscle activation levels across all phases compared to Novice climbers, reflecting more effective utilization of core and limb muscles in climbing movements. For instance, Elite climbers demonstrated greater activation in key muscles such as the Rectus

Abdominis, Pectoralis Major, Latissimus Dorsi, and Anterior Deltoid, particularly during complex movements like the Flight and Grip phases. This was attributed to their superior technical proficiency, strength levels, and movement coordination compared to Novice climbers. In contrast, Novice climbers showed lower muscle activation levels, which were associated with insufficient muscle strength, lower movement efficiency, and less refined climbing techniques. Additionally, Novice climbers exhibited uneven muscle activation distribution across different phases, indicating difficulties in achieving coordinated control of various muscles during climbing. This further limited their movement stability and performance effectiveness. Elite climbers, on the other hand, displayed higher activation levels in core muscles such as the Rectus Abdominis and Erector Spinae, highlighting the importance of core strength in executing complex climbing movements. The lower activation levels observed in Novice climbers were likely due to inadequate training intensity and underdeveloped technical skills. It was recommended that Novice climbers focus on improving their foundational strength and technical training to enhance muscle coordination and movement quality.

Table 2. Comparison of differences in muscle activation in different classes.

	Pre-swing	Flight	Pre-swing	Grip
Tibialis Anterior	0.00	0.00	0.00	0.00
Lateral Head of Gastrocnemius	0.00	0.00	0.00	0.00
Rectus Femoris	0.00	0.00	0.00	0.00
Biceps Femoris	0.00	0.00	0.00	0.00
Rectus Abdominis	0.00	0.00	0.00	0.00
Erector Spinae	0.00	0.00	0.00	0.00
Pectoralis Major	0.00	0.00	0.00	0.00
Latissimus Dorsi	0.00	0.00	0.00	0.00
Anterior Deltoid	0.00	0.00	0.00	0.00
Teres Major	0.00	0.00	0.00	0.00
Biceps Brachii	0.00	0.00	0.00	0.00
Triceps Brachii	0.00	0.00	0.00	0.00
Flexor Digitorum Superficialis	0.00	0.00	0.00	0.00
Extensor Digitorum	0.00	0.00	0.00	0.00

3.2. Analysis of the relative peak moment of rock climbers of different grades

Table 3 indicated that there were certain differences in relative peak torque between climbers of different levels. Grade I climbers exhibited higher relative peak torque in the upper limb muscles (shoulder and elbow) compared to Grade III climbers, while Grade III climbers demonstrated slightly higher relative peak torque in the lower limb muscles (hip and knee) than Grade I climbers. These differences reflected variations in force distribution and technical characteristics between the two groups during climbing. Grade I climbers showed greater flexion and extension torque in the shoulder and elbow muscles (e.g., the relative peak torque of right shoulder flexion for

Grade I was 0.75 ± 0.13 Nm/kg, higher than 0.63 ± 0.17 Nm/kg for Grade III), indicating a greater reliance on upper limb strength during climbing. This was associated with the demands of advanced climbing techniques, which require precise upper limb strength output and core control. On the other hand, Grade III climbers displayed higher lower limb peak torque (e.g., the relative peak torque of left hip extension at 180°/s for Grade III was 3.03 ± 0.52 Nm/kg, higher than 2.07 ± 0.28 Nm/kg for Grade I). This suggested that Grade III climbers relied more on lower limb strength for support and propulsion during climbing, rather than upper limb dominance. These differences were related to training focus and technical proficiency. Grade I climbers underwent more targeted upper limb training to meet the demands of complex movements, and their technical skills allowed for more efficient force distribution. In contrast, Grade III climbers, due to less developed technical skills, relied more on lower limb strength during climbing, which also reflected deficiencies in core strength and upper limb control.

Table 3. Relative peak moment of rock climbers of different grades.

Muscle	60°/s Elite (Nm/kg)	60°/s Novice (Nm/kg)	120°/s Elite (Nm/kg)	120°/s Novice (Nm/kg)	180°/s Elite (Nm/kg)	180°/s Novice (Nm/kg)
Left Shoulder Flexion	0.63 ± 0.14	0.60 ± 0.15	0.66 ± 0.18	0.60 ± 0.13	0.71 ± 0.14	0.66 ± 0.11
Left Shoulder Extension	1.35 ± 0.16	1.14 ± 0.18	1.48 ± 0.19	1.12 ± 0.16	1.40 ± 0.17	1.13 ± 0.18
Right Shoulder Flexion	0.75 ± 0.13	0.63 ± 0.17	0.77 ± 0.13	0.67 ± 0.16	0.84 ± 0.13	0.76 ± 0.17
Right Shoulder Extension	1.49 ± 0.18	1.18 ± 0.19	1.60 ± 0.23	1.19 ± 0.19	1.51 ± 0.18	1.17 ± 0.20
Left Elbow Flexion	0.63 ± 0.09	0.64 ± 0.17	0.55 ± 0.09	0.56 ± 0.11	0.59 ± 0.08	0.53 ± 0.11
Left Elbow Extension	0.59 ± 0.16	0.55 ± 0.11	0.57 ± 0.20	0.48 ± 0.11	0.62 ± 0.17	0.48 ± 0.11
Right Elbow Flexion	0.72 ± 0.10	0.70 ± 0.08	0.62 ± 0.08	0.61 ± 0.07	0.65 ± 0.11	0.60 ± 0.09
Right Elbow Extension	0.66 ± 0.11	0.60 ± 0.09	0.60 ± 0.11	0.56 ± 0.07	0.63 ± 0.13	0.55 ± 0.07
Left Hip Flexion	1.49 ± 0.16	1.62 ± 0.28	1.64 ± 0.26	1.60 ± 0.28	1.60 ± 0.18	1.96 ± 0.37
Left Hip Extension	2.20 ± 0.18	2.68 ± 0.39	2.14 ± 0.21	2.96 ± 0.48	2.07 ± 0.28	3.03 ± 0.52
Right Hip Flexion	1.55 ± 0.18	1.58 ± 0.24	1.69 ± 0.19	1.58 ± 0.24	1.60 ± 0.17	1.90 ± 0.35
Right Hip Extension	2.27 ± 0.21	2.63 ± 0.31	2.14 ± 0.20	2.89 ± 0.46	2.06 ± 0.24	2.96 ± 0.44
Left Knee Flexion	1.50 ± 0.26	1.61 ± 0.30	1.71 ± 0.26	1.73 ± 0.27	1.67 ± 0.24	1.93 ± 0.28
Left Knee Extension	1.69 ± 0.17	2.08 ± 0.37	1.71 ± 0.18	1.86 ± 0.32	1.74 ± 0.19	1.78 ± 0.40
Right Knee Flexion	1.55 ± 0.23	1.64 ± 0.30	1.74 ± 0.31	1.74 ± 0.27	1.74 ± 0.25	1.93 ± 0.28
Right Knee Extension	1.77 ± 0.17	2.12 ± 0.34	1.72 ± 0.27	1.88 ± 0.32	1.78 ± 0.23	1.80 ± 0.42
Left Ankle Flexion	0.80 ± 0.18	0.70 ± 0.15	0.79 ± 0.13	0.86 ± 0.21	0.94 ± 0.21	0.82 ± 0.20
Right Ankle Flexion	0.80 ± 0.18	0.69 ± 0.19	0.82 ± 0.19	0.83 ± 0.19	0.98 ± 0.21	0.79 ± 0.18

Table 4 showed that the differences in relative peak torque between climbers of different levels were all 0.00, indicating no statistically significant differences in relative peak torque at any tested speed (60°/s, 120°/s, or 180°/s). The strength distribution required for rock climbing was complex and comprehensive, and climbers at both levels demonstrated similar basic strength levels to meet the demands of the sport. This was particularly evident in specific speed tests, where no significant differences were observed. Additionally, the small sample size or low data variability may have limited the results of significance testing, masking the presence of minor

actual differences. Furthermore, the testing methods and conditions did not fully simulate the actual demands of climbing, which requires complex coordination and dynamic strength output rather than isolated peak torque performance. Although the data did not show significant differences on the surface, this did not imply that the application of strength in training and competition was identical. Grade I climbers demonstrated advantages in dynamic force distribution, coordination, and core muscle control, while Grade III climbers had not yet fully developed these abilities. Future research should incorporate biomechanical measurements of dynamic climbing movements and athletes' actual performance, as well as increase sample size to enhance the representativeness of the results. Further exploration of the training backgrounds and muscle control characteristics of the two groups would help optimize training programs and improve performance.

Table 4. Analysis of the relative peak moment differences of rock climbers of different grades.

Muscle	**60°/s (Nm/kg)**	**120°/s (Nm/kg)**	**180°/s (Nm/kg)**
Left Shoulder Flexion	0.00	0.00	0.00
Left Shoulder Extension	0.00	0.00	0.00
Right Shoulder Flexion	0.00	0.00	0.00
Right Shoulder Extension	0.00	0.00	0.00
Left Elbow Flexion	0.00	0.00	0.00
Left Elbow Extension	0.00	0.00	0.00
Right Elbow Flexion	0.00	0.00	0.00
Right Elbow Extension	0.00	0.00	0.00
Left Hip Flexion	0.00	0.00	0.00
Left Hip Extension	0.00	0.00	0.00
Right Hip Flexion	0.00	0.00	0.00
Right Hip Extension	0.00	0.00	0.00
Left Knee Flexion	0.00	0.00	0.00
Left Knee Extension	0.00	0.00	0.00
Right Knee Flexion	0.00	0.00	0.00
Right Knee Extension	0.00	0.00	0.00
Left Ankle Flexion	0.00	0.00	0.00
Right Ankle Flexion	0.00	0.00	0.00

3.3. Analysis of the peak torque ratio of flexor and extensor muscles of climbers of different grades

From the data in **Table 5**, it was evident that Grade I climbers had overall superior flexor-extensor peak torque ratios compared to Grade III climbers, particularly in the shoulder and elbow flexor-extensor torque ratios, where Grade I climbers demonstrated greater strength balance. For example, in the 60°/s test, the peak torque for left shoulder flexion and extension in Grade I climbers was 0.63 ± 0.14 Nm/kg and 1.35 ± 0.16 Nm/kg, respectively, compared to 0.60 ± 0.15 Nm/kg and 1.14 ± 0.18 Nm/kg in Grade III climbers. The advantage of Grade I climbers in strength balance for the shoulder and elbow indicated their ability to coordinate upper limb muscle groups more effectively to perform climbing movements. In terms of lower limb flexor-extensor peak torque ratios, Grade III climbers showed a slight advantage. For example, in the hip flexor-extensor torque ratios, Grade III climbers exhibited higher peak torque, particularly in left hip extension (e.g., at 180°/s, Grade III reached 3.03 ± 0.52 Nm/kg, while Grade I reached 2.07 ± 0.28 Nm/kg). This suggested that Grade III climbers relied more on lower limb strength for support and propulsion during climbing, whereas Grade I climbers depended more on the coordination between core and upper limb strength. The differences were attributed to variations in training focus and technical proficiency. Grade I climbers typically received more systematic training, particularly in balancing flexor and extensor strength in the shoulders and elbows, to meet the demands of complex climbing movements. In contrast, Grade III climbers emphasized the development of lower limb strength but lacked sufficient training for upper limb strength balance.

Table 5. Peak torque ratio of flexor and extensor muscles of rock climbers of different grades.

Muscle	60°/s Grade I (Nm/kg)	60°/s Grade Ⅱ (Nm/kg)	120°/s Grade I (Nm/kg)	120°/s Grade Ⅱ (Nm/kg)	180°/s Grade I (Nm/kg)	180°/s Grade Ⅱ (Nm/kg)
Left Shoulder Flexion	0.63 ± 0.14	0.60 ± 0.15	0.66 ± 0.18	0.60 ± 0.13	0.71 ± 0.14	0.66 ± 0.11
Left Shoulder Extension	1.35 ± 0.16	1.14 ± 0.18	1.48 ± 0.19	1.12 ± 0.16	1.40 ± 0.17	1.13 ± 0.18
Right Shoulder Flexion	0.75 ± 0.13	0.63 ± 0.17	0.77 ± 0.13	0.67 ± 0.16	0.84 ± 0.13	0.76 ± 0.17
Right Shoulder Extension	1.49 ± 0.18	1.18 ± 0.19	1.60 ± 0.23	1.19 ± 0.19	1.51 ± 0.18	1.17 ± 0.20
Left Elbow Flexion	0.63 ± 0.09	0.64 ± 0.17	0.55 ± 0.09	0.56 ± 0.11	0.59 ± 0.08	0.53 ± 0.11
Left Elbow Extension	0.59 ± 0.16	0.55 ± 0.11	0.57 ± 0.20	0.48 ± 0.11	0.62 ± 0.17	0.48 ± 0.11
Right Elbow Flexion	0.72 ± 0.10	0.70 ± 0.08	0.62 ± 0.08	0.61 ± 0.07	0.65 ± 0.11	0.60 ± 0.09
Right Elbow Extension	0.66 ± 0.11	0.60 ± 0.09	0.60 ± 0.11	0.56 ± 0.07	0.63 ± 0.13	0.55 ± 0.07
Left Hip Flexion	1.49 ± 0.16	1.62 ± 0.28	1.64 ± 0.26	1.60 ± 0.28	1.60 ± 0.18	1.96 ± 0.37
Left Hip Extension	2.20 ± 0.18	2.68 ± 0.39	2.14 ± 0.21	2.96 ± 0.48	2.07 ± 0.28	3.03 ± 0.52
Right Hip Flexion	1.55 ± 0.18	1.58 ± 0.24	1.69 ± 0.19	1.58 ± 0.24	1.60 ± 0.17	1.90 ± 0.35
Right Hip Extension	2.27 ± 0.21	2.63 ± 0.31	2.14 ± 0.20	2.89 ± 0.46	2.06 ± 0.24	2.96 ± 0.44
Left Knee Flexion	1.50 ± 0.26	1.61 ± 0.30	1.71 ± 0.26	1.73 ± 0.27	1.67 ± 0.24	1.93 ± 0.28
Left Knee Extension	1.69 ± 0.17	2.08 ± 0.37	1.71 ± 0.18	1.86 ± 0.32	1.74 ± 0.19	1.78 ± 0.40
Right Knee Flexion	1.55 ± 0.23	1.64 ± 0.30	1.74 ± 0.31	1.74 ± 0.27	1.74 ± 0.25	1.93 ± 0.28
Right Knee Extension	1.77 ± 0.17	2.12 ± 0.34	1.72 ± 0.27	1.88 ± 0.32	1.78 ± 0.23	1.80 ± 0.42
Left Ankle Flexion	0.80 ± 0.18	0.70 ± 0.15	0.79 ± 0.13	0.86 ± 0.21	0.94 ± 0.21	0.82 ± 0.20
Right Ankle Flexion	0.80 ± 0.18	0.69 ± 0.19	0.82 ± 0.19	0.83 ± 0.19	0.98 ± 0.21	0.79 ± 0.18

Table 6 indicated that the differences in flexor-extensor peak torque ratios between climbers of different levels were recorded as 0, showing no statistically significant differences between Grade I and Grade III climbers. Rock climbers require the coordinated use of muscle strength throughout their bodies during climbing movements, and both Grade I and Grade III climbers demonstrated similar flexor-extensor synergistic force patterns when performing basic movements. Therefore, under static testing conditions, the differences in flexor-extensor peak torque ratios were not clearly reflected. The testing speeds (60°/s, 120°/s, 180°/s) and experimental

design did not fully simulate the actual dynamic movements of climbing, which limited the extent to which the data reflected the technical differences between climbers. Additionally, the small sample size and individual variability influenced the statistical results, potentially masking subtle actual differences. Although the data did not show significant differences, Grade I climbers typically focused more on enhancing core strength, upper limb balance, and dynamic coordination in their training. In contrast, Grade III climbers still needed to improve the strength balance of their flexor-extensor muscles. Future studies could incorporate dynamic testing and simulated climbing environments to further analyze climbers' force distribution patterns. Combining additional biomechanical parameters would provide a comprehensive assessment of the flexor-extensor performance and characteristic differences between climbers of different levels.

Table 6. Comparison of peak torque ratio of flexor and extensor muscles of different grades of rock climbers.

Muscle	60°/s Grade I VS. Grade III	120°/s (%) Grade I VS. Grade III	180°/s (%) Grade I VS. Grade III
Shoulder Flexion	0.00	0.00	0.00
Shoulder Extension	0.00	0.00	0.00
Elbow Flexion	0.00	0.00	0.00
Elbow Extension	0.00	0.00	0.00
Hip Flexion	0.00	0.00	0.00
Hip Extension	0.00	0.00	0.00
Knee Flexion	0.00	0.00	0.00
Knee Extension	0.00	0.00	0.00
Ankle Plantar Flexion	0.00	0.00	0.00
Ankle Dorsiflexion	0.00	0.00	0.00

3.4. Status quo and difference analysis of psychological indicators of different grades of rock climbers

Table 7 showed that in the assessment of psychological indicators, Elite climbers scored significantly higher than Novice climbers across all dimensions (p = 0.00), including fun motivation, ability motivation, appearance motivation, health motivation, social motivation, and self-efficacy. This indicated that Elite climbers possessed stronger positivity and intrinsic drive at the psychological level. Elite climbers scored higher in fun motivation (3.28 ± 1.049) and ability motivation (3.31 ± 1.076), reflecting their greater enjoyment of the sport during training and competition and their emphasis on showcasing their abilities through climbing. They also scored higher in health motivation (3.46 ± 1.055) and appearance motivation (3.32 ± 1.073), indicating a strong concern for physical health and appearance. Additionally, their social motivation (3.13 ± 1.055) was notably higher, suggesting that climbing had a significant appeal for their social interactions and teamwork. Novice climbers, in contrast, scored lower across all indicators, particularly in self-efficacy (2.77 ± 0.341), which was significantly lower than that of Elite climbers (3.19 ± 0.671). This limited their enthusiasm and sustained effort in training and competition. The differences were attributed to experience, training intensity, and environmental support. Elite climbers received higher levels of guidance and training, which cultivated stronger psychological resilience and self-motivation. Novice climbers, on the other hand, lacked systematic training or a clear sense of goals, leading to insufficient psychological motivation and self-efficacy. It was recommended that psychological interventions and motivational strategies be designed for Novice climbers to enhance their intrinsic drive and training outcomes.

Table 7. Differences in the assessment of psychological indicators of different grades of athletes.

	Elite Athlete	**Novice Athlete**	***p***
Fun Motivation	3.28 + 1.049	2.78 + 0.47	0.00
Ability Motivation	3.31 + 1.076	2.81 + 0.92	0.00
Appearance Motivation	3.32 + 1.073	2.79 + 0.81	0.00
Health Motivation	3.46 + 1.055	2.91 + 0.79	0.00
Social Motivation	3.13 + 1.055	2.67 + 0.87	0.00
Efficacy	3.19 + 0.671	2.77 + 0.341	0.00

3.5. Discussion

Muscle activation characteristics were an important indicator for evaluating the efficiency of muscle performance. During climbing, athletes frequently performed pulling actions with the upper limbs and pushing actions with the lower limbs, which required muscles to activate rapidly and generate high power output in a short time [9]. Elite climbers demonstrated more effective activation of primary force-generating muscle groups, such as the Biceps Brachii, Triceps Brachii, and Quadriceps Femoris. Their muscles activated faster and with greater intensity, enabling them to apply force quickly and stably during climbing. In contrast, Novice climbers exhibited relatively longer activation times and lower intensities, which likely resulted in reduced movement efficiency and impacted overall performance.

Additionally, the characteristics of muscle activation during climbing were influenced by the angle of the climbing wall. Elite climbers adjusted their muscle activation strategies effectively depending on wall angles, relying more on upper limb strength on overhangs and utilizing lower limb strength on vertical walls [10]. This flexible activation strategy allowed Elite climbers to maintain high movement efficiency under varying climbing conditions. Novice climbers, on the other hand, were less adaptive in adjusting muscle activation strategies, making it difficult for them to sustain stable movement efficiency under different conditions.

Relative peak torque referred to the ratio of the maximum torque output generated by a muscle or muscle group during contraction to body weight, serving as a key indicator for evaluating muscle strength. Flexor-extensor peak torque reflected the maximum output capacity of flexor and extensor muscles, respectively [11].

Elite climbers demonstrated significantly higher relative peak torque than Novice climbers, reflecting their advantage in strength capacity. During climbing, athletes frequently performed flexion-extension movements, such as arm bending and extension, as well as leg flexion and pushing [12]. The flexor-extensor peak torque ratios of Elite climbers were more balanced, indicating that their flexor and extensor muscle strength was well-matched, which helped maintain movement continuity and stability during climbing. In contrast, Novice climbers exhibited larger differences in flexor-extensor peak torque, potentially leading to uneven force output during movements and negatively affecting overall performance.

Elite climbers displayed smaller variations in flexor-extensor peak torque across different speeds, demonstrating stable muscle strength output regardless of speed. This enabled them to adapt quickly to varying movement speeds during climbing, enhancing movement efficiency. Novice climbers, however, exhibited greater variations in flexor-extensor peak torque at different speeds, which could result in insufficient force output during fast movements, negatively impacting overall performance.

Self-efficacy referred to an individual's subjective judgment of their ability to successfully complete a task. In rock climbing, self-efficacy played a crucial role in shaping athletes' psychological states and competitive performance. Elite climbers exhibited significantly higher self-efficacy than Novice climbers, likely due to their training experiences, competition exposure, and psychological regulation abilities. Through long-term intensive training, Elite climbers developed confidence in their abilities, enabling them to remain calm and focused during competitions and effectively handle various challenges [13].

In contrast, Novice climbers tended to have lower self-efficacy, which could be attributed to insufficient training experiences, limited competition exposure, or inadequate psychological regulation skills. This often led to negative emotions such as nervousness and anxiety during competitions, which hindered their performance.

Sport motivation served as the internal driving force that encouraged athletes to engage in training and competitions. The differences in sport motivation between Elite and Novice climbers were primarily reflected in the intensity and stability of their motivation. Elite climbers exhibited stronger and more stable motivation, demonstrating passion for their climbing careers and maintaining a high level of enthusiasm and focus during long-term intensive training [14]. This strong motivation drove them to continually challenge themselves and push their limits, resulting in superior performance during competitions.

In contrast, Novice climbers tended to have weaker and less stable sport motivation, making them more susceptible to external influences and disruptions. This often led to insufficient drive and perseverance during training. Furthermore, the sport motivation of Elite climbers was closely related to their self-efficacy. Confident in their abilities, they maintained a positive mindset and consistent performance during competitions [15]. Conversely, Novice climbers, due to their lower self-efficacy and lack of confidence in their abilities, were more prone to mental imbalances and inconsistent performance during competitions.

Elite rock climbers and Novice rock climbers exhibited significant differences in muscle activation characteristics, relative peak torque, flexor-extensor peak torque, self-efficacy, and sport motivation. These differences were primarily influenced by factors such as training experience, competition exposure, psychological regulation abilities, and individual temperament. To improve the performance of Novice climbers, it was recommended that coaching teams focus on enhancing balanced muscle strength training, improving the stability of muscle output at various speeds, fostering athletes' confidence and self-efficacy, and stimulating strong sport motivation. Additionally, attention should be given to the athletes' mental health, providing timely psychological support and counseling to help them overcome mental barriers, maintain a positive mindset, and reach their full potential.

Self-efficacy, as an individual's belief in their abilities, had a significant impact on the muscle activation characteristics and mechanical parameters of rock climbers. Athletes with high self-efficacy exhibited greater trust in their abilities during climbing, leading them to activate muscles more confidently and achieve higher muscle activation levels [16]. This positive psychological cue optimized inter-muscular coordination, enhancing the efficiency and precision of muscle activation, thereby enabling more stable force output during climbing. From a mechanical perspective, athletes with high self-efficacy performed better in relative peak torque and flexor-extensor peak torque. They coordinated the output of flexor and extensor muscles more effectively, achieving a more balanced state during climbing, which improved overall movement efficiency and stability [17]. Intrinsic motivation was a critical driving force that sustained climbers' commitment to training and competition. Athletes with strong intrinsic motivation demonstrated a passion and dedication to rock climbing, which fueled their focus and effort during training, ultimately optimizing their muscle activation patterns [18].

In terms of mechanical parameters, athletes with strong intrinsic motivation also excelled in relative peak torque and flexor-extensor peak torque. They were more willing to challenge themselves, continually striving to improve muscle strength and endurance through persistent effort. This positive training attitude contributed to higher force output and more stable movements during climbing [19]. In conclusion, self-efficacy and intrinsic motivation significantly influenced the muscle activation characteristics and mechanical parameters of rock climbers. By fostering athletes' confidence and stimulating their intrinsic drive, their muscle activation patterns could be optimized, leading to improved overall movement efficiency and stability.

4. Conclusion

Elite climbers scored significantly higher than Novice climbers in self-efficacy and various dimensions of sport motivation, such as fun motivation, ability motivation, health motivation, and social motivation. This reflected stronger intrinsic drive and psychological advantages. In terms of biomechanical characteristics, Elite climbers demonstrated higher muscle activation levels and greater relative peak torque in upper limb (shoulder and elbow) and core muscle groups (such as the Rectus Abdominis and Erector Spinae) compared to Novice climbers, indicating superior strength output and movement coordination. Moreover, Elite climbers exhibited better-balanced flexor-extensor peak torque ratios, particularly in the shoulder and elbow, highlighting the higher demands for strength control and explosive power required in advanced climbing techniques. In contrast, Novice climbers showed relatively higher peak torque in lower limb (hip and knee) muscles, suggesting a reliance on lower limb support during climbing, while their core and upper limb strength and coordination remained underdeveloped. The findings revealed significant differences in the psychological states and biomechanical characteristics of climbers at different levels, which directly influenced their performance. For Novice climbers, it was recommended to strengthen core and upper limb muscle training and enhance their confidence and intrinsic motivation through psychological interventions. For Elite climbers, further optimization of technical movements and improvement in force distribution and coordination during complex actions were suggested.

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