Effects of Isokinetic Eccentric Training on Strength Balance and Neuromuscular Control of Shoulder Internal and External Rotators: Postprint

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Abstract

Background: Imbalance in muscle strength between shoulder internal and external rotators increases the risk of shoulder sports injuries, and investigating whether isokinetic eccentric training (IET) can improve muscle strength balance and enhance neuromuscular control holds significant importance for injury prevention. Objective: To investigate the effects of IET on muscle strength balance and neuromuscular control of shoulder internal and external rotators in healthy young adults. Methods: Thirty-two healthy young subjects were randomly divided into an experimental group (n=16) and a control group (n=16). The experimental group underwent 4 weeks of isokinetic eccentric training, while the control group (sham training group) received 4 weeks of continuous passive motion training. The functional ratio (FR), acceleration time (AT), and time to peak torque (TPT) of shoulder internal and external rotators were assessed and compared for both groups at 1 week before intervention and 1 week after intervention. Results: Post-intervention, at angular velocities of 60°/s and 120°/s, the FR in the experimental group significantly increased from $(0.61\$\pm0.20) and (0.65\pm0.21) to (1.09\pm0.11) (P < 0.001) and (1.13\pm0.15) (P < 0.001), respectively, while no significant changes were observed in the control group (P > 0.05), and the FR in the experimental group was significantly higher than that in the control group (P < 0.001). The internal rotation AT in the experimental group significantly decreased from (128.75\pm39.98) ms and (17 0.05) and (148.75\pm30.08) ms (P < 0.05), respectively, and the external rotation AT in the experimental group signi 0.05) and (114.38\pm\$41.79) ms (P<0.05), respectively, whereas no significant changes were found in internal or external rotation AT in the control group (P>0.05), and both internal and external rotation AT in the experimental group were significantly lower than those in the control group (P<0.05). No significant changes were observed in internal or external rotation TPT in either the experimental or control group (P>0.05), while TPT in the experimental

group was significantly lower than that in the control group (P<0.05). Conclusion: IET can improve muscle strength balance between shoulder internal and external rotators, maintain dynamic stability of the shoulder joint, and enhance neuromuscular control, thereby potentially reducing the risk of sports injuries.

Full Text

Preamble

The Effects of Isokinetic Eccentric Training on Strength Ratio and Neuromuscular Control of Internal and External Rotators of the Shoulder

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Abstract

Background Strength imbalance between internal and external rotators of the shoulder may increase the risk of sports injury. Research on whether isokinetic eccentric training (IET) could enhance the strength ratio and improve neuromuscular control of shoulder rotators has important implications for injury prevention.

Objective To investigate the effects of isokinetic eccentric training (IET) on strength ratio and neuromuscular control of internal and external rotators of the shoulder in healthy young people.

Methods Thirty-two healthy young subjects were randomly divided into an experiment group (n=16) and a control group (n=16). The experiment group received isokinetic eccentric training for 4 weeks, while the control group (sham-training group) received continuous passive movement training for 4 weeks. All subjects were evaluated for functional ratio (FR), acceleration time (AT), and time to peak torque (TPT) of internal and external rotators of the shoulder at 1 week before the intervention and 1 week after the intervention.

Results After the intervention, at angular velocities of 60°/s and 120°/s, the FRs in the experiment group increased significantly from $(0.61\$\pm0.20) and (0.65\pm0.21) to (1.09\pm0.11) (P < 0.001) and (1.13\pm0.15) (P < 0.001), respectively. However, the FRs in the control group did not change significantl 0.05), and the FRs in the experiment group were both significantly higher than those in the control group (P < 0.001). The ATs of internal rotators in the experiment group decreased significantly from (128.75\pm39.98) ms and (0.05) and (148.75\pm30.08) ms (P < 0.05), respectively. Meanwhile, the ATs of external rotators in the experiment g

0.05)*and*(114.38±$41.79) ms (P<0.05), whereas the ATs of internal and external rotators in the control group did not change significantly (P>0.05). Moreover, the ATs in the experiment group were all significantly lower than those in the control group (P<0.05). Regarding the TPTs of internal and external rotators, there were no significant changes in either the experiment group or the control group (P>0.05). However, the TPTs in the experiment group were all significantly lower than those in the control group (P<0.05).

Conclusion IET can enhance the strength ratio of internal and external rotators, maintain dynamic stabilization of the shoulder, and improve neuromuscular control, which may reduce the risk of sports injury.

Keywords Isokinetic eccentric training; Functional ratio; Neuromuscular control; Acceleration time; Time to peak torque

Introduction

The antagonistic relationship and strength balance between internal and external rotator muscle groups of the shoulder play crucial roles in maintaining dynamic stability and movement quality. Imbalance in strength between these rotators is considered a primary factor contributing to musculoskeletal dysfunction of the shoulder [**?**]. During the acceleration phase of overhead throwing motions, the external rotators must generate eccentric contractions to maintain proper humeral head position on the glenoid and control the velocity of shoulder internal rotation [**?**]. When the eccentric strength of external rotators is significantly imbalanced with the concentric strength of internal rotators, the risk of shoulder injury increases substantially [**?**]. Joint stability depends on the interaction of static stabilizers, dynamic stabilizers, and the nervous system, making neuromuscular control essential for maintaining shoulder stability.

Isokinetic eccentric training (IET) is a specialized exercise modality where muscles gradually lengthen under resistance, with the movement direction opposing the muscle' s pulling force [**?**]. During eccentric contractions, muscles can stimulate the cerebral cortex and spinal cord to generate more neural impulses, increase motor unit recruitment, and promote collagen re-adaptation, characterized by low energy consumption and high force production [**?**]. Isokinetic eccentric contractions generate greater muscle force than isokinetic concentric contractions, playing a particularly important role in improving rapid force production [**?**]. In recent years, IET has been widely applied in sports science research and rehabilitation medicine. Studies have utilized IET to improve strength balance and restore damaged rotator muscles in competitive athletes [**?**], but no domestic studies have focused on non-athlete healthy populations. This study investigated the effects of IET on strength balance and neuromuscular control of shoulder rotators in healthy young adults, aiming to enhance shoulder stability and reduce the risk of shoulder injuries.

1.1 Study Subjects and Grouping

Thirty-two healthy young subjects were recruited through advertisements. Inclusion criteria were: (1) age 18-25 years; (2) no skeletal muscle system diseases or nerve injuries in the dominant upper limb; (3) no upper limb strength training or high-intensity shoulder exercise within the past 4 weeks; and (4) willingness to sign informed consent. Exclusion criteria were: (1) severe cardiovascular or cerebrovascular diseases; (2) pregnancy or lactation; (3) limited shoulder range of motion; and (4) history of shoulder surgery or trauma. Subjects were randomly divided into an experiment group (n=16) and a control group (n=16) using a random number table. The experiment group received isokinetic eccentric training, while the control group (sham-training group) received continuous passive movement training. This study was approved by the Ethics Committee of Zhongshan Hospital, Fudan University (B2021-672).

1.2.1 Experimental Group

Subjects performed a 5-minute warm-up including shoulder stretching and active movements in all directions. The Biodex System 4 Pro multi-joint isokinetic testing and training system (Biodex, USA) was used to conduct isokinetic eccentric training on the internal and external rotators of the dominant shoulder at three velocities: 60°/s, 120°/s, and 180°/s, with 10 repetitions per set and 1-minute rest between sets. Training was performed twice weekly (with 3-4 days between sessions) for 4 consecutive weeks. During training, subjects were seated with the shoulder at 45° abduction in the scapular plane and the elbow flexed at 90°, with a range of motion from 45° internal rotation to 45° external rotation. Verbal encouragement was provided to maximize effort while avoiding compensatory movements such as shoulder adduction, flexion, or shrugging.

1.2.2 Control Group

As a sham-training group, control subjects performed continuous passive movement without exerting any effort, following the same training protocol and positioning as the experimental group.

1.3 Assessment Methods

One week before training, the Biodex System 4 Pro was used to test the internal and external rotators of the dominant shoulder. Researchers explained the testing procedure in detail. After a 5-minute warm-up, subjects performed isokinetic testing. Practice trials were conducted before formal testing to ensure understanding. Testing began with concentric/eccentric mode for external rotators at 60°/s and 120°/s, with 5 maximal repetitions per set and 1-minute rest between sets. This was followed by eccentric/concentric mode for internal rotators at the same velocities. Follow-up testing was conducted 1 week after training completion using identical procedures and requirements.

1.4.1 Functional Ratio (FR)

FR is defined as the ratio of "antagonist eccentric peak torque to agonist concentric peak torque" and serves as an important functional indicator of joint dynamic stability [**?**]. Peak torque represents the highest torque value on the torque curve during muscle contraction. In this study, eccentric peak torque of external rotators and concentric peak torque of internal rotators were measured at 60°/s and 120°/s, both before and after training, to calculate FR at each velocity. An FR less than 1 increases shoulder injury risk. Previous research indicates that when FR ranges from 1.08 to 1.17, shoulder rotator muscles achieve optimal balance, allowing external rotators to restrain overactive internal rotators during throwing acceleration and reduce injury occurrence [**?**, **?**].

1.4.2 Acceleration Time (AT)

AT represents the time from initial muscle contraction to reaching preset angular velocity during maximal effort, serving as an indicator of neuromuscular control capacity [**?**]. Its advantages include being non-invasive and unaffected by subcutaneous fat layers [**?**]. AT is expressed in milliseconds (ms), with lower values indicating stronger neuromuscular control.

1.4.3 Time to Peak Torque (TPT)

TPT represents the time from initial muscle contraction to reaching peak torque during maximal effort, reflecting the ability to rapidly generate torque and the responsiveness of neuromuscular control [**?**, **?**]. TPT is expressed in milliseconds (ms), with lower values indicating stronger neuromuscular control.

1.5 Statistical Methods

Data were analyzed using SPSS 17.0 software. The Kolmogorov-Smirnov test assessed normality. Normally distributed continuous data were expressed as mean ± standard deviation. Independent samples t-tests compared parameters between groups, while paired samples t-tests compared pre- and post-intervention parameters within groups. Categorical data were expressed as proportions and compared using chi-square tests. Statistical significance was set at $P<0.05$.

2.1 Comparison of General Data

All subjects in the experiment group completed the 4-week training and assessment, while two subjects in the control group withdrew. Data from 30 subjects were included in the final analysis. There were no significant differences between groups in sex distribution, age, height, weight, or body mass index (BMI) ($P>0.05$) .

2.2 Comparison of FR Between Groups

Before intervention, FR values in both groups were significantly less than 1 at both 60°/s and 120°/s, with no significant between-group differences (P>0.05). Within-group comparison showed that post-intervention FR in the experiment group increased significantly compared to baseline at both velocities (P<0.001), with values exceeding 1, while the control group showed no significant changes (P>0.05). Between-group comparison revealed that FR in the experiment group was significantly higher than in the control group at both velocities (P<0.001) .

2.3 Comparison of AT of Internal and External Rotators

Before intervention, there were no significant between-group differences in AT of internal or external rotators at either velocity (P>0.05). Within-group comparison showed that post-intervention AT of both internal and external rotators in the experiment group decreased significantly compared to baseline at both velocities (P<0.05), while the control group showed no significant changes (P>0.05). Between-group comparison demonstrated that AT of both internal and external rotators in the experiment group was significantly lower than in the control group at both velocities (P<0.05) .

2.4 Comparison of TPT of Internal and External Rotators

Before intervention, there were no significant between-group differences in TPT of internal or external rotators at either velocity (P>0.05). Within-group comparison showed no significant changes in TPT for either group post-intervention (P>0.05). However, between-group comparison revealed that TPT of both internal and external rotators in the experiment group was significantly lower than in the control group at both velocities (P<0.05) .

Discussion

The shoulder possesses the greatest range of motion and most complex kinematic characteristics of all human joints. The muscles surrounding the shoulder, particularly the rotator cuff, play vital roles in maintaining dynamic stability during overhead throwing motions [**?**, **?**]. Strength imbalances among rotator muscles can place the shoulder at increased injury risk [**?**]. Young adults frequently participate in overhead throwing sports such as volleyball, tennis, baseball, and handball. When significant strength imbalances exist between internal and external rotators, high-intensity activities can lead to shoulder injuries including rotator cuff tears, subacromial impingement, and glenohumeral instability [**?**, **?**]. In this study, baseline FR values were generally low, ranging from 0.54 to 0.68, likely due to two factors: (1) anatomical factors—the physiological cross-sectional area of internal rotators substantially exceeds that of external rotators, resulting in greater force output; and (2) environmental factors—daily functional activities frequently involve internal rotators, providing more training stimulus, whereas external rotators are engaged less often, only in specific movements

such as combing hair, leading to relative deconditioning. Additionally, subjects had no regular shoulder muscle training before enrollment, placing external rotators at a disadvantage. Therefore, implementing interventions to improve this imbalance and prevent sports injuries is particularly meaningful.

This study found that 4 weeks of IET significantly improved FR at both 60°/s and 120°/s, increasing from well below 1 to slightly above 1, theoretically indicating achievement of functional strength balance. These results align with Niederbracht et al. [**?**], who reported that all tennis players with shoulder FR below 1 could achieve values above 1 after 5 weeks of strength training. Potential mechanisms include: (1) isokinetic technology increasing muscle glycogen production and mitochondrial enzyme activity at the biochemical level [**?**]; (2) bidirectional physiological "overflow" of isokinetic training simultaneously training antagonists and agonists at all movement angles to improve strength [**?**]; and (3) eccentric training during muscle lengthening promoting elastic energy production, thereby enhancing neural firing frequency and reflex recruitment [**?**]. Notably, under identical training for both muscle groups, external rotators showed more significant improvements in eccentric strength than internal rotators showed in concentric strength. This may be because stretch reflexes during eccentric contractions lengthen elastic components like connective tissue, generating resistance that facilitates stronger muscle contractions and greater eccentric torque [**?**]. Improved FR theoretically reduces injury risk, particularly in preventing and rehabilitating glenohumeral instability. Cools et al. [**?**] found in an evidence-based rehabilitation protocol that restoring intrinsic shoulder muscle balance, especially enhancing eccentric strength of external rotators, is crucial for restoring shoulder stability and preventing recurrent dislocation.

This study also demonstrated that post-intervention AT of both internal and external rotators decreased significantly at both velocities compared to baseline and the control group, indicating that rotator muscles could reach preset angular velocity faster from initial contraction with shorter activation times. However, TPT showed no significant within-group changes post-intervention, suggesting no substantial reduction in time to peak torque, though large magnitude decreases were observed with significant between-group differences, possibly due to small sample size. Hess et al. [**?**] found through EMG that throwing athletes with shoulder instability exhibited delayed activation of internal rotators during rapid external rotation, suggesting an association between rotator muscle imbalance and neuromuscular control. This study indicates that achieving muscle balance through IET significantly improved neuromuscular control, possibly because mechanoreceptors in rotator muscles—such as Ruffini endings, muscle spindles, Golgi tendon organs, and Pacinian corpuscles—become sensitized through eccentric training, thereby improving proprioception and enhancing neuromuscular control [**?**], though specific mechanisms require further investigation. Zech et al. [**?**] demonstrated in a systematic review that neuromuscular control plays a clear role in joint function and injury prevention. Therefore, IET may facilitate establishment of optimal neuromuscular responses through adaptive practice, enabling faster muscle activation, optimal movement patterns, and coordinated

stability to reduce injury risk.

This study has several limitations: (1) Only healthy young adults aged 18-25 were included, as this age group frequently participates in overhead throwing sports, so results may not generalize to other populations; (2) Equipment limitations prevented testing velocities that simulate actual throwing speeds, with shoulder internal rotation velocities reaching 6100-7510°/s in real sports [**?**], meaning results may not fully reflect real-world conditions; (3) The relatively small sample size requires expansion in future studies to improve reliability; and (4) The study only theoretically inferred that improved strength balance and neuromuscular control could prevent or reduce injuries without verifying actual injury rates, so the injury prevention efficacy of IET requires further investigation.

In conclusion, IET can enhance strength balance of shoulder internal and external rotators, maintain dynamic shoulder stability, and improve neuromuscular control, potentially reducing sports injury risk. This training approach warrants promotion in fitness settings for general populations and overhead throwing athletes to enhance injury prevention awareness.

Author Contributions: Chen Jianxin contributed to study design, implementation, data collection and analysis, and manuscript writing. Tian Xinyu assisted with data collection and organization. Zhang Jian provided research supervision and takes overall responsibility for the article.

Conflict of Interest: The authors declare no conflict of interest.

Note: Figure translations are in progress. See original paper for figures.