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The Effect of Resistance Strength Training on Muscle Cross Education:A Meta analysis

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Abstract

Introduction:

At present, a large number of studies have found that the phenomenon of cross transfer has achieved significant research results in sports training, rehabilitation therapy, and influencing mechanisms. Cross training refers to increasing muscle strength on the training side, while there is also a significant increase in muscle strength on the untrained homologous side. The main purpose of this review is to explore the impact mechanism of cross transfer phenomenon and summarize the optimal training methods and rehabilitation methods for cross transfer phenomenon.

Aim of the study:

Using meta-analysis method to systematically evaluate the effects of cross training (also known as cross education) on upper and lower limb muscle strength in different age groups and compare the training results.

Material and methods:

The system searched databases such as Wanfang Digital Resource Database, China National Knowledge Infrastructure Database, EBSCOhost, PubMed, Web of Science, and Cochrane Library from the default start time to December 2024. Two evaluators independently screened research literature on resistance strength training improving upper and lower limb muscle strength and hypertrophy in various age groups based on inclusion and exclusion criteria. Revmen 5.3 was used to evaluate all included literature and analyze their data.

Result:

1)After 4 rounds of exclusion, 7 articles were finally included with a total sample size of 257 people; 2) Cross education intervention under resistance strength training can significantly enhance the strength of the quadriceps muscle in adults, with better results than the control group. The combined effect size is SMD=8.03, 95% CI:- 1.32，17.37， P＜0.01， 3) The degree to which cross education intervention enhances the strength of the gastrocnemius and wrist extensor muscles under resistance strength training is similar. The combined effect quantities are: SMD＝0.17，95% CI：-2.28，2.62，P≥0.01； SMD＝-0.39，95% CI：-3.02，2.25，P≥0.01；SMD=0.20, 95% CI: -0.81, 1.21, P ≥ 0.01

Conclusion:

Cross education intervention under resistance strength training can significantly improve quadriceps strength and promote muscle hypertrophy in adults; The effect of cross education intervention under resistance force on promoting the strength and hypertrophy of the gastrocnemius muscle and wrist extensor muscle is similar.

Key words: Resistance training; Cross disciplinary education; Muscle strength; Muscle hypertrophy; Meta analysis

1 Research Methods

This study strictly followed the standards of meta-analysis guidelines (Liberati et al., 2009).

1.1 Literature search

Two search personnel logged into databases such as Wanfang Digital Resource Database, China National Knowledge Infrastructure Database, EBSCOhost, PubMed, Web of Science, and Cochrane Library to complete literature searches, with a deadline of December 30, 2024. in

The search terms for the text include: strength training, resistance training, age groups, muscle strength, cross training, cross education, randomized controlled trials, etc. The English search terms include: Randomized randomized controlled trial, Cross Training, Employee, Muscle strength, etc. A combination search will be conducted.

1.2 Inclusion and exclusion criteria for literature

Literature inclusion criteria: 1) The experimental design should be a randomized controlled trial or a self controlled trial; 2) The experimental subjects are healthy individuals aged 18 to 40, regardless of race or country, and without cardiovascular diseases; 3) At least one experimental group uses unilateral resistance training as an intervention method, with an intervention time of ≥ 3 weeks, while the control group includes no training intervention or bilateral resistance training; 4) The outcome indicators should include at least one of upper and lower limb muscle strength indicators and upper and lower limb muscle hypertrophy effect indicators; 5) If there are multiple sets of available data in the same literature, it can be used as multiple studies.

Literature exclusion criteria: 1) Literature review, conference literature, or case studies; 2) Non Chinese or English literature; 3) Repeatedly published, low-quality literature; 4) Animal experiments; 5) The experimental intervention is a single acute intervention; 6) The experimental data is not presented in the form of mean ± standard deviation (M ± SD); 7) There is no valid data in the experiment, and the request from the author of the literature was unsuccessful; 8) The experimental group consists of literature on combined interventions, such as cross strength training combined with aerobic training and protein intake combined interventions.

1.3 Literature screening

Two evaluators independently screened based on literature inclusion and exclusion criteria, selected relevant literature according to the title and abstract, downloaded literature that met the criteria for intensive reading, and jointly conducted consistency statistics on the evaluation results after completion. If there is a disagreement, consult the third evaluator and decide whether to include it after joint discussion.

1.4 Data Extraction

Extracting basic information of included literature in a tabular format: 1) research information, including author, year, nationality, etc; 2) Experimental intervention information, including experimental design, etc; 3) Basic intervention measures include exercise cycle, exercise intensity, exercise frequency, etc;

1.5 Literature Quality Evaluation

Two evaluators used the risk bias assessment tool in the Cochrane Handbook to evaluate the included literature item by item based on high bias risk, low bias risk, and this information was not provided.

1.6 Data Analysis

Revman 5.3 was used to statistically analyze the outcome measures included in the literature. Firstly, perform heterogeneity test using I2

Statistical analysis is used to test the level of heterogeneity between studies. According to the Cochrane Handbook evaluation criteria, when I2

=At 0 o'clock, there was no heterogeneity among the studies; When I2<50%, a fixed effects model is used for analysis, and subgroup analysis is used to explore the intermediate variables of heterogeneity between studies. Otherwise, a random effects model is used. The result indicators included in the literature were tested with consistent units, using mean difference (MD) as the effect measure. Conversely, standardized mean difference (SMD) was used as the effect measure, and calculated with a 95% confidence interval, with $P<0.05$ indicating significant differences. Use a funnel plot for publication bias analysis, and conduct a meta-analysis using post measured values from the experimental and control groups.

2 Results

2.1 Literature search information

This study retrieved a total of 561 relevant literature, analyzed the titles, abstracts, and full-text reading of the literature, and after excluding unqualified literature, 7 literature ultimately met the inclusion criteria (Figure 1).

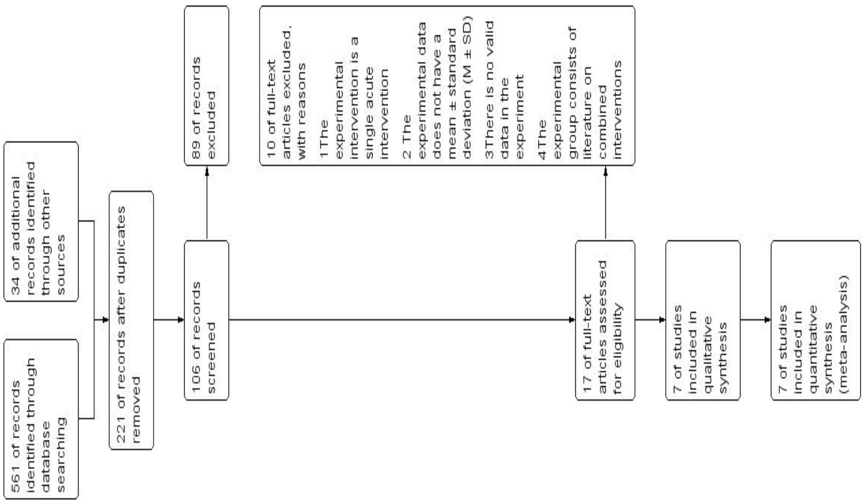

Figure 1. Flow Diagram of Study Selection

2.2 Basic characteristics of included literature

The 7 articles included in this study were published between 2015 and 2024; The subjects included are from all age groups, with a total sample size of 257 people. The experimental group consists of 135 people and the control group consists of 123 people, aged between 20 and 80 years old; The intervention methods for the experimental group were resistance strength training or muscle strength training under nerve control, while the control group received low-intensity resistance training or no training; Other included information includes exercise cycle, intensity, frequency, and intervention measures (Table 1).

Table 1. Basic Information of Included Studies

Author, time, country	sample	Age (MD ± SD)	cycle	frequency	Intervention measures
Coleman[1]，2024，America	M:29 F:10	28±8.3	9wk	4d/1wk	The participants conducted 5 sets of 8-12 repetitions of the maximum (RM) exercises, with a 2-minute break between the two groups.
Otsuka[2], 2022,Japan	N-Ex 17：F 47.1% L-Ex 16：F 50.0% M-Ex 17：F 52.9%	N-Ex 17：63.5 ± 8.5 L-Ex 16：63.6 ± 8.1 M-Ex 17:63.5 ± 8.3	24wk	3d/1wk	Resistance training; The training weight of the low Ex group is 40% 1-RM, and the training weight of the medium Ex group is 60% 1-RM
Nakamura[3]，2022，Japan	HI-SS：M 14 LI-SS：M 14;	HI-SS：20.9 ± 0.5 LI-SS：21.4 ± 1.0	4wk	3d/1wk	Static stretching of plantar flexor muscles, participants underwent stretching interventions consisting of three groups of 60 seconds with intervals of 30 seconds.
Coratella[4]，2015，Italy	IK：M 15 DCER：M 15 CON：M 15	20.5 ± 2.3	8wk	2d/1wk	IK, 5 groups, with 8 maximum unilateral isokinetic knee joint extensions per group, ranging from 5 ° to 90 °DCER performed 5 sets of 8 unilateral eccentric knee joint extensions on a knee joint extension device, using a similar range of motion and a load setting of 120%
Holm[5]，2024，Denmark	NEMEX：F 20 (59 %) NEMEX+ST：F 15 (52 %)	NEMEX：67.0 ±9.1 NEMEX+ST：63.9 ±10.2	12wk	2d/1wk	All exercises are conducted in 2-3 groups, with 10-15 sessions per group, and the difficulty gradually increases
Coombs[6]，2016，Australia	RHT：4 M 4 F LHT：4 M 4 F CON：3 M 4 F	RHT：22.20 ± 2.06 LHT：21.00 ± 2.21 CON：25.20 ± 2.71	3wk	3d/1wk	Four groups of wrist extensor strength training, 6-8 times per group, 70% 1RM, with a 3-minute recovery time between each group
Pearcey[7]，2022，America	F：9	22-24	5wk	1d/1wk	Participants complete three attempts of maximum voluntary contraction (MVC) with each hand for hand and grip testing. Maintain MVC for 3 seconds and take a 2-minute break.

WK,weekM,Male;F,femaleN-Ex,No exercise;L-Ex,low exercise;M-Ex,Moderate-Ex;NEMEX,CON,control group;Neuromuscular control exercises;NEMEX+ST,Neuromuscular control exercises + strength training;LHT,Left hand training;RHT,Right hand training;isokinetic;IK,isokinetic exercise;DCER,dynamic external resistance exercise;HI-SS,high-intensity static stretching ; LI-SS,low-intensity static stretching

2.3 Analysis of Bias in Inclusion of Literature

A total of 7 articles were included in the literature, including 4 descriptions of random grouping methods, 4 detailed descriptions of hidden allocation schemes, 1 using single blind method, and 2 using outcome evaluation blind method; Three results data are complete, and four experimental data have been requested from the original authors; Three articles have high quality, while four articles have certain risk bias and belong to medium quality literature (Figure 2).

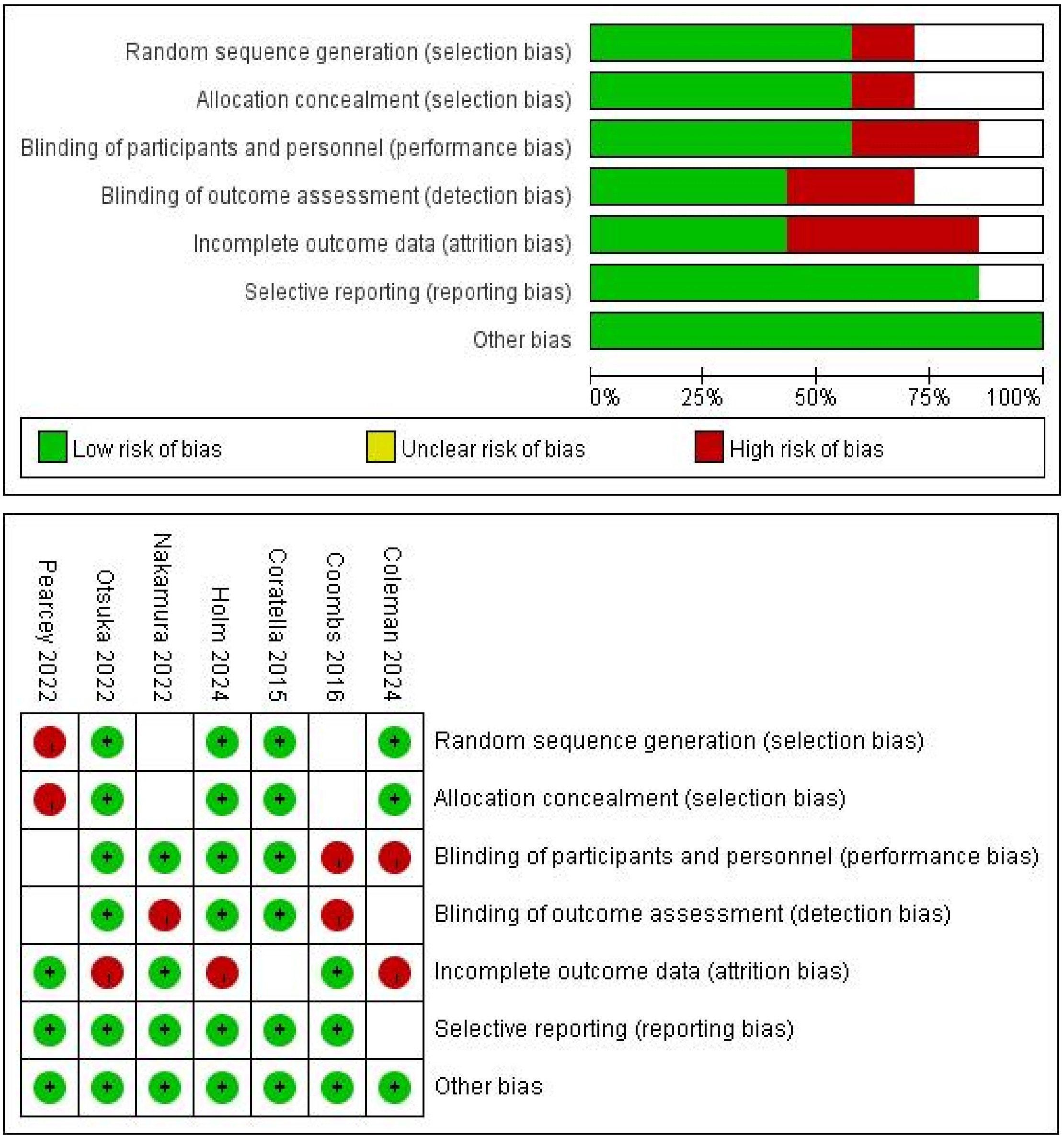

Figure 2. Risk of Bias Analysis of Included Studies

2.4 Meta analysis results of cross educational effects of resistance strength training

2.4.1 The impact of resistance strength training on cross education of quadriceps muscle strength

Two articles were included in the literature to explore the effect of resistance strength training on cross education of quadriceps muscle strength, with a total of 88 experimental subjects. As shown in Figure 3, $I^2=0$， There is no heterogeneity among the studies, therefore a fixed effects model is chosen for analysis. The meta-analysis results showed that resistance strength training interventions can enhance the muscle strength of the quadriceps femoris in adults, with no significant difference in intervention effect. Among them, SMD=8.03, 95% CI:- 1.32，17.37， $P<0.01$， This indicates that cross education intervention under resistance strength training in the experimental group can significantly enhance the strength of the quadriceps muscle in adults, and the effect is better than that of the control group.

2.4.2 The impact of resistance strength training on cross education of medial gastrocnemius muscle strength

Two articles were included in the literature to explore the effect of resistance strength training on cross education of medial gastrocnemius muscle strength, with a total of 70 experimental subjects. As shown in Figure 4, $I^2=76\%$， Analyze and select a random effects model. The meta-analysis results showed that resistance strength training interventions can promote an increase in the strength of the medial gastrocnemius muscle in elderly people, with no statistically significant difference in intervention effect. Among them, SMD=0.17, 95% CI:-2.28，2.62， $P\geq0.01$， This indicates that the degree to which resistance strength training intervention enhances the strength of the medial gastrocnemius muscle is similar between the experimental group and the control group.

2.4.3 The effect of resistance strength training on cross education of lateral gastrocnemius muscle strength

Two articles were included in the literature to explore the effect of resistance strength training on cross education of lateral gastrocnemius muscle strength, with a total of 70 experimental subjects. As shown in Figure 5, $I^2=78\%$， Indicating moderate heterogeneity among various studies, a random effects model was chosen for analysis. The meta-analysis results showed that, SMD＝-0.39，95% CI：-3.02，2.25，$P\geq0.01$， This indicates that the degree to which resistance strength training intervention enhances the strength of the lateral gastrocnemius muscle is similar between the experimental group and the control group.

2.4.4 The impact of resistance strength training on cross education of wrist extensor muscle strength

Two articles were included in the literature to explore the effect of resistance strength training on cross education of wrist extensor muscle strength, with a total of 33 experimental subjects. As shown in Figure 6, the heterogeneity I ²=0%, therefore a fixed effects model was chosen for analysis. Meta analysis shows that, SMD＝0.20， 95% CI： -0.81， 1.21， P≥0.01， Indicating that the degree of resistance strength training intervention in enhancing wrist extensor muscle strength is similar between the experimental group and the control group.

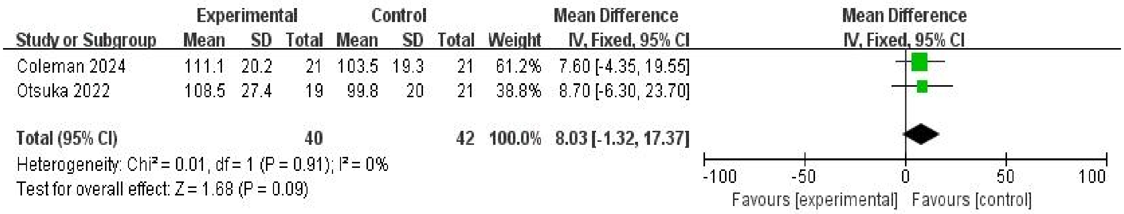

Figure 3. The effect of resistance strength training on cross education of quadriceps muscle strength

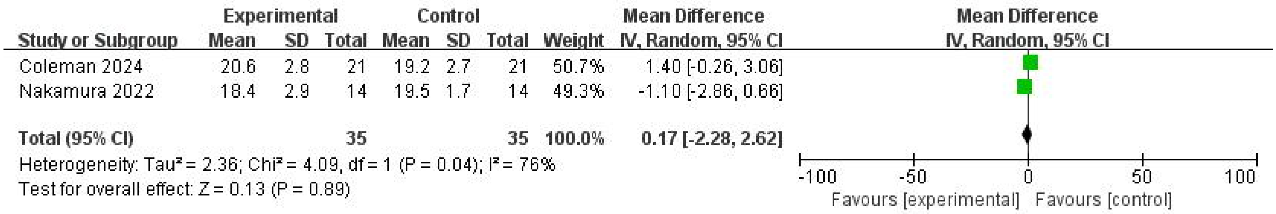

Figure 4. The effect of resistance strength training on cross education of medial gastrocnemius muscle strength

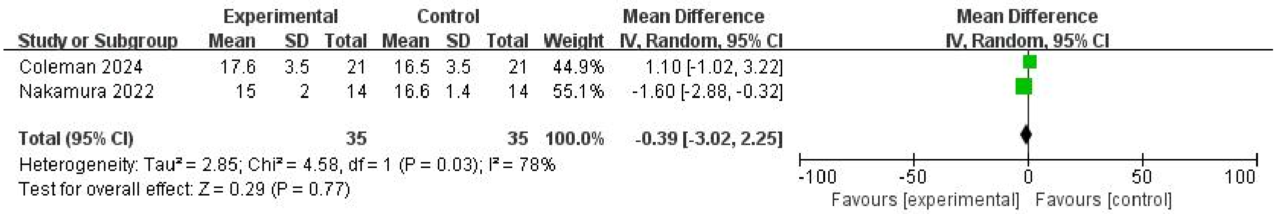

Figure 5. The effect of resistance strength training on cross education of lateral gastrocnemius muscle strength

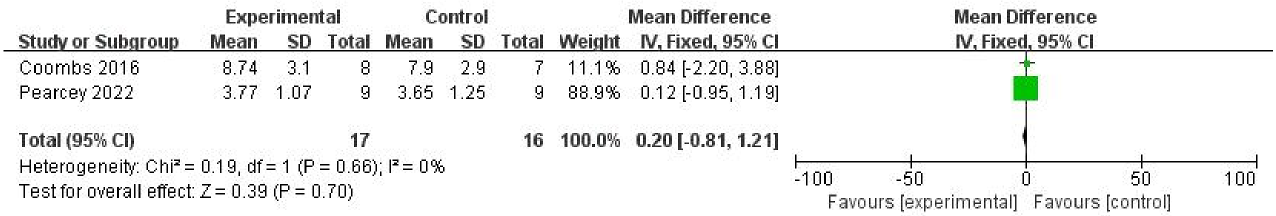

Figure 6. The effect of resistance strength training on cross education of wrist extensor muscle strength

3 Discussions

3.1 Mechanism of Resistance Strength Training Promoting Muscle Cross Education Effect

3.1.1 The Role of Neuronal Systems in Cross Training

Giuseppe Coratela et al. found through studying the cross teaching effect of unilateral centrifugal isokinetic training and dynamic constant external resistance training that the mechanism involved in the cross education effect may be neural rather than structural muscle changes. To investigate the effects of unilateral eccentric training with constant speed and constant external load on untrained limbs. Forty nine participants were randomly divided into isokinetic (IK), dynamic constant external resistance (DCER) unilateral centrifugal training group, or control group. Measure the peak torque of knee extensor 1 RM and isometric, eccentric, and concentric extensor muscles, as well as changes in the thickness of the lateral thigh muscle, muscle bundle length, feather angle, and fat free mass of the quadriceps femoris muscle. After training, both IK and DCER increased, but over time, there was no significant increase in the thickness of the lateral thigh muscle, muscle bundle length, feather angle, and fat removal mass of the quadriceps femoris muscle. Centrifugal training is effective in inducing strength adaptation in untrained limbs, but ineffective in structural adaptation. In rehabilitation and training practice, the use of easily accessible gym equipment can effectively replace expensive and often unavailable isokinetic equipment, and only eccentric training can be performed using isokinetic force gauges or dynamic constant external resistance [8].

In summary, we demonstrate for the first time that unilateral eccentric training of IK and DCER induces similar adaptations in untrained limbs. The changes in strength rather than structural muscles confirm that the mechanisms involved in cross educational effects may be neural. Tjerk Zult et al. proposed an untested hypothesis that using mirrors for cross education can increase the transfer of motor function to resting limbs compared to standard cross education interventions without mirrors. This review identified 6 chronic studies investigating the effects of unilateral strength training on neural adaptation, as well as 15 cross-sectional studies investigating acute changes in brain activation, motor cortex, and corticospinal excitability using imaging, electroencephalography, magnetoencephalography, and magnetoencephalography. Research has shown that the mirror neuron system (MNS), which connects sensory neurons to respond to observed visual characteristics of actions and motor neurons, releases action potentials during the execution of similar actions, and may enhance cross education. The combination of cross education and mirror training can further accelerate functional recovery [9].

3.1.2 Cross education on neural adaptation to muscle strength

In addition to neurons as one of the representatives explaining the impact mechanism of cross training, Ashlyn K. Frazer et al. believe that cross education of neural adaptation to muscle strength is most likely to represent continuous changes within the central nervous system. Cross training involves structural and functional changes in cortical motor and non motor areas, including increased cortical excitability, decreased cortical inhibition, decreased interhemispheric inhibition, changes in autonomous activation, and new areas of cortical activation [11]. Does ipsilateral corticospinal excitability play a decisive role in cross training; Amandine Bouguetoch et al. also confirmed that partial activation of the neuromuscular system can affect the effectiveness of cross training. To analyze the effects of motor imagery (MI) or second largest neuromuscular electrical stimulation (NMES) on untrained limbs, 27 subjects were divided into three groups: MI group, NMES group, and control group. The training group received a 10 time training program within two weeks, targeting the plantar flexor muscle of one limb. It has been confirmed that MI appears to effectively induce cross education, possibly due to the activation of cortical motor areas affecting the corticospinal nerve drive in both the training and non training groups. On the contrary, non maximum NMES will not lead to cross education. This study tends to suggest that the mechanism of cross education depends on the type of neural tender training limb. This suggests that voluntary corticospinal activation may be necessary to induce early cross education [11].

3.1.3 Sports area and white matter pathway in cross training

Kathy L. Ruddy et al. used multimodal neuroimaging to investigate mediating neural mechanisms by correlating quantitative estimates of functional and structural cortical connections with individual levels of limb to limb transfer. Perform resting state (rs) fMRI and diffusion-weighted imaging (DWI) scans before unilateral ballistic wrist flexion training. Immediately repeat the rs fMRI sequence. The performance improvement of untrained limbs was 83.6% of that of trained limbs, significantly higher than the untrained control group. After training, the functional connectivity of the resting motor network between the right and left middle motor areas (SMA) increased. However, these changes are not related to the individual's level of transfer. The analysis of DWI data using fiber bundle imaging based on constrained sphere deconvolution shows that the anisotropy fraction and apparent fiber density in the fiber bundles connecting bilateral SMA are negatively correlated with transfer and can predict transfer. The research results indicate that the hemispherical interaction between bilateral SMA plays an important role in CE, and the structural integrity of the pathway connecting white matter affects the level of metastasis [12].

D. Colomer Poveda et al. searched for 10 articles on measuring corticospinal excitability using transcranial magnetic stimulation, combined with electromyography (EMG) and TMS for recording motor evoked potentials (MEPs), which are electrical signals recorded in muscles after applying magnetic pulses to the primary motor cortex. Recording the MEP of untrained limbs after long-term unilateral resistance training can help determine the impact of this type of training on controlling the corticospinal tract of the limb and its potential association with cross training effects. 60% of the studies reported an increase in CE in the untrained M1 region, while 40% of the studies did not observe significant changes, indicating that there may be no functional association between increased muscle strength and CSE [13]. A. Manca et al. used an improved Delphi online survey method to identify 56 renowned experts (i.e. physiologists, exercise scientists, neurologists, physical therapists, doctors, clinical doctors), and reached consensus on the mechanisms of short interval subcortical inhibition (SICI), interhemispheric inhibition, and decreased IHI as the transfer of strength and skills. Functional magnetic resonance imaging (fMRI) and TMS based assessment are effective tools for studying transfer mechanisms, and the ranking order of "primary motor cortex", "auxiliary motor area", "primary somatosensory area", and "dorsal prefrontal cortex" as factors affecting the central nervous system's impact on cross training [14].

4 Conclusion

Resistance strength training can significantly improve upper and lower limb muscle strength and muscle hypertrophy in all age groups; The training method of resistance strength training through cross education can achieve similar effects to simultaneous resistance strength training on the same side of the limb while reducing load and joint mechanical stress; In intervention measures, exercise cycle is a factor that affects the training effectiveness of different age groups.

Disclosure

Author's contribution

Authors have read and agreed with the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Conflict of interest

The authors deny any conflict of interest.

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