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PREFACE

Dear colleagues and readers,

I am delighted to welcome you to the first issue of our new journal, “Trends in Physical Education and Sport”. This project is the result of an international collaboration between scientists from Kazakhstan and China, the collective expertise and accomplishments of the journal’s editorial board in the field of physical education and sport, and the dedicated team of professionals from our publishing house. We hope that it will become an important platform for the exchange of knowledge, ideas and innovations in this field.

Physical education and sport play a vital role in society by promoting physical development, encouraging healthy lifestyles, strengthening social bonds and enhancing psychological well-being. We are confident that our journal will significantly advance the science and practice of physical education and sport by providing relevant research, analytical materials and practical recommendations.

Each issue will cover the latest trends, share insights of leading experts and explore new educational, training and sports medicine approaches. We warmly invite researchers, educators, coaches and anyone with an interest in physical education and sport to join the conversation and share their findings and opinions.

We hope that the journal “Trends in Physical Education and Sport” will become a valuable source of information, inspiration and professional growth. We welcome your suggestions and ideas, and look forward to featuring your articles and research in future editions.

Thank you for your interest in our journal. We wish you productive reading and inspiration for new achievements in physical education and sport!

Sincerely,
Kuanyshbek Bulanovich Adanov,
Editor-in-Chief of “Trends in Physical Education and Sport”.

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Integrating music mobile applications into students' physical education classes

This article examines the integration of music mobile applications into the educational process within the discipline of Physical Education among university students. A comprehensive analysis of current research was conducted, focusing on the effects of musical accompaniment on students' cognitive, emotional, and physiological responses during physical activity. The experimental study involved 60 students, divided into control and experimental groups. During the trial phase, mobile applications were used to personalize music track selection based on genre, tempo, and rhythm according to individual student preferences. The results demonstrated a significant increase in student engagement and improvement in emotional state. Positive changes were observed in anxiety levels and negative attitudes toward physical education classes. The subjective perception of physical exertion in the experimental group shifted toward a favorable range, suitable for cardio and aerobic training. Integrating music mobile applications into physical education practice encourages a positive attitude toward physical activity, enhances student involvement, and helps develop a sustainable habit of maintaining a healthy lifestyle. The implementation of modern digital solutions, such as music-based mobile applications, contributes to the individualization of the educational process by making physical education more responsive to each student's needs. The findings of this pedagogical study confirm that the integration of mobile technologies supports the modernization of traditional approaches to teaching physical education, expands the range of educational tools, and increases students' motivation to engage in regular physical activity.

Keywords: digitalization, motivation, music mobile applications, Fit Radio, PANAS, positive affect, negative psychological affect, Borg Scale, subjective perception of physical exertion.

Introduction

Kazakhstan's national strategy for digitalization is a fundamental pillar of contemporary development, particularly in the context of economic growth and improvements in citizens' quality of life. President Kassym-Jomart Tokayev emphasizes that in order to enhance competitiveness and optimize service delivery, digitalization must be employed as a tool for ensuring the country's sustainable internal development.

Over the past decade, digitalization has been actively incorporated into the country's educational landscape, facilitating the modernization of teaching practices and enhancing both the accessibility and quality of educational services. For instance, electronic textbooks for school students are now widely used and available on specialized platforms — currently 11 publisher platforms are providing access to 704 educational resources. Additionally, the digital platform *Kundelik.kz* functions as an electronic documentation system for educational institutions and other participants in the learning process.

Digital transformation in higher education in Kazakhstan is progressing in three main directions:

- modernization of the educational process (e.g., the "smart university" concept);
- enhancement of teaching quality (e.g., high-tech studios for recording lectures and conducting online lessons);

- alignment with international standards (e.g., integration of the global Coursera platform, offering 853 online courses).

The relevance of this study is determined by the integration of digital technologies into the practice of physical education and sports (PES) for university students, which necessitates the development of innovative strategies aimed at increasing students' motivation and engagement in the educational process.

Digitalization in the field of PES involves the comprehensive implementation of information and communication technologies (ICT) for the following purposes:

- optimization of training processes;
- enhancement of student motivation for physical education and sports;
- analysis of performance indicators.

For consumers in the field of motor activity (MA), the digital services market offers a wide range of options:

− mobile applications (MAs) and wearable devices (e.g., Apple Watch, Xiaomi Mi Band, Garmin fitness trackers; MyFitnessPal, Strava, Nike Training Club) provide biofeedback functionality;

− online platforms for physical activity (PA) (e.g., Zoom, YouTube, "Fizkultura Online", LesMills+) or interactive trainers (e.g., Peloton, Zwift);

− digital diaries and monitoring systems (e.g., the platform "Fizkultura.kz");

− VR/AR technologies (virtual and augmented reality) for simulating game situations, spatial orientation, and reaction improvement;

− Big Data and analytics in elite sports. For example, HUDL, Catapult programs for optimizing athlete training and recovery.

Integration of ICT allows the implementation of new digital tools into the educational process of physical education (PE) for personalized learning and athletic training of students. Personal productivity in PE classes depends on individual motivation. Motivation is defined as a combination of internal and external human drives. Within the framework of pedagogical science, motivation is a dynamic component of learning that influences the acquisition of knowledge, skills, and the formation of value orientations in the field of PE.

The effectiveness of PE classes depends on intrinsic motivation: interest, enjoyment, and self-realization. From a psychological perspective, motivation drives individuals to perform specific actions. In the context of physical activity, motivation serves several functions:

− motor. Motivation stimulates physical activity among participants. Intrinsic motivation is represented by the pursuit of self-development, the need for self-improvement, and concern for health. Extrinsic motivation includes social approval, status enhancement, rewards, or the avoidance of punishment;

− regulatory. Motivation sets priorities and goals, regulates behavior, and helps to optimally allocate physical effort during training;

− cognitive. For example, it improves memory, sharpens attention, and contributes to clear perception of information, which enables more effective learning during PE classes;

− emotional. Interest and enjoyment from PA contribute to emotional regulation and enhance the overall quality of classes.

In the context of motivational functions, music mobile applications (MMAs) can stimulate student engagement in physical education (PE) classes. From a physiological perspective, listening to music activates various areas of the brain, including the cerebral cortex, the limbic system, and the cerebellum. According to studies by Petri Toiviainen (University of Jyväskylä, Finland), conducted in the laboratory of cognitive neuroscience using magnetic resonance imaging (MRI), it has been proven that listening to music activates different areas of the brain (pleasure centers, memory, motor areas, and the prefrontal cortex). Several publications from Harvard Medical School (USA) report that regular music training or playing musical instruments develops memory, speech, analytical and mathematical abilities, thereby influencing a person's cognitive capacities.

The influence of music on the emotional sphere has been demonstrated in studies conducted at the University of Southern California (USC, USA) in the laboratory of Antonio Damasio. Researchers confirmed that music can elicit persistent emotional responses by engaging the amygdala (emotion centers), reducing stress, anxiety, and even pain sensations.

Professor Susan Hallam (Research Center for Music & Science, University of Oxford, UK) studied the effect of background music on cognitive functions. According to her review, music can either improve or impair attention and memory, depending on the type of music and listener preferences. For example, the well-known Mozart Effect study (Gordon Shaw, University of California, Irvine) [1] showed that listening to

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Mozart's music temporarily improves spatial reasoning, but the effect was overestimated and is now considered minor and short-lived. Numerous publications by Robert J. Zatorre (McGill University, Canada) support the claim that music triggers dopamine release, which is responsible for the sensation of pleasure and joy [2].

Most researchers agree that music can elicit emotional responses, influence overall mood, and affect motivational levels. The selection of specific musical rhythms can contribute to increased productivity, reduced fatigue, or have a relaxing effect. In experiments conducted by faculty at Wilfrid Laurier University in Canada, it was demonstrated that lyrical and calm music has a relaxing impact on individuals by reducing cortisol levels. To achieve this effect, it is necessary to select music with a tempo of 60–80 beats per minute; this rhythm is most "harmonious" with the human heartbeat and promotes calmness, rest, or soft concentration. Classical music (e.g., Bach, Mozart, Vivaldi) is characterized by regular rhythm and harmonious melodies that help relieve tension and improve psycho-emotional well-being. Accordingly, music with a clear rhythm and energetic tempo (pop, rock, electronic music) increases alertness and motivation and makes it easier to perform repetitive tasks. The greatest effect is achieved when the listener enjoys the music — personal preferences amplify emotional and cognitive responses. Therefore, the integration of MMAs into the physical education process is one of the promising areas for the application of digital technologies in PE classes [3].

Musical accompaniment of PA can have a positive impact on the psychophysiological state of participants, improving mood, reducing the perception of fatigue, increasing performance, and enhancing resistance to stress factors. In 2016, Clark, I. N., Baker, F. A., and Peiris, C. L., in their meta-analysis "Music interventions and physical activity," noted that using MMAs during aerobic training led to increased heart rate, reduced perceived exertion, and greater enjoyment of the activity. In 2020, Silva-Batista C., in studies on the effect of music-movement synchronization through mobile applications during group workouts, demonstrated an increase in group performance efficiency and improvement in participants' psycho-emotional condition [4].

In the context of the educational environment, especially among the student audience with a high level of digital literacy and a tendency to use mobile devices, the integration of mobile applications (MAs) into PE classes appears both appropriate and scientifically justified. Despite the high level of technological infrastructure in educational institutions and the active development of mobile platforms, scientific research aimed at evaluating the effectiveness of such integration remains at an early stage. This highlights the need to analyze various aspects of using music-based MAs in students' physical education activities.

The purpose of the study is to identify and assess the impact of integrating music mobile applications on the psychophysiological parameters of students during physical education classes.

Research Objectives:

- to systematize and summarize data on the influence of music on a person's psychophysiological and emotional state;
- to develop an experimental methodology for the study: to form student groups, select suitable music mobile applications (MMAs), and determine the evidence base;
- to assess and analyze changes in the psychophysiological condition of the participants;
- to formulate conclusions and practical recommendations.

The expected outcome is the confirmation of the hypothesis regarding the positive impact of integrating MMAs into students' physical activity, leading to increased motivation for PE and improved psychophysiological well-being.

Methods and materials

The study on the integration of music mobile applications (MMAs) into the physical education (PE) process of university students employed a combination of methods that allowed for an objective assessment of the impact of digital technologies on the psychophysiological condition of the participants.

To examine and synthesize existing scholarly publications relevant to the research topic and to develop the methodological framework, the method of analysis of scientific and methodological sources was used. Methods of systematization, evaluation, and comparison were applied to define the functional capabilities and to select the most suitable MMAs among ten music applications: Spotify, Yandex Music, SoundCloud, Apple Music, Deezer, Fit Radio, RockMyRun, Music for Fitness, Jabra Sport Life, and Peloton.

Based on criteria, such as functional convenience and operational reliability, five applications were selected for the study:

1) Spotify — the largest music streaming platform, enabling the creation of themed playlists for various types of physical activity (e.g., cardio, strength training, yoga); features personalized recommendation algorithms and integration with fitness trackers;

2) Fit Radio — a specialized fitness music application that offers curated playlists with optimal BPM for different workouts, along with timers and voice coaching;

3) RockMyRun — an application that generates special music mixes for running, walking, and training; it automatically adjusts to the heart rate rhythm, helping to maintain motivation and proper pace;

4) Deezer — a platform with a wide range of sport-oriented playlists; allows offline playback and supports integration with fitness devices;

5) Peloton — a well-known fitness application with music support, offering playlists for strength and cardio workouts, audio coaching sessions with music, and real-time feedback.

For the integration of a music mobile application (MMA) into students' physical education activities, we selected **Fit Radio** due to its optimal user-friendliness and intuitive interface.

To actively influence the study subject, a **pedagogical experiment** was conducted with the aim of testing the hypothesis and evaluating the effectiveness of MMA implementation. To substantiate the findings, two groups were formed: an **experimental group** and a **control group**, each consisting of 30 first-year students from the Faculty of Humanities and Social Sciences at *Torayghyrov University* (Pavlodar, Kazakhstan). The experimental procedure involved the use of **sociological methods** (observation, interviews) and **psychological methods** (questionnaires). The final conclusions were based on objective data validated through surveys using the **PANAS questionnaire** (Positive and Negative Affect Schedule) and the **Borg Scale**, followed by mathematical processing of the results. To formulate conclusions and recommendations, methods of **synthesis, induction**, and **generalization** were applied. The materials included **personal mobile devices** were used to access the **Fit Radio** application. Individual playlists were created within the MMA based on the personal music preferences of the participants.

Additional tools included the **PANAS questionnaire,** the **Borg Rating of Perceived Exertion (RPE) Scale,** a **computer with data processing software,** and **software for statistical analysis**.

Results and Discussion

1) The PANAS questionnaire measures the balance of Positive Affect (PA) and Negative Affect (NA) — a spectrum of emotional states (effect). It was developed in 1988 by D. Watson, L. Clark, and A. Tellegen, and later adapted into Russian by E.N. Osin in 2012 [5].

Students were given a questionnaire containing a list of adjectives describing various feelings and emotions, which they were asked to evaluate using a 5-point Likert scale (short-term version), reflecting their emotional state at the moment of the class [6–8]. The results are presented in Figure 1.

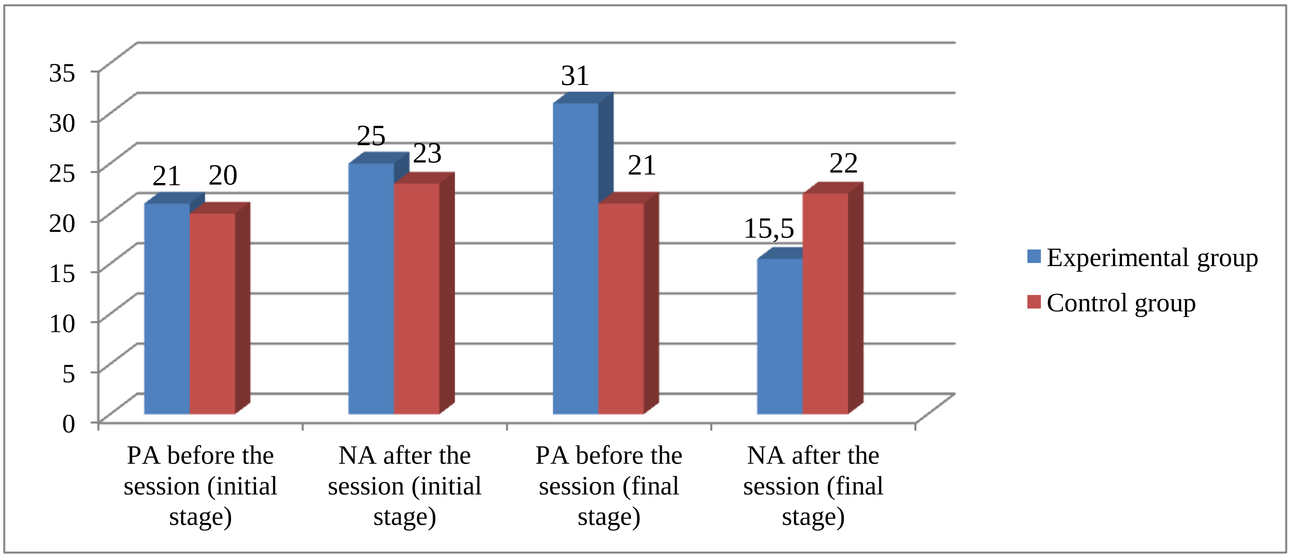

Figure 1. Dynamics of PA and NA at the stages of the experiment

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According to the obtained data (Figure 1), at the beginning of the experiment, the PA levels in both groups were approximately equal and relatively low (21 in the experimental group and 22 in the control group), indicating a low level of emotional engagement and interest in physical education classes. The NA values — 25 in the experimental group (EG) and 23 in the control group (CG) — reflect a high level of negative emotions and anxiety. The PANAS measurement results at the final stage of the experiment (after 8 sessions) show an increase in the level of positive mood, emotional engagement, and energy in the experimental group — up to 31 points, which falls within the normal PA range (30–35 points) for a healthy student. Meanwhile, the control group showed stagnation, with the PA score remaining at 21. At the final stage, the experimental group demonstrated a low level of negative effect — 15 points, which corresponds to the lower boundary of the anxiety range (15–20). The control group showed a slight decrease in average NA from 23 to 22 points, which is not statistically significant for the purposes of this experiment.

2) The Borg Scale is a tool used for the subjective assessment of perceived physical exertion. It enables the evaluation of cumulative sensations related to changes in the cardiovascular, musculoskeletal, and respiratory systems experienced during physical activity. The Borg Scale is a vertical scale with numerical values from 6 (no exertion at all) to 20 (maximal exertion) and corresponding verbal descriptors of increasing intensity. The results obtained during the experiment using the Borg Scale are presented in Figure 2.

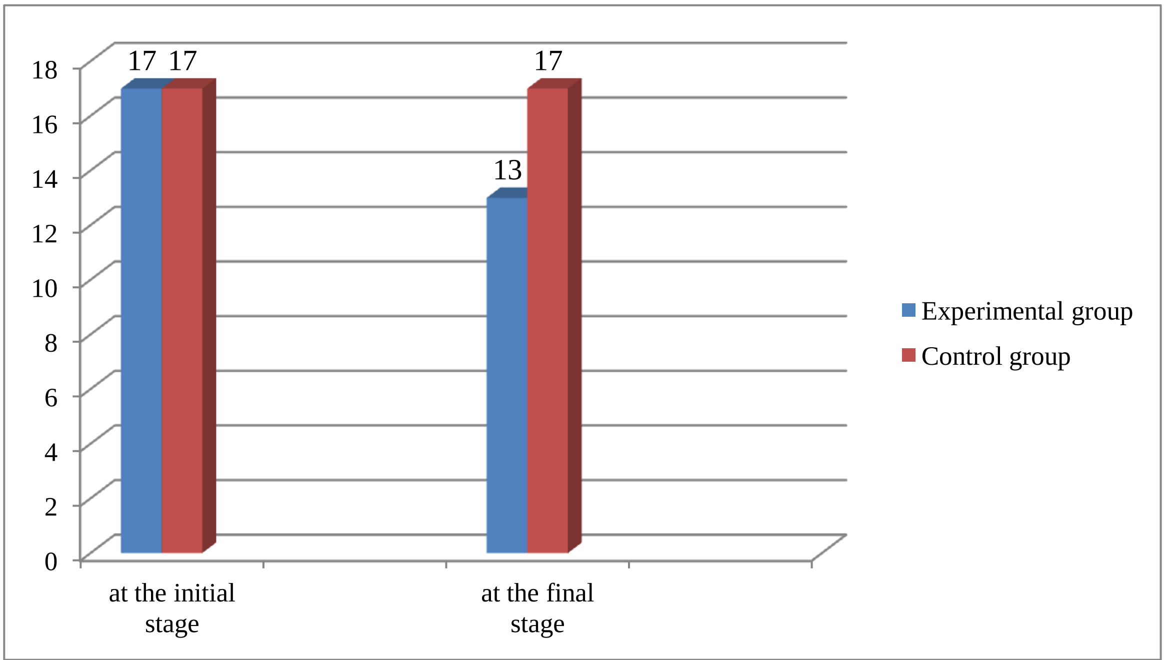

Figure 2. Dynamics of perceived physical exertion

Analyzing the diagram (Figure 2), it is important to note the identical initial level of the subjective assessment of physical exertion in both groups, characterized by the descriptor "very hard," with a numerical equivalent of 17 points. At the control stage of the experiment, following the integration of the Fit Radio music application into the educational process, the experimental group (EG) demonstrated a reduction in perceived exertion from 17 to 13 points, corresponding to the "somewhat hard" level. The range of 12 ("slightly hard") to 14 ("hard") is considered aerobic and physiologically safe, particularly in the context of physical education. A score of 13 in the EG indicates that the individual experiences strain but is still able to continue exercising. In contrast, the control group (CG) showed no change in the level of perceived physical exertion.

Conclusions

1) Psychological and emotional state of students.

The study using the PANAS questionnaire revealed that the integration of the Fit Radio music mobile application into the physical education curriculum significantly increased the level of positive affect (PA) in the experimental group (EG). After eight sessions, PA scores increased from low baseline values (21–22 points) to the normative level (31 points), reflecting a rise in positive emotions, energy, and student engagement in PE classes. At the same time, there was a substantial decrease in negative affect (NA) scores from 25 to 15 points, indicating reduced anxiety and emotional tension. In the control group (CG), no significant changes were recorded; PA and NA levels remained at the same level.

2) Subjective assessment of physical exertion.

According to the Borg Scale data, the initial level of perceived physical exertion in both groups corresponded to a high intensity (“very hard” — 17 points). By the end of the experiment, students in the EG reported a significant decrease in subjective fatigue (to 13 points), indicating a transition to the “somewhat hard” range, which is considered aerobic, physiologically safe, and conducive to optimal training adaptation. In the CG, the level of perceived physical exertion remained unchanged.

Recommendations:

- implementation of audio-musical technologies. The results of the study support the systematic use of music mobile applications (e.g., Fit Radio) in the organization of physical education classes. Audio-musical accompaniment contributes to the improvement of students’ emotional state, a reduction in anxiety levels, and an increase in the perceived attractiveness of physical activity.

- integration of MMAs to optimize the training process. Musical accompaniment enhances tolerance to physical exertion by reducing subjective feelings of fatigue and discomfort. This allows for the optimization of training intensity and duration, making sessions more effective and comfortable for learners.

- individual playlists support a personalized learning approach. When planning PE sessions, it is recommended to take into account students’ individual music preferences in order to maximize the positive effects on emotional well-being and physical exertion tolerance.

- monitoring and assessment of students’ condition during PE classes. To objectively assess and monitor psychophysiological states and exertion tolerance, it is advisable to regularly apply validated psychometric tools (PANAS and the Borg Scale) in the format of repeated measurements.

The integration of innovative music-based mobile solutions into PE sessions contributes to the development of stable positive motivation, reduction of anxiety, and optimization of the training process, which overall has a beneficial effect on the psychophysiological condition of students. Digital tools enhance the scientific and methodological foundation of physical training, support learners’ motivation and self-regulation, and make physical education more accessible and attractive to various social groups, including youth and university students.

Thus, this study, which explores the potential of music mobile applications as a means of increasing motivation, engagement, and the effectiveness of physical education, represents a relevant area of scientific inquiry aligned with the objectives of modernizing higher education and fostering a culture of healthy living among young people.

References

1 Hallam, S. (2010). The power of music: Its impact on the intellectual, social and personal development of children and young people. *International Journal of Music Education, 28*(3), 269–289. https://doi.org/10.1177/0255761410370658.

2 Zatorre, R.J. (2003). Music and the Brain. *The neurosciences and music, 999, 1,* 4–14. https://doi.org/10.1196/annals.1284.001.

3 Morrison, L.Ch. (2024). Laurier unveils innovative, updated Bachelor of Music program. Retrieved from https://www.wlu.ca/news/news-releases/2024/sept/laurier-unveils-innovative-updated-bachelor-of-music-program.html.

4 Clark, I.N., Baker, F.A., Peiris, C.L., Shoebridge, G., & Taylor, N.F. (2017). Participant-selected music and physical activity in older adults following cardiac rehabilitation: a randomized controlled trial. *Clin Rehabil, 31, 3,* 329–339. DOI: 10.1177/0269215516640864.

5 Osin, E.N. (2012). Izmerenie pozitivnykh i negativnykh emotsii: razrabotka russkoiazychnogo analoga metodiki PANAS [Measuring positive and negative emotions: development of a Russian-language analogue of the PANAS method] *Psikhologiia. Zhurnal VSHE — Psychology. JHSE,* 4, 28–29. Retrieved from https://psytests.org/emo/panas.html.

6 Trost, W., Frühholz, S., Cochrane, T., Cojan, Y., & Vuilleumier, P. (2015). Temporal dynamics of musical emotions examined through intersubject synchrony of brain activity. *Soc Cogn Affect Neurosci,* 10, 12. DOI: 10.1093/scan/nsv060.

7 Thoma, M.V., La Marca, R., Brönnimann, R., Finkel, L., Ehlert, U., et al. (2013). The Effect of Music on the Human Stress Response. Plos one, 8, 8, 258–269. https://doi.org/10.1371/journal.pone.0070156.

8 Rauscher, F., Shaw, G., & Ky, C. (1993). Music and spatial task performance. Nature, 365, 611–624. https://doi.org/10.1038/365611a0.

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Effects of swimming and running training on the physical condition and working capacity of students

The study aimed to assess the effects of swimming and track running training on the physical condition, physical fitness level, health coefficient, and working capacity of students. The experiment involved 50 male students with a mean age of 20.16±1.4 years, studying at a pedagogical university in Uzbekistan. Over a three-year period, their physical condition was monitored using morphofunctional methods, physical working capacity was evaluated through the Harvard step test, and physical fitness was assessed with standard control exercises for the development of basic physical qualities. The health coefficient was calculated based on heart rate, blood pressure, body mass, height, and age. Data processing was performed using mathematical and statistical methods, including the calculation of arithmetic mean, standard deviation, and the Student's t-test to determine the significance of differences. The results showed a positive dynamic in the development of physical qualities and working capacity in both groups; however, swimming training led to more pronounced improvements across most measured indicators. The level of physical condition and the health coefficient increased to a greater extent in the swimming group compared to the running group. The findings confirm the high effectiveness of cyclic aerobic exercises, particularly swimming, for improving students' health and enhancing their functional capabilities.

Keywords: physical exercises, physical working capacity, physical fitness, physical condition, health coefficient.

Introduction

The improvement of physical fitness and the promotion of health among university students remains one of the key objectives of state policy in the Republic of Uzbekistan. In the context of the modernization of the higher education system, special attention is given to the development of a high level of physical fitness, sports skills, and commitment to a healthy lifestyle among students. However, despite the efforts undertaken, the level of physical activity among students remains insufficient. The decline in motor activity is associated with increased academic workload, changes in lifestyle, and insufficient integration of aerobic exercises into university educational programs [1–4].

The problem of decreasing physical activity among young people is of a global nature. Studies conducted in European countries, the United States, and Asia also report a trend towards reduced motor activity among students, largely linked to urbanization, technological development, and lifestyle changes [5, 6]. In a number of countries, efforts are being made to incorporate systematic aerobic activities, such as running and swimming into educational programs, which significantly improves physical condition, endurance, and functional resilience among young people [7, 8].

Considering the above, conducting a comparative analysis of the effects of swimming and track running on the physical condition of students in the context of the Republic of Uzbekistan appears to be a timely and relevant task aimed at developing effective health-promoting technologies within the higher education system.

Scientific literature reflects a diversity of physical education methodologies based on the application of various forms and means of physical activity [3, 6, 7]. Particular attention is given to cyclic types of exercises, such as walking, running, and swimming, due to their proven effectiveness in enhancing aerobic capacity.

Training processes based on the use of cyclic aerobic loads contribute to improved coordination of movements, development of endurance, reaction speed, strength, and overall physical working capacity among students [9, 10].

At the same time, a number of studies have been limited to comparing the effects of different types of exercises based on a small set of indicators or without considering the characteristics of the study participants, which complicates the formation of a comprehensive understanding of the effectiveness of various types of physical activity within the framework of health-oriented physical education [5, 9].

Current evidence indicates that achieving a sustainable health-promoting effect requires systematic training involving large muscle groups, rhythmic activity of moderate to high duration, and predominantly aerobic energy supply mechanisms (Thomas et al., 2020; Boltobaev & Kostikova, 2022). In this context, a comparative study of the effects of swimming and track running on the physical condition and working capacity of students acquires special practical and scientific significance, given the differences in the movement mechanics and loading characteristics of these activities [7, 11].

The aim of this study is to evaluate the impact of systematic swimming and running training on students' physical fitness, physical condition, health coefficient, and physical working capacity. Special attention was given to analyzing the dynamics of basic physical qualities, changes in the level of physical condition, and determining the degree of effectiveness of these types of physical activities within the framework of student health promotion programs.

The objectives of the study included:

1. To analyze the dynamics of physical fitness development among students in both experimental groups.
2. To identify changes in the level of physical condition and physical working capacity during systematic training sessions.
3. To evaluate the effectiveness of swimming and track running exercises in improving students' physical condition, health coefficient, and functional capacities.

To achieve the stated aims and to address the research objectives, an experimental program was developed, based on the application of a set of morphofunctional, testing, and statistical methods for the assessment of students' physical condition.

Organization of the Study

The study was conducted at the Department of Physical Culture and Sports of a pedagogical university in Uzbekistan. The research included students selected according to the following criteria: mean age — 20.16±1.4 years; eligibility for the main medical group based on health status; initial level of physical condition determined through morphofunctional assessments using express methods of physical condition evaluation (Thomas et al., 2020); expressed interest in the selected types of physical and sports activities — swimming and track running; and prior motor experience reflecting the level of mastery of basic motor skills and their practical application [7].

All students who expressed a desire to participate in the experiment confirmed their basic proficiency in the relevant types of physical activity and experience in systematic training in the chosen sports. Following preliminary assessment, 50 first-year male students who met the established requirements and completed the full experimental program (attending at least 80 % of all sessions and participating in all control tests) were selected.

Training sessions were conducted twice a week, each lasting 90 minutes. Based on the students' preferences and the results of initial physical fitness assessments, two experimental groups were formed: the "Running" group (25 students), who engaged in track running training, and the "Swimming" group (25 students), who trained according to a health-promoting swimming program.

The selection of means and methods of physical training was based on the students' age, gender, health status, physical development, functional capabilities, and baseline fitness level. The experimental work spanned the entire academic period during which students attended the "Physical Culture" course, with control measurements conducted at the beginning and end of the training cycle.

Training in the "Running" group was based on the principle of gradual increase in aerobic load. At the initial stage, students engaged in mixed locomotion involving walking and running at varying paces and durations. This approach allowed for progressive adaptation of the cardiovascular and respiratory systems to increasing physical demands. Subsequently, the proportion of walking was reduced, and the focus shifted to running, with an emphasis on increasing the speed of covering a 1 km distance. As a result, after a twomonth preparatory phase, 45–50 minutes of continuous running no longer caused signs of fatigue or health deterioration among the students [7, 9].

The organization of training in the “Swimming” group was based on a comprehensive approach incorporating health-oriented swimming exercises using the front crawl, backstroke, and breaststroke techniques. Each session was structured into introductory, main, and concluding parts. The introductory part included general developmental exercises aimed at improving flexibility, preparatory exercises for mastering swimming techniques, and light cyclic loads, such as walking and running on land. The main part focused on learning and reinforcing swimming techniques, with gradual increases in distance and active swimming time. As students’ skills improved, sessions increasingly incorporated continuous swimming with short recovery periods in the water. The concluding part included strength exercises and special breathing exercises. All training sessions were standardized in terms of duration, intensity, and frequency according to the approved methodology [7, 9].

Methods and materials

A comprehensive methodology was applied in the study, incorporating morphofunctional tests, assessment of physical working capacity, physical fitness, and the general physical condition of the students. Physical working capacity was determined using the Harvard Step Test and the calculation of the Harvard Step Test Index (HSTI), allowing for the evaluation of the recovery rate of the cardiovascular system following a standardized physical load (Thomas et al., 2020).

The health coefficient was calculated based on morphofunctional data using heart rate, blood pressure, body mass, height, and age, according to the approved formula [11].

Physical fitness was assessed through control tests reflecting the development level of major physical qualities, such as strength, endurance, speed, and coordination [6]. Physical condition was evaluated based on morphofunctional indicators using modern express-assessment techniques [7].

Statistical analysis of the results included the calculation of the arithmetic mean, standard deviation, and application of the Student’s t-test to determine the statistical significance of differences between groups (Borg, 2019).

A comparative analysis of the influence of swimming and running activities on students’ physical fitness, general physical condition, and health coefficient enabled an objective evaluation of the dynamics of changes throughout the experiment.

Thus, the applied set of methods ensured a comprehensive evaluation of the investigated indicators and provided a solid foundation for interpreting the obtained results.

Results and Discussion

An analysis of the dynamics of heart rate (HR) during the preparatory phase of the training sessions allowed for the assessment of the adequacy of the “internal” load in both experimental groups. The HR indicators of students engaged in track running and swimming showed a consistent increase throughout the session, as presented in Table 1.

Table 1

Pulse Cost of Load During the Preparatory Phase of the Session in Experimental Groups at the First Stage of the Main Period

Group	Start of session	5th minute	10th minute	15th minute	20th minute
Running	69.2±4.5	86.1±5.8	96.5±8.1	106.7±6.7	117.2±5.8
Swimming	69.9±4.1	84.8±3.5	98.3±5.9	109.1±3.9	118.3±7.5

As can be seen from the data in Table 1, a gradual increase in HR was observed in both groups, reflecting a normal physiological response to the growing physical load. The differences between the groups, according to the t-test results, were not statistically significant ($p > 0.1$). At the same time, the load in the main part of the session caused an increase in heart rate up to 150–170 beats per minute, regardless of the type of exercise. Thus, despite differences in the structure of physical activity, cardiovascular responses in students of both groups were similar.

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At the beginning of the experiment, the physical condition of students in both groups was homogeneous for almost all measured indicators, except for the results of the “shuttle run” test. The level of development of students’ physical qualities is presented in Tables 2 and 3.

Table 2

Indicators of Students’ Physical Fitness at the Beginning and End of the Experiment

No.	Indicators	Running (Start)	Running (End)	Swimming (Start)	Swimming (End)
1	Speed (shuttle run 10×10 m, sec)	24.87±1.85	25.01±1.45	25.91±1.24	25.93±1.55
2	Handgrip strength (dynamometry, kg)	51.6±4.85	55.5±4.66	50.8±2.71	52.7±2.8
3	Muscular endurance (pull-ups, reps)	14±2.75	16±2.55	13.5±2.33	14.7±2.5
4	General endurance (1000 m run, min)	3.51±0.23	2.88±0.44	3.25±0.28	3.05±0.21
5	Adaptation level to physical load (Harvard step test, arbitrary units)	79.33±9.87	80.75±9.66	80.15±10.5	82.33±10.55

The results in Table 2 demonstrate a positive dynamic in the development of physical qualities in both groups. When comparing the 1000-meter running times, improvements were observed in both groups: 3.05±0.21 sec in the swimming group and 2.88±0.44 sec in the running group, with statistically significant differences between the groups. Statistically significant differences were also established in the “shuttle run” test results, where the students in the running group demonstrated higher speed levels (Table 3).

Table 3

t-Test Values Between the Experimental Groups “Running” and “Swimming” in the Study of Students’ Physical Fitness Levels

No.	Indicators	Groups	Mean Values	t-test
1	Speed (shuttle run 10×10 m, sec)	Running / Swimming	24.87±1.85 / 25.91±1.24	1.37
		Running / Swimming	25.01±1.45 / 25.93±1.55	5.12*
2	Handgrip strength (dynamometry, kg)	Running / Swimming	51.6±4.85 / 50.8±2.71	0.26
		Running / Swimming	55.5±4.66 / 52.7±2.8	1.48
3	Muscular endurance (pull-ups, reps)	Running / Swimming	14±2.75 / 13.5±2.33	0.43
		Running / Swimming	16±2.55 / 14.7±2.5	2.41*
4	General endurance (1000 m run, min)	Running / Swimming	3.51±0.23 / 3.25±0.28	4.05*
		Running / Swimming	2.88±0.44 / 3.05±0.21	5.6*

*Note**. Statistically significant differences.

As shown in Table 3, most indicators of physical fitness demonstrated positive dynamics, particularly pronounced in the “Running” group. Changes in the physical condition of students in the experimental groups are indicated in Table 4.

Table 4

Students’ Physical Condition Level at the Beginning and End of the Experiment (%)

Group	High (start)	Above average (start)	Average (start)	Below average (start)	Low (start)	High (end)	Above average (end)	Average (end)	Below average (end)	Low (end)
Swimming	6.4	32.9	44.9	11.2	3.6	9.3	38.9	34.8	12.2	2.7
Running	6.7	33.8	43.92	12.0	3.3	9.1	37.8	36.9	12.1	2.9

The data in Table 4 show that both groups experienced positive changes in students’ physical condition levels. In the “Swimming” group, the increase in students with a high level of physical condition was 2.9 %, while in the “Running” group it was 2.4 %. As illustrated in Figure 1, the dynamics of changes in the level of physical condition were positive in both groups.

Thus, the conducted analysis allows us to conclude that both swimming and track running had a beneficial effect on the students' physical condition. However, the effectiveness of health-promoting swimming activities was somewhat higher, as evidenced by a greater increase in the proportion of students with a high level of physical condition and a decrease in the proportion of students with low indicators.

Physical working capacity is an important indicator of the body's functional state, reflecting a person's ability to perform specified physical work with minimal physiological costs while achieving maximum results. The assessment of students' physical working capacity was carried out using the Harvard Step Test (HSTI), which determines the recovery rate of the cardiovascular system after a standardized physical load. The dynamics of students' physical condition during the experiment are presented in Figure 1.

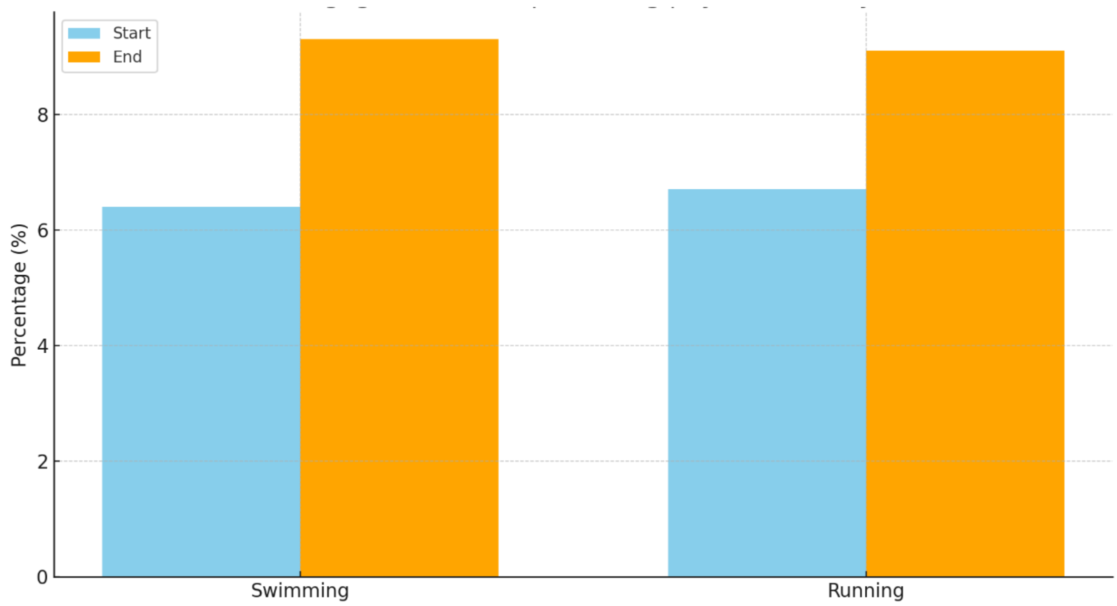

Figure 1. Physical condition level ("Above Average") of students engaged in health-promoting physical activity

Note. White cells indicate the beginning of the experiment; grey cells indicate the end; differences are not statistically significant.

The results of the Harvard Step Test Index (HSTI) calculations are demonstrated in Table 5.

Table 5

Level of Physical Performance of Students at the Beginning and End of the Experiment

Indicator	Group	Mean Value	t-test
Physical performance level (Harvard Step Test, arbitrary units)	Running	77.45±9.86 / 78.97±9.59	0.21 / 0.76
	Swimming	79.44±10.45 / 80.97±10.33	—

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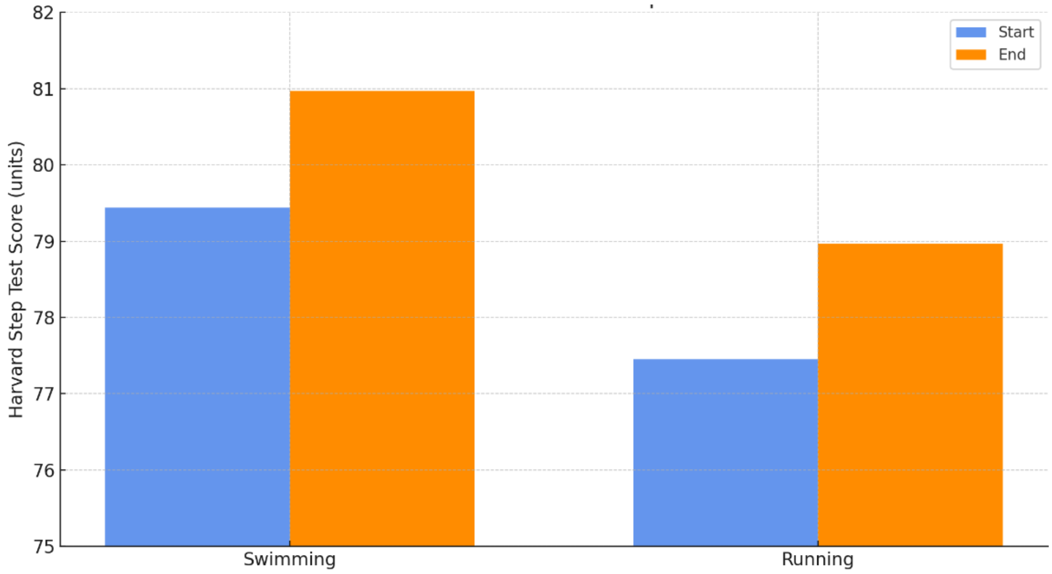

Figure 2. Students' Physical Performance Level

The analysis of the given data shows that the level of physical working capacity in the "Swimming" group was slightly higher compared to the "Running" group; however, no statistically significant differences between the groups were found. The visualization of the results is shown in Figure 2.

Additionally, an assessment of the students' health coefficient (HC) was conducted. Calculations were performed using the following formula:

HC = 0.01HR + 0.01SBP + 0.008DBP + 0.014A + 0.009BM − 0.009H − 0.27

where:

HR — heart rate,

SBP — systolic blood pressure,

DBP — diastolic blood pressure,

A — age,

BM — body mass,

H — height.

The mean health coefficient values were 2.115±0.19 in the "Swimming" group and 2.131±0.15 in the "Running" group. Differences between the groups were found to be statistically non-significant (Figure 3).

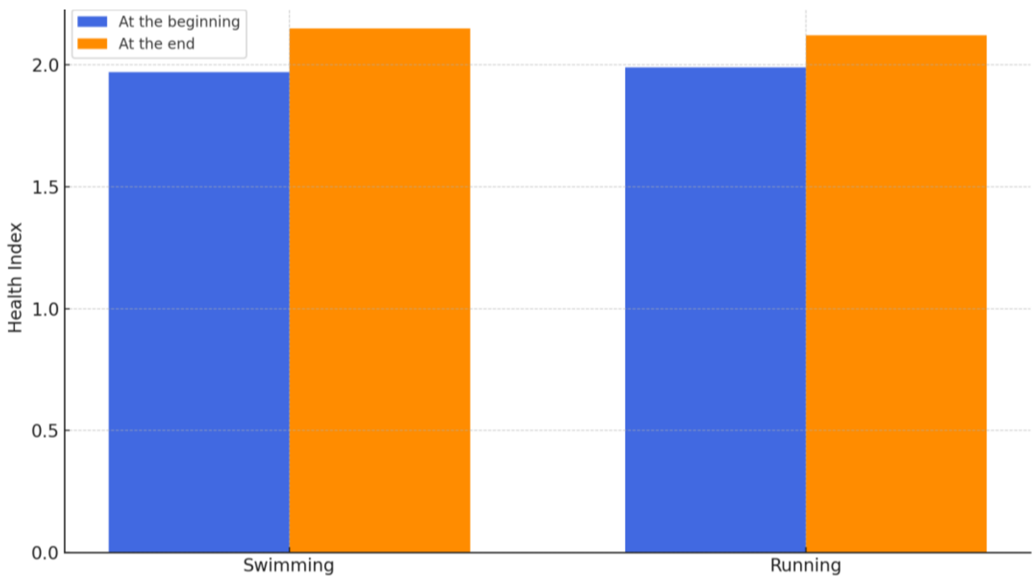

Figure 3. Health Index Indicators in the Experimental Groups

Summarizing the results, it can be noted that regular aerobic-oriented activities, regardless of the selected type of physical exercise, contribute to the improvement of students' physical working capacity and functional state. However, more pronounced positive trends were observed in the swimming group. These findings confirm the effectiveness of the systematic use of health-promoting swimming activities within the framework of university physical education programs.

Conclusions

The conducted study confirmed the high effectiveness of systematic aerobic-oriented physical training in improving the physical fitness, physical condition, and working capacity of students. The experimental results are consistent with current scientific findings emphasizing the important role of cyclic types of exercise, such as swimming and running, in developing the body's functional resilience [5–7].

The analysis of heart rate dynamics, physical fitness levels, physical condition, and health coefficient demonstrated positive changes in both experimental groups. Regular physical loads contributed to the activation of adaptive processes, which manifested in the improvement of key physiological indicators, a finding also confirmed by previous studies [3, 12].

The greatest effect was observed among students engaged in health-promoting swimming. This group showed a more pronounced positive dynamic in the development of physical qualities, improvement in physical working capacity, and enhancement of the health coefficient. These results align with the findings of Tanaka and Swensen (2022), who emphasized the significant health-promoting impact of regular swimming practice [13].

The comprehensive evaluation of the obtained data allows the conclusion that the inclusion of aerobic-oriented exercises, especially swimming, in university physical education programs is highly advisable:

1. The development of physical qualities showed positive dynamics in both experimental groups, with a greater increase in results by the end of the experiment observed among students in the "Swimming" group.
2. The dynamics of physical condition and working capacity were positive in both studied groups. However, the level of physical working capacity was slightly higher in the group engaged in health-promoting running, whereas the health coefficient and physical condition level were more pronounced in the "Swimming" group.
3. The most effective physical exercises contributing to the improvement of students' physical condition and working capacity were health-promoting swimming activities. The increase in the proportion of students with a high level of physical condition was 2.9 % in the "Swimming" group, compared to 2.4 % in the "Running" group.

The obtained results highlight the importance of aerobic exercises within the educational environment, particularly in shaping a healthy lifestyle and enhancing students' functional readiness. The integration of health-promoting swimming into university physical education programs appears to be a promising direction for strengthening students' health and fostering sustainable active lifestyle habits.

References

1 Azizov, N.N., Gaziyey, N.R., Boltobaev, S.A., & Zhakhangirov, S.Z. (2019). Studying the attention and specifically stressogenous conditions of sportsmen. *Scientific Bulletin of Namangan State University,* 1(3), 303–306.

2 Kholodov, Zh.K. (2012). Teoriia i metodika fizicheskoi kultury [*Theory and methodology of physical culture and sports]. Moscow: Akademiia — Academy* [in Russian].

3 Barber-Westin, S.D., Noyes, F.R., & Smith, S.T. (2019). Improving aerobic fitness and muscular endurance in young athletes: Training recommendations. *Sports Health,* 11(4), 280–286. https://doi.org/10.1177/1941738119846107.

4 Rice, L.A., & Thombs, L.A. (2021). Strategies for enhancing students' aerobic capacity through physical education programs. *Pediatric Exercise Science,* 33(1), 30–36. https://doi.org/10.1123/pes.2020-0074.

5 Johnson, S.T., & Doherty, T.J. (2021). The role of endurance exercise in health promotion among young adults. *Journal of Physical Activity and Health,* 18(2), 129–137. https://doi.org/10.1123/jpah.2020-0321.

6 Krustrup, P., & Bangsbo, J. (2020). Physical fitness and performance improvements with recreational football. *Scandinavian Journal of Medicine & Science in Sports,* 30(S1), 70–79. https://doi.org/10.1111/sms.13599.

7 Thomas, E., Bianco, A., Pomara, F., & Palma, A. (2020). The importance of aerobic exercise for physical fitness and student health. *International Journal of Environmental Research and Public Health,* 17(5), 1715. https://doi.org/10.3390/ijerph17051715.

8 Tanaka, H., & Swensen, T. (2022). Impact of swimming training on cardiovascular health and fitness in youth. *Current Sports Medicine Reports,* 21(2), 50–56. https://doi.org/10.1249/JSR.0000000000000910.

9 Boltobaev, S.A., Muzaffarova, L.M., Azizov, S.V., & Mirzaev, S. (2019). Dvizheniia v bege na dlinnye distantsii i marafone kak sredstvo preodoleniia travm begunov [Movements in long-distance running and marathon as overcoming runners' injuries]. *Nauka i mir — Science and World,* 1(12), 37–39 [in Russian].

10 Muller, A.B., Dyadichkina, N.S., Bogashchenko, Yu.A., Bliznevskiy, A.Yu., & Ryabinina, S.K. (2013). Fizicheskaia kultura: Uchebnik dlia vuzov [*Physical culture: Textbook for universities]*. Moscow: Yurait [in Russian].

11 Boltobaev, S.A., & Kostikova, O.V. (2022). Age features of physical development parameters and component composition of the body of young urban athletes. *World Bulletin of Public Health,* 17, 80–86. https://doi.org/10.37547/ejmph/Volume17Issue4-12.

12 Rice, L.A., & Thombs, L.A. (2021). Strategies for enhancing students' aerobic capacity through physical education programs. *Pediatric Exercise Science,* 33(1), 30–36. https://doi.org/10.1123/pes.2020-0074.

13 Tanaka, H., & Swensen, T. (2022). Impact of swimming training on cardiovascular health and fitness in youth. *Current Sports Medicine Reports,* 21(2), 50–56. https://doi.org/10.1249/JSR.0000000000000910.

References

1 Azizov N.N. Studying the attention and specifically stressogenous conditions of sportsmen / N.N. Azizov, N.R. Gaziyev, S.A. Boltobaev, S.Z. Zhakhangirov // Scientific Bulletin of Namangan State University. — 2019. — 1(3). — P. 303–306.

2 Холодов Ж.К. Теория и методика физической культуры / Ж.К. Холодов. — М.: Академия, 2012.

3 Barber-Westin S.D. Improving aerobic fitness and muscular endurance in young athletes: Training recommendations / S.D. Barber-Westin, F.R. Noyes, S.T. Smith // *Sports Health. — 2019.* — 11(4). — P. 280–286. https://doi.org/10.1177/1941738119846107.

4 Rice L.A. Strategies for enhancing students' aerobic capacity through physical education programs / L.A. Rice, L.A. Thombs // Pediatric Exercise Science. — 2021. — 33(1). — P. 30–36. https://doi.org/10.1123/pes.2020-0074.

5 Johnson S.T. The role of endurance exercise in health promotion among young adults / S.T. Johnson, T.J. Doherty // Journal of Physical Activity and Health. — 2021. — 18(2). — P. 129–137. https://doi.org/10.1123/jpah.2020-0321.

6 Krustrup P. Physical fitness and performance improvements with recreational football / P. Krustrup, J. Bangsbo // Scandinavian Journal of Medicine & Science in Sports. — 2020. — 30(S1). — P. 70–79. https://doi.org/10.1111/sms.13599.

7 Thomas E. The importance of aerobic exercise for physical fitness and student health / E. Thomas, A. Bianco, F. Pomara, A. Palma // International Journal of Environmental Research and Public Health. — 2020. — 17(5). — P. 1715. https://doi.org/10.3390/ijerph17051715.

8 Tanaka H. Impact of swimming training on cardiovascular health and fitness in youth / H. Tanaka, T. Swensen // Current Sports Medicine Reports. — 2022. — 21(2). — P. 50–56. https://doi.org/10.1249/JSR.0000000000000910.

9 Болтобаев С.А. Движения в беге на длинные дистанции и марафоне как средство преодоления травм бегунов / С.А. Болтобаев, Л.М. Музафарова, С.В. Азизов, С. Мырзаев // Наука и мир, 2019. — 1(12). — С. 37–39.

10 Муллер А.Б. Физическая культура: Учебник для вузов / А.Б. Муллер, Н.С. Дядичкина, Ю.А. Богащенко, А.Ю. Близневский, С.К. Рябинина. — М.: Юрайт. — 2013.

11 Boltobaev S.A. Age features of physical development parameters and component composition of the body of young urban athletes / S.A. Boltobaev, O.V. Kostikova // World Bulletin of Public Health. — 2022. — 17. — P. 80–86. https://doi.org/10.37547/ejmph/Volume17Issue4-12.

12 Rice L.A. Strategies for enhancing students' aerobic capacity through physical education programs / L.A. Rice, L.A. Thombs // Pediatric Exercise Science. — 2021. — 33(1). — P. 30–36. https://doi.org/10.1123/pes.2020-0074.

13 Tanaka H. Impact of swimming training on cardiovascular health and fitness in youth / H. Tanaka, T. Swensen // Current Sports Medicine Reports. — 2022. — 21(2). — P. 50–56. https://doi.org/10.1249/JSR.0000000000000910.

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Features of EEG and EMG Signals Before and After Different Forms of Isokinetic Contraction of the Upper Limb Muscle of Male Basketball Players

This study explores the differences between peripheral fatigue and central fatigue after eccentric and concentric contraction fatigue. Eight male basketball student-athletes were selected as study subjects, with an age of 20.0±1.2 years, height 190.3±7.6 cm and weight 90.1±5.8 kg. Each subject was required to perform 10 sets of 10 eccentric and concentric contraction fatigue tests at equal speeds. During equal-speed training, EMG signals of the biceps and triceps were recorded simultaneously. Centrifugal contraction was performed one week after centriolar contraction. The EMG signal and EEG signal were processed and analyzed using the MR3 EMG signal analysis software and MATLAB. Paired sample t-test was conducted for peak torque before and after isokinetic contraction, EMG, MF, MPF of EMG signal and power spectrum ratio of EEG signal in each frequency band. One-way ANOVA was conducted for each index after centripetal contraction and eccentric contraction. The inflection point of the peak moment of isokinetic muscle force is basically the same as that of the electromyographic signal. The fatigue time of centripetal contractile muscles is earlier than that of centrifugal contractile muscles, and the degree of peripheral fatigue after centripetal contractile muscles is obviously higher than that of centrifugal contractile muscles. The degree of central fatigue after centrifugal motion is greater than that after centripetal contraction.

Keywords: exercise-induced muscle fatigue, concentric contractions, eccentric contractions, EMG, EEG.

Introduction

Exercise-induced muscle fatigue results from a transient decrease in the maximal voluntary contraction capacity (MVC) of the muscles engaged in exercise due to excessive exertion [1, 2]. It is a prominent research topic in exercise training and physiology [3]. According to the different physiological parts of fatigue, it can be classified as central fatigue and peripheral fatigue [4]. Central fatigue can be attributed to the degree of active activation of nerves and a reduction in the ability of nerve impulses to generate fatigue signals, which in turn create a psychological resistance response. Peripheral fatigue, in contrast, is the decline in musculoskeletal motor function caused by excessive exercise [5]. Both types of physiological fatigue directly affect athletes' balance ability, muscle control ability, movement accuracy and so on, thereby significantly impacting sports performance. The effective regulation of athletes' neuromuscular systems has become the way for athletes to choose their own training methods [6]. Currently, EEG and EMG can be used to evaluate human exercise fatigue [7]. It has been shown that there is a large change in the threshold in the EMG signal after exercise fatigue in humans [8], and the EEG signal changes accordingly with body fatigue [9]. The synchronous coordination of EEG, EMG and sports can provide a better theoretical basis for athletes' training.

At present, some scholars [10–12] have combined isokinetic training instruments with surface electromyography technology to study the functional characteristics of muscles, such as the changes in muscle peak torque and EMG time domain indexes (iEMG, RMS, etc.) and frequency domain indexes (MF, MPF, etc.) during isokinetic training. However, few scholars combine isokinetic training systems with EMG and EEG testing systems to observe the physiological changes in athletes after exercise fatigue. Therefore, muscle fatigue is induced by different forms of isokinetic training with centrifuge and centrifuge; the changes in EMG and EEG signals on the surface of the lower limbs before and after muscle fatigue are detected. The two signals are analyzed synchronously with the isokinetic testing system, and the difference in fatigue mechanism between centrifugal and centrifugal isokinetic contraction is discussed, which provides a reference for scientific training of upper limb muscle strength of athletes.

Materials and methods

1 Research subjects

Eight male basketball student-athletes, aged 20.0 ±1.2 years, height 190.3 ±7.6 cm and weight 90.1 ±5.8 kg, were recruited as subjects. All subjects had healthy upper limb joints, no history of brain injury, regular routine of work and rest for nearly three months, and no strenuous exercise within 72 hours before the experiment. All subjects signed informed consent forms before the experiment.

2 Experimental instruments

The PHYSIOMED CON-TREX MJ Multi-Joint Isokinetic Training System (Germany) was used to induce upper limb muscle fatigue in the subjects. The occurrence time of muscle fatigue was determined by measuring the peak torque.

EMG signal of subjects during isokinetic contraction was measured by a Noraxon surface EMG tester (USA), which included a wireless data receiving box, surface electromyogram acquisition module, electrode piece and data line, and the sampling frequency was 1000 Hz. The surface electromyographic signals of the biceps brachii and triceps brachii were measured and recorded during centripetal and centrifugal isokinetic flexion and extension of the elbow joint.

EEG signals of subjects before and after fatigue during isokinetic centrifugal and centrifugal exercise were recorded using the BP-32 electroencephalogram signal acquisition system produced by Brain Products, Germany. The hardware includes 32 conductive caps, amplifiers, external power supplies and computers, and the software includes BP Recorder 2.0 signal acquisition software and EEGLAB signal processing analysis software (Figure 1).

Figure 1. Display diagram of experimental equipment and test site example

2.1 Experimental procedure

2.2 Isokinetic muscle strength training and testing

The elbow joint of the subject was fixed according to the operation manual of the Con-Trex MJ isokinetic training system, and the subject was required to complete each flexion and extension with maximum strength. The test mode was “elbow flexion and extension isokinetic — normal”, the movement mode was "centripetal — centripetal", the test speed was 60 °/s, 10 groups ×10 times, rest between groups for 1 min, and the movement range was 60 °. At an interval of one week, the same test method was used to induce muscle fatigue training in the "centrifugal — centrifugal" exercise mode, and the surface EMG signals were recorded at the same time. After 1 min of rest after exercise, EEG signals were collected immediately.

2.3 Collection and Processing of EEG Signals

EEG signals before exercise and EEG signals after 10 groups × 10 isokinetic centripetal and centrifugal movements were collected from each subject 3 times. The preparation was completed before the experiment in strict accordance with the requirements. The impedance of each channel is less than 10 KΩ, and the sampling frequency is 1000 Hz.

2.4 EMG signal acquisition and processing

Acquisition: The subjects of this experiment were collected twice with an interval of one week, which were 10 groups ×10 isokinetic centripetal and isokinetic centrifugal motions. The dominant side of the upper limb of the subjects was the right side, so the right biceps brachii and triceps brachii were selected for testing. After 75 % medical alcohol disinfects the tested part, the electrode piece is stuck along the muscle fiber. The center distance between the two electrodes was approximately 2 cm. Connect the electrode and the amplifier with wires. Checking the signal, the subjects carry out the active muscle force and collect the surface EMG signal.

Processing: full wave rectification, smoothing, filtering and "normalization" of EMG signals by the ratio of EMG amplitude to maximum peak torque are performed on the collected EMG signals.

2.5 Statistical analysis

Statistical statistics were performed using SPSS 20.0. Data are reported as the mean ± standard deviation (SD). Images were processed by use of Graphpad Prism 5 (GraphPad Software, La Jolla, CA, United States) and Adobe Photoshop (Adobe, San Jose, CA, United States). Student's t-test was used for analysis between two groups with only one factor involved. A one-way ANOVA was used for analysis when more than two treatments were compared. Significant differences were established at $p < 0.05$.

Results

3 Changes in force parameters during isokinetic contractions of different forms

Processing for averaging the calculation of the peak moment of isometric contraction movement for the subject 10 times/group yielded the peak moment average/group. Trends in peak moment changes during isometric contraction of the subject's biceps brachii with triceps, as shown in Figure 2A, elbow flexors and extensors both showed a tendency to peak moment drops during centripetal versus eccentric contractions with significant inflection points. Contrasting the centripetal versus the peak moment change during eccentric contraction for biceps and triceps reveals that the time to peak moment change during eccentric contraction lags behind that during centripetal contraction (Figure 2).

Contrasting the peak moment values before and after the peak moment drop inflection points during isometric contraction of biceps and triceps (Table 1), there was a significant difference in peak moment values before and after the peak moment drop inflection points between elbow flexors and extensors when they performed centripetal and centrifugal contractions ($P < 0.05$). Therefore, it was judged that the muscle might have developed fatigue after the peak moment showed an obvious descending inflection point.

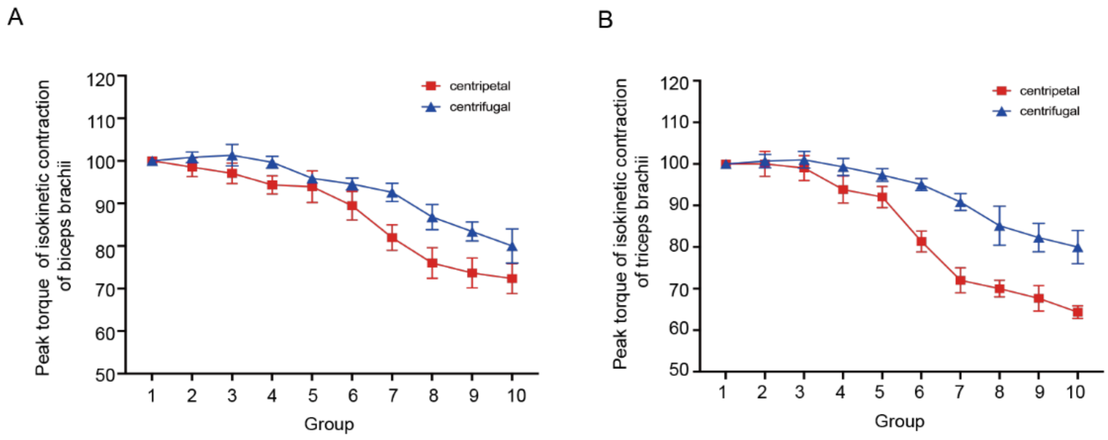

Figure 2. Variation in the peak torque of isokinetic contractions of the biceps and triceps brachii

Table 1

Comparison of the isokinetic peak contraction moment of the biceps and triceps brachii before and after inflection point (Nm)

		Before inflection point	After inflection point	t	P
biceps	centripetal	44.1±6.2	35.8±5.3	2.878	0.012
	centrifugal	42.5±5.2	36.8±4.2	2.413	0.03
triceps	centripetal	34.5±5.2	27.6±4.5	2.832	0.013
	centrifugal	39.8±4.2	34.6±4.9	2.279	0.039

3.1 Changes in sEMG parameters during different forms of isokinetic contraction

3.1.1 iEMG changes during isokinetic contraction

Based on the data of integrated EMG values after normalization to the brachial biceps, it was found that the inflection point of the change in integrated EMG values of the biceps in centripetal contraction appeared significantly earlier than that of the inflection point in eccentric contraction (Figure 3A). Based on the changes in integrated EMG values after normalization to the triceps, it was concluded that the inflection point of the rise of integrated EMG values during centripetal contraction was earlier than that during eccentric contraction (Figure 3B).

When the biceps brachii were subjected to centripetal and eccentric contraction, respectively (Table 2), the iEMG after the emergence of the inflection point was all significantly higher than that before the inflection point ($P < 0.05$); When the triceps brachii underwent centripetal contraction (Table 2), the iEMG after the inflection point was significantly higher ($P < 0.01$) than that before the inflection point, and the iEMG after the inflection point increased ($P < 0.05$) during isometric eccentric contraction. The biceps brachii gradually developed fatigue after performing group 6 isometric centripetal contraction exercise and group 8 isometric centrifugal exercise, respectively; Triceps brachii developed muscle fatigue after group 6 isometric centrifugation exercise and group 7 isometric centrifugal exercise, respectively (Figure 3). The inflexions of the iEMG changes of the biceps and triceps centripetally were all found to occur significantly earlier than the inflexions of their respective eccentric contractions.

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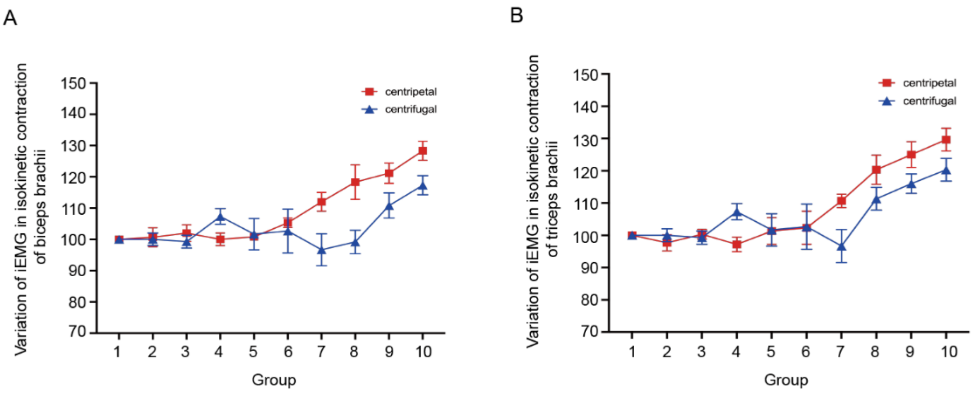

Figure 3. Variation of iEMG in isokinetic contractions of biceps and triceps brachii

Table 2

Comparison of isokinetic iEMG of biceps and triceps brachii before and after inflection point (uV*s)

		Before inflection point	After inflection point	t	P
biceps	centripetal	163.1±20.2	194.8±23.3	2.908	0.011
	centrifugal	151.5±18.3	171.8±16.2	2.349	0.034
triceps	centripetal	168.5±18.9	208.6±28.3	3.332	0.005
	centrifugal	163.8±20.3	195.8±23.9	2.886	0.012

According to the following formulas, the iEMG growth rate after different forms of isometric contraction-induced muscle fatigue was calculated, and using one-way ANOVA, we concluded that the iEMG growth of biceps and triceps after isometric centrifugation contraction-induced muscle fatigue were both significantly larger than the growth value after isometric centrifugal contraction ($P < 0.01$), so the degree of muscle fatigue was greater after isometric centrifugation contraction (Fig.4A). The time to fatigue of the muscle during isometric centripetal contraction is significantly earlier than the time to fatigue of the muscle during isometric centrifugal contraction (Figure 3). Thus, isometric centripetal contraction is more prone to peripheral muscle fatigue.

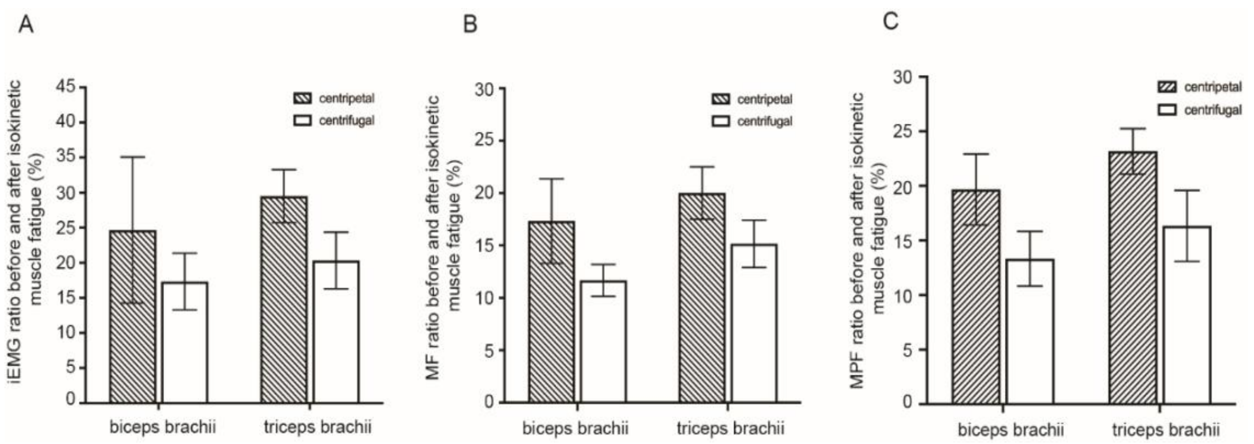

Figure 4. Rate of iEMG, MF and MPF before and after isokinetic muscle fatigue in different forms

Calculation formula: R_{iEMG} = [iEMG (10) — iEMG (1)] iEMG (1);

Note: R_{iEMG} represents the rate of integral EMG growth, iEMG (10) represents the integrated EMG of the tenth set of isokinetic movements, and iEMG (1) represents the integrated EMG of the first set of isokinetic movements.

3.1.2 MF changes during isokinetic contraction

The time inflexions of the change in the median frequency of centripetal contractions of both biceps and triceps were significantly earlier than those of eccentric contractions (Figure 5). The normalized MFS after the appearance of the inflexion point was significantly lower than that before the inflexion point ($P < 0.05$), and the tendency for the MF to decrease was largely consistent with its peak moment as well as with the inflexion point at the appearance of the iEMG (Table 3). Taken together, the decreasing trend of MF in EMG indicates fatigue phenomenon in muscle.

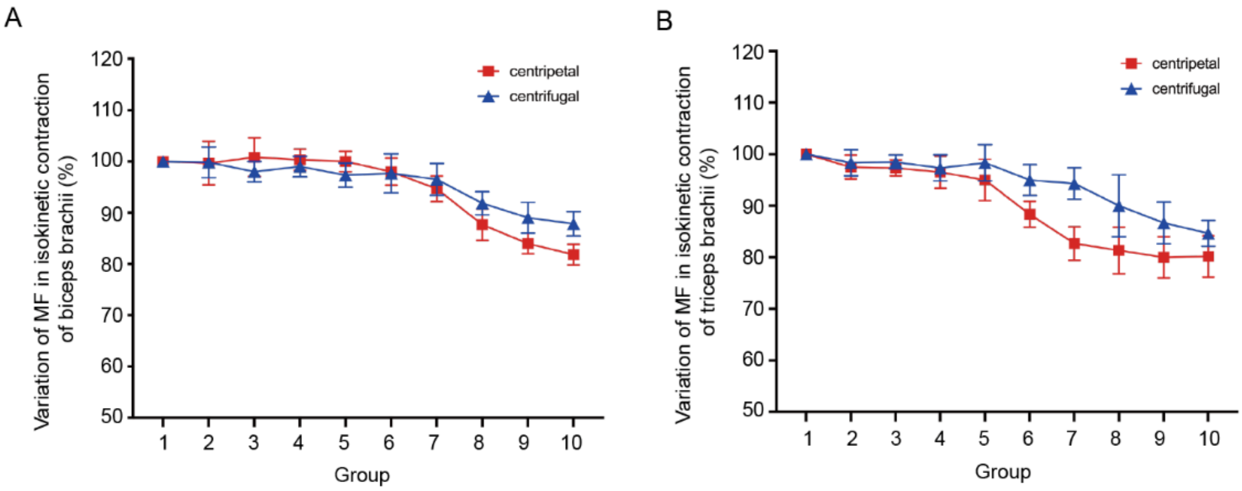

Figure 5. Variation of MF in the isokinetic contractions of biceps and triceps brachii

Table 3

Comparison of the isokinetic MF of the biceps and triceps brachii before and after the inflection point (Hz)

		Before inflection point	After inflection point	t	P
biceps	centripetal	63.2±9.6	51.3±8.2	2.665	0.018
	centrifugal	64.1±8.3	55.4±7.8	2.16	0.048
triceps	centripetal	65.4±10.2	52.3±7.1	2.981	0.009
	centrifugal	64.5±9.8	54.3±7.8	2.303	0.037

According to the following formula, the decline rate of the median frequency of the EMG signal after different forms of isokinetic contraction induced muscle fatigue was calculated (Figure 4), and one-way ANOVA was performed to conclude that the decline of the median frequency of biceps and triceps after isokinetic contraction induced muscle fatigue were both larger than that after isokinetic centrifugal contraction ($P < 0.01$), so the degree of muscle fatigue was greater after isokinetic centrifugation contraction. The fatigue time that the muscles appeared during isometric centripetal contraction was significantly earlier than that during isometric centrifugal contraction (Figure 5), and this result was basically consistent with the iEMG results of the elbow flexor and extensor muscle groups. Therefore, isometric centripetal contraction is more likely to produce peripheral muscle fatigue than isokinetic centrifugal contraction.

Calculation formula: : R_{MF}=[MF(1)-MF(10)]/MF(1)

Note. RMF represents the median frequency rate of decline, MF (10) represents the median frequency of the tenth set of isokinetic movements, and MF (1) represents the median frequency of the first set of isokinetic movements.

3.2.3 MPF changes during isokinetic contraction

During progressive centripetal and eccentric contractions, the normalized mean power frequency (MPF) of the biceps and triceps showed an overall gradual decline with significant inflection points. The MPF values after the appearance of the inflexion point were significantly lower than those before the inflexion point ($P < 0.05$), largely consistent with their inflexions in iEMG and MF values (Table 4), and the change in MPF

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during centripetal contraction occurred significantly earlier than the inflexion point during eccentric contraction (Figure 6), a result that was identical to the change in MF after fatigue during isometric contraction.

Table 4

Comparison of the isokinetic MF of biceps and the triceps brachii before and after the inflection point (Hz)

		Before inflection point	After inflection point	t	P
biceps	centripetal	94.1±17.5	77.3±13.2	2.168	0.048
	centrifugal	104.1±15.6	88.4±12.7	2.207	0.045
triceps	centripetal	96.5±16.2	75.3±10.5	3.106	0.008
	centrifugal	105.5±17.1	85.3±11.2	2.795	0.014

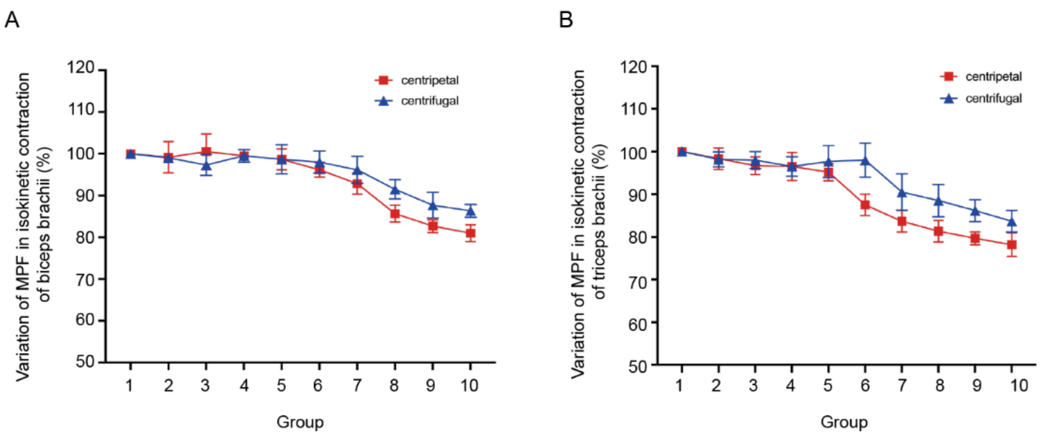

Figure 6. Variation of MPF in isokinetic contractions of biceps and triceps brachii

According to the following formula, to calculate the decline rate of the MPF value of the electromyographic signal (Figure 4C), The decrease in the average power frequency of the biceps and triceps after muscle fatigue caused by isometric cardiac contraction was significantly greater than that caused by isometric cardiac contraction (*P* < 0.01). In other words, muscle fatigue was greater after isometric centrifugation contraction. The time that the muscle developed fatigue during isometric centripetal contraction was significantly earlier than that during isometric centrifugal contraction (Figure 6); this result was consistent with the muscle contraction EMG signal iEMG and MF results. Thus, isometric centripetal contraction is more prone to fatigue in peripheral muscles than isokinetic eccentric contraction.

Calculation formula: : R_{MPF}=[MPF(1)-MPF(10)]/MPF(1) ;

Note. R_{MPF} represents the average rate of power frequency decline, MPF (10) represents the average power frequency of the tenth set of isokinetic movements, and MPF (1) represents the average power frequency of the first set of isokinetic movements.

3.3 Changes in EEG parameters before and after different forms of isokinetic contraction

3.3.1 EEG power spectral changes before and after isokinetic contraction

The subjects underwent EEG signal acquisition and processing in triplicate before, after centripetal, and after eccentric exercise, to derive the ratio of energy at different frequency bands in each lead. The power of the prefrontal and parietal leads was studied when the change in EEG power values was greater after exercise fatigue.

By comparing the percentage of wave power values obtained before and after isometric centripetal movement, the wave power values obtained for the leads of the FP1, F3, F4, FC1, FC2, C3 and C4 channels all improved after isometric centripetal movement (P < 0.05), indicating that waves in the frontal and parietal lobes following isometric centripetal movement power increased (Tab. 5). The power ratio of EEG signal waves increased significantly (P < 0.01) in the FP1, FP2, F3, FC1, FC2, C3, C4 and CP1 channels after isometric centrifugal exercise compared to that before exercise. There was a significant increase in the power of the prefrontal and parietal EEG signal waves after the subject performed an isokinetic centrifugal contraction exercise (Figure 7).

Table 5

Ratio of δ power before and after exercise (%)

Lead	Before exercise	After centripetal movement	After eccentric exercise
Fp1	16.4±2.5	20.3±3.8*	23.2±4.1**
Fp2	16.6±3.1	19.8±3.6	22.2±4.2**
F3	17.8±3.5	21.9±4.0*	24.3±4.5**
F4	16.7±3.2	20.6±3.4*	21.8±4.6*
Fc1	16.4±3.2	20.8±3.6*	23.2±4.1**
Fc2	16.6±3.3	21.3±4.1*	22.8±4.5**
C3	17.0±3.8	22.3±4.3*	24.8±3.9**
C4	17.1±4.1	22.8±4.2*	25.2±4.8**
CP1	17.0±4.2	21.3±4.1	23.8±4.6**
CP2	16.6±3.5	19.5±4.0	21.8±4.3*

*Notes**. Indicates significant difference before and after fatigue ($P < 0.05$).
*Notes***. Indicates a highly significant difference before and after fatigue ($P < 0.01$).

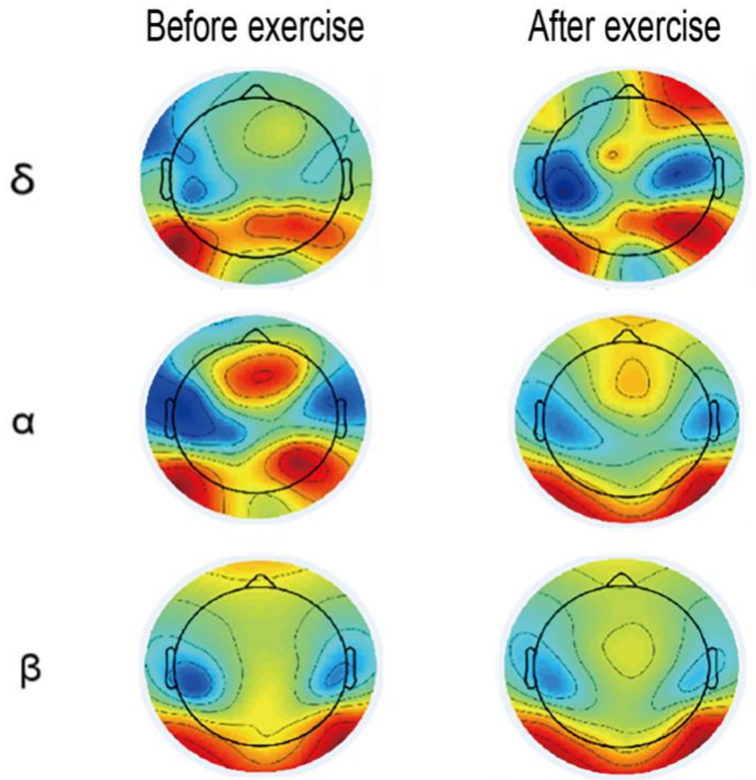

Figure 7. Changes in brain topography before and after isokinetic exercise

The percentage change in the wave power value of brain waves after isometric centripetal movement compared with that before movement was not statistically significant for all channels ($P > 0.05$, Table 6). The decrease in the ratio of the power value of the EEG signal wave of the four channels F4, C3, C4 and CP1 after isometric centrifugal exercise was statistically significant ($P < 0.05$). Therefore, part of the EEG signal wave power in the parietal lobe decreased when the subject performed isokinetic centrifugal contraction exercise.

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Table 6

Ratio of θ power before and after exercise (%)

Lead	Before exercise	After centripetal movement	After eccentric exercise
Fp1	18.5±3.4	19.8±3.5	17.9±3.8
Fp2	18.7±3.6	19.2±4.1	18.5±3.1
F3	20.3±4.3	19.3±4.0	17.6±3.4
F4	20.4±3.8	21.8±3.6	16.4±3.5*
Fc1	20.2±3.2	20.8±3.9	19.2±3.6
Fc2	20.6±3.3	21.5±3.6	18.6±3.2
C3	21.0±3.8	20.3±3.5	16.5±3.5*
C4	21.5±4.1	20.8±4.3	17.5±3.1*
CP1	21.0±3.9	19.5±4.1	17.2±3.2*
CP2	20.6±3.5	19.8±3.9	18.9±3.4

*Notes**. Indicates a significant difference before and after fatigue ($P < 0.05$).

After isometric centripetal movement, all channels α None of the changes in the ratio of wave power values (Table 7) were statistically significant ($P > 0.05$). When the subject performed isokinetic eccentric contraction exercise, the C3 and C4 channel EEG signal α wave power decreased somewhat ($P < 0.05$), consistent with the trend of changes in brain topography (Figure 7).

Table 7

Ratio of α power before and after exercise (%)

Lead	Before exercise	After centripetal movement	After eccentric exercise
Fp1	46.5±8.4	43.6±7.4	41.8±6.9
Fp2	45.7±7.6	43.9±7.1	41.6±7.2
F3	42.0±8.3	39.7±6.3	39.5±6.6
F4	42.8±7.8	40.8±6.5	39.1±6.1
Fc1	43.3±7.2	41.6±6.2	40.7±5.8
Fc2	42.7±8.3	39.3±7.4	38.3±6.5
C3	42.5±8.8	38.8±6.5	35.9±6.3*
C4	41.3±9.1	38.3±7.2	35.2±6.2*
CP1	42.3±7.9	39.6±6.8	38.5±7.3
CP2	42.7±8.5	40.9±8.4	38.8±6.4

*Notes**. Indicates significant difference before and after fatigue ($P < 0.05$).

After isometric centripetal movement, there was no change in channels β Wave power. When subjects performed isokinetic eccentric systolic exercise postexercise (Table 8), EEG signals were obtained from FC2, C3, and C4 channels β Wave power decreased compared with that before exercise ($P < 0.05$), and this result was in the same trend as that of brain topography (Figure 7).

Table 8

Ratio of β power before and after exercise (%)

Lead	Before exercise	After centripetal movement	After eccentric exercise
Fp1	18.5±3.4	17.3±4.1	16.6±3.1
Fp2	18.7±3.6	17.8±3.9	16.5±3.7
F3	20.3±4.3	19.3±4.1	17.3±3.2
F4	20.4±3.8	21.1±4.8	19.2±3.8
Fc1	20.2±3.2	20.9±3.7	17.9±3.5
Fc2	20.6±3.3	19.3±3.8	16.3±3.2*
C3	21.0±3.8	17.2±4.1	16.2±3.1*
C4	21.5±4.1	18.5±3.7	16.5±3.5*
CP1	21.0±3.9	20.5±4.1	19.5±3.9
CP2	20.6±3.5	19.6±3.9	18.6±4.1

Notes.* Indicates a significant difference before and after fatigue ($P < 0.05$).

3.3.2 Comparison of EEG power spectral changes before and after centrifugation contraction

When human exercise produces central fatigue, there is a left shift in the EEG signal energy spectrum, that is, an increase in the power of EEG signal waves at low frequencies, whereas α Wave and β Wave such high frequency segment wave form power overall shows a decreasing trend [13–16]. The results were generally consistent with the conclusion that the wave occupancy ratio was higher after centrifugation and centrifugation than before exercise in some channels α Wave and β the bozantic ratio appears reduced.

Table 9

The change value in δ power after different forms of isokinetic fatigue (%)

Lead	Centripetal contraction	Eccentric contraction	P
Fp1	3.9±1.1	6.8±1.8	0.002
Fp2	3.2±1.3	5.6±1.2	0.002
F3	4.1±1.4	6.5±1.7	0.008
F4	3.9±1.1	5.1±1.3	0.066
Fc1	4.4±1.2	6.8±1.7	0.006
Fc2	4.7±1.4	6.3±1.4	0.038
C3	5.3±1.3	7.8±2.3	0.018
C4	5.7±1.2	8.1±1.8	0.007
CP1	4.3±1.5	6.8±1.7	0.008
CP2	3.3±1.1	5.2±1.8	0.023

When isokinetic centrifugal contraction exercise fatigue was followed, the specific growth rate of brain wave power accounted for by all channels in the prefrontal and parietal lobes was higher than the isokinetic centrifugal contraction fatigue growth rate (Table 9), indicating that isokinetic centrifugal contraction exercise generated a greater degree of central fatigue.

Discussion

4.1 Relationship between sEMG and peripheral fatigue during different forms of isokinetic exercise

When muscle appears fatigued, it shows a tendency of increasing time domain indexes and decreasing frequency domain indexes. During the experiment, the time-domain index iEMG gradually increased, while the frequency-domain indexes MF and MPF both showed a gradual decreasing trend. When each cycle of isometric movement reached a certain amount, significant inflexions occurred in the broken line plots between iEMG, MF, and MPF and the number of movements, and the data before and after the inflexions were all significantly different. The appearance times of iEMG, MF, and MPF inflexions during isometric centrifugation contraction were all earlier than those during isometric centrifugation contraction. In addition, the isometric centripetal contraction iEMG growth rate was significantly higher than the isometric centrifugal contraction growth rate. Similarly, centripetal contraction had a higher rate of MF and MPF decline after fatigue than did centrifugal contraction. Thus, centripetal contractions are more likely to produce muscle fatigue than eccentric contractions.

IEMG indicates the sum of myofiber discharge involved in muscle contraction in unit time, and an enlarged iEMG indicates an increased number of myofibers involved in movement or discharge from each muscle fiber. Edwards et al. (1956) noted an increase in time and exercise intensity with a consequent increase in the slope of the iEMG curve and as the slope increased the point at which the muscle began experiencing fatigue. The experimental results were consistent with the findings of Edwards et al. When the exercise load increases, the fast twitch fibers involved in locomotion gradually increase, the slow twitch fibers decline in number, and the fast twitch fibers have higher amplitudes than the slow twitch fibers, thus producing an elevation of the integrated electromyographic value. In addition, the number of myofibers mobilized by the muscle increases to satisfy the contractile activity of the muscle, so the overall discharge of the muscle increases, manifested as an increased integrated myoelectric value.

When a muscle experiences fatigue, there is an overall upward trend in iEMG, possibly because the fatiguing muscle needs to recruit more muscle fibers to participate in exercise (Figure 2B). The muscle fatigability of the upper limb muscles when performing centripetal contraction was significantly higher than that during eccentric contraction, and the change time was also earlier than that during eccentric contraction. This may be because contraction is met by fewer myofibers recruited when the muscle is undergoing initiation of centripetal contraction, fatigue occurs when the muscle is subjected to increased exercise time, and centrifugal contraction is met by more myofibers recruited to the movement, as well as more fast myofibers recruited to the contraction. Therefore, the integral EMG value increased less after fatigue in eccentric contraction muscles than in centripetal contraction, and the recruitment of new myofibers to exercise by centripetal contraction also occurred earlier than in eccentric contraction.

The spectrum and power spectrum obtained from the fast Fourier transform (FFT) of the surface EMG, MF and MPF, can respond to the change in the EMG signal between different frequencies. The EMG power spectrum is essentially a reflection of the relationship between EMG energy and frequency. Therefore, some scholars have proposed [18] analysis of the frequency-domain index of the EMG signal, which can reflect the number of different types of muscle fibers involved in exercise during muscle contraction and the discharge amount of muscle in different frequency bands. In turn, the EMG frequency-domain analysis is used as an analysis method for judging muscle fatigue. When the muscle produces fatigue, the spectrum of the muscle EMG signal shifts to the left, so that the median frequency and mean power frequency of the muscle EMG show decreased numerical MF and MPF values [19–21]. When the degree of muscle fatigue deepens, the amplitude of the left shift of the frequency-domain index of EMG signal increases, which manifests as the decrease amplitude of MF and MPF of the frequency-domain index of EMG signal increases [22]. The main reason why the frequency-domain index of EMG appears to decrease when muscle appears fatigued at present is the following points: some scholars believe [23] that muscle appears fatigued when it produces accumulation of acidic metabolites such as lactate, leading to the decrease of action potential conduction velocity of muscle fiber; Another scholars believe [24] that the proportion of type II muscle fibers involved in exercise increases when the muscle fatigues, resulting in the decrease of frequency-domain indexes; It has also been argued that muscle fibers involved in exercise when fatigue occurs produce fatigue, and muscle recruits more slow muscle fibers to participate in exercise, thus leading to a decrease in frequency-domain metrics [25]. Taken together, the mechanistic level of the generation of EMG changes after fatigue awaits further study by scholars.

4.2 Relationship between EEG power spectra and central fatigue during different forms of isokinetic exercise

When muscles fatigued with isometric centripetal movement, the ratio of power values of EEG signal waves in leads of FP1, F3, F4, FC1, FC2, C3 and C4 channels significantly improved ($P < 0.05$). The power values of channel EEG signals in the frontal and parietal lobes of FP1, FP2, F3, F4, FC1, FC2, C3, C4, CP1, CP2 all had significantly higher values after isometric centrifugal exercise muscle fatigue compared to before exercise ($P < 0.05$, Table 5). When fatigue is induced by exercise, the EEG signal wave energy of the prefrontal and parietal lobes of the brain will increase, indicating that the brain center also produces fatigue. The central nervous system prevents excessive fatigue in the brain. The inhibitory signal of the cerebral cortex is constantly increasing, the excitation signal is gradually decreasing. Therefore, the phenomenon of the left shift of the EEG signal energy spectrum and the proportion of slow wave energy in the main wave will increase. However, when the exercise muscle fatigued by centrifugal contraction, the proportion of power value of EEG signal wave of F4, C3, C4 and CP1 four channels decreased significantly ($P < 0.05$, Table 6), because the wave was the same slow wave as the wave, but the wave was 4-7 Hz waveform, while the wave was 1-3 Hz waveform, so the reason for the wave decline might be that during the 10 group isometric centrifugal exercise, the center developed fatigue before the end of the exercise, fatigue and continued to perform isometric centrifugal exercise after fatigue, leading to the deepening of fatigue, This causes a continuing left shift of the EEG signal energy spectrum, producing a rise and fall of waves after isometric centrifugal exercise fatigue.

Contractile movements of skeletal muscle are innervated by brain centers, and brain EEG signals control muscle fiber gains and losses during muscle contraction via motor nerves, which in turn control the contractile effects of peripheral skeletal muscle while, when stimulated peripherally, feedback to the central nerves in the form of electrical signals [26]. Changes in EEG signals are a protective behavior during central motor fatigue [27]. When the brain receives fatigue signals from peripheral feedback, the center will produce inhibitory transmitters, at the same time excitatory transmitters gradually decrease, in turn leading to the cerebral cortex less excitability in the frequency of neural excitation, and the phenomenon of producing an EEG signal energy spectrum shift to low frequency.

When the growth rate of the power occupied ratio of brain waves in most channels of the prefrontal and parietal lobes was higher than that of the fatigue of isokinetic centrifugation contraction after isokinetic centrifugal motion (Table 9), that is, the degree of central fatigue generated by isokinetic centrifugal contraction exercise was greater, and this result agreed well with the results of previous scholars' research. There are studies that induced fatigue in knee extensors by isometric muscle strength trainers and extracted central activation level VA for analysis after fatigue of centripetal and centrifugal contraction, the central fatigue after isometric centrifugal exercise is greater than that of centripetal exercise [28–30]. However, there are mixed accounts of the mechanisms leading to central fatigue after isometric centrifugal contraction exercise. Michaut et al. (2002) considered that isokinetic centrifugal contraction when exercise, muscle fiber over contraction caused muscle pain and weakness sensation, the motor nerve transmitted the signal to the central nerve in the form of negative feedback, the brain to avoid producing excessive fatigue, the cerebral cortex of reduced excitability, higher inhibition, produces the phenomenon of central fatigue, and then leads to the decrease of the brain's ability to innervate muscle contraction. Martin et al. (2005) suggested that the mechanism of central fatigue after isokinetic eccentric exercise may be due to muscle class III and IV afferent fibers being affected by accumulated metabolic substances.

Conclusion

In the process of muscle fatigue induced by isokinetic training, the extrinsic performance of muscle and the change in electrical signal have mutual reference value, and the index of isokinetic muscle force and the index of electromyographic signal can be combined as an evaluation index of muscle fatigue. Elbow flexors and extensors developed significant muscle fatigue after performing 100 cycles of maximal isometric centrifugation and isometric eccentric exercise, and the rate of change of iEMG, MF, and MPF of EMG signal after isometric centrifugation fatigue was higher, and the inflection point of change was earlier than that of centrifugal contraction, indicating that centrifugal contraction was more fatigue resistant and the degree of peripheral fatigue after centrifugation contraction was higher than that of centrifugal contraction. There was a clear increase in the wave to duty ratio of the brain's prefrontal and parietal EEG signals, indicating that centripetal and centrifugal isokinetic movements produced significant central fatigue. The magnitude of the increase in the wave duty ratio was greater after isometric centrifugal exercise, and the degree of central fatigue was stronger after isometric centrifugal exercise than after isometric centripetal exercise.

Ethical statements

The study was approved by the Biomedical Research Ethics Committee (No. 5/2018) and was conducted in accordance with the Declaration of Helsinki. The study was approved by the Bioethics Committee of Research of the School of Kinesiology and Health Promotion of Dalian University of Technology. All participants gave written informed consent to participate in the study and publish the obtained results including registered images. Personal data and the images of patients were collected and processed in a database that complies with the personal data protection regulations. The equipment used in the tests did not pose any threat that could in any way affect the safety of the human body.

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References

1 Lievens, E., Klass, M., Bex, T., et al. (2020). Muscle fiber typology substantially influences time to recover from high-intensity exercise. *Journal of Applied Physiology, 128*(3), 648–659. DOI: 10.1152/japplphysiol.00636.2019.

2 Andersen, B., Westlund, B., & Krarup, C. (2003). Failure of activation of spinal motoneurones after muscle fatigue in healthy subjects studied by transcranial magnetic stimulation. *The Journal of Physiology, 551*(1), 345–356. DOI: 10.1113/jphysiol.2003.043562.

3 Kenney, W., Wilmore, J., & Costill, D. (2021). *Physiology of sport and exercise* (7th ed.). Human Kinetics.

4 Skurvydas, A., Kazlauskaite, D., Zlibinaite, L., et al. (2021). Effects of two nights of sleep deprivation on executive function and central and peripheral fatigue during maximal voluntary contraction lasting 60 s. *Physiology & Behavior, 229,* 113226. DOI: 10.1016/j.physbeh.2020.113226.

5 Silva-Cavalcante, M. ., Couto, P.G., Azevedo, R.A., et al. (2019). Stretch–shortening cycle exercise produces acute and prolonged impairments on endurance performance: Is the peripheral fatigue a single answer? *European Journal of Applied Physiology, 119*(7), 1479–1489. DOI: 10.1007/s00421-019-04135-4.

6 Naderifar, H., Minoonejad, H., Barati, A.H., et al. (2018). Effect of a neck proprioceptive neuromuscular facilitation training program on body postural stability in elite female basketball players. *Journal of Rehabilitation Sciences & Research, 5*(2), 41–45.

7 Brambilla, C., Pirovano, I., Mira, R.M., et al. (2021). Combined use of EMG and EEG techniques for neuromotor assessment in rehabilitative applications: A systematic review. *Sensors, 21*(21), 7014. DOI: 10.3390/s21217014.

8 Enoka, R.M. (2019). Physiological validation of the decomposition of surface EMG signals. *Journal of Electromyography and Kinesiology, 46,* 70–83. DOI: 10.1016/j.jelekin.2019.03.010.

9 Yang, Z., & Ren, H. (2019). Feature extraction and simulation of EEG signals during exercise-induced fatigue. *IEEE Access, 7,* 46389–46398. DOI: 10.1109/ACCESS.2019.2909035.

10 Portela, M.A., Sánchez-Romero, J.I., Pérez, V.Z., et al. (2020). Torque estimation based on surface electromyography: Potential tool for knee rehabilitation. *Revista de la Facultad de Medicina, 68*(3), 438–445. DOI: 10.1016/j.jneumeth.2020.108998.

11 Sheng, Y., Liu, J., Zhou, Z., et al. (2021). Musculoskeletal joint angle estimation based on isokinetic motor coordination. IEEE Transactions on Medical Robotics and Bionics, 3(4), 1011–1019. DOI: 10.1109/TMRB.2021.3122931.

12 Weavil, J.C., Sidhu, S.K., Mangum, T.S., et al. (2015). Intensity-dependent alterations in the excitability of cortical and spinal projections to the knee extensors during isometric and locomotor exercise. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 308(12),* R998–R1007. DOI: 10.1152/ajpregu.00021.2015.

13 Ghorbani, M., & Clark, C.C.T. (2021). Brain function during central fatigue induced by intermittent high-intensity cycling. *Neurological Sciences, 42(9),* 3655–3661. DOI: 10.1007/s10072-020-04965-7.

14 Engchuan, P., Wongsuphasawat, K., & Sittiprapaporn, P. (2019). Brain electrical activity during bench press weight training exercise. *Asian Journal of Medical Sciences, 10(5),* 80–85. DOI: 10.3126/ajms.v10i5.21034.

15 Liu, J., Sheng, Y., Zeng, J., et al. (2019). Corticomuscular coherence for upper arm flexor and extensor muscles during isometric exercise and cyclically isokinetic movement. *Frontiers in Neuroscience, 13,* 522. DOI: 10.3389/fnins.2019.00522.

16 Li, D., & Chen, C. (2022). Research on exercise fatigue estimation method of Pilates rehabilitation based on ECG and sEMG feature fusion. *BMC Medical Informatics and Decision Making, 22(1),* 1–11. DOI: 10.1186/s12911-022-01808-7.

17 Edwards, R.G., & Lippold, O.C.J. (1956). The relation between force and integrated electrical activity in fatigued muscle. *The Journal of Physiology, 132(3),* 677–681. DOI: 10.1113/jphysiol.1956.sp005558.

18 Turgunov, A., Zohirov, K., Rustamov, S., et al. (2020). Using different features of signal in EMG signal classification. *In 2020 International Conference on Information Science and Communications Technologies (ICISCT)* (pp. 1–5). IEEE. DOI: 10.1109/ICISCT50599.2020.9351392.

19 Cadore, E.L., González-Izal, M., Grazioli, R., et al. (2019). Effects of concentric and eccentric strength training on fatigue induced by concentric and eccentric exercises. *International Journal of Sports Physiology and Performance, 14(1),* 91–98. DOI: 10.1123/ijspp.2018-0254.

20 Rampichini, S., Vieira, T.M., Castiglioni, P., et al. (2020). Complexity analysis of surface electromyography for assessing the myoelectric manifestation of muscle fatigue: A review. *Entropy, 22(5),* 529. DOI: 10.3390/e22050529.

21 Jung, C.Y., Park, J.S., Lim, Y., et al. (2018). Estimating fatigue level of femoral and gastrocnemius muscles based on surface electromyography in time and frequency domain. *Journal of Mechanics in Medicine and Biology, 18(05),* 1850042. DOI: 10.1142/S0219519418500422.

22 Liu, X., & Li, Z. (2021). Influence mechanism of running sportswear fatigue based on BP neural network. *EURASIP Journal on Advances in Signal Processing, 2021(1),* 1–15. DOI: 10.1186/s13634-021-00778-8.

23 Farina, D., Fosci, M., & Merletti, R. (2002). Motor unit recruitment strategies investigated by surface EMG variables. *Journal of Applied Physiology, 92(1),* 235–247. DOI: 10.1152/jappl.2002.92.1.235.

24 Solomonow, M., Baten, C., Smit, J.O.S., et al. (1990). Electromyogram power spectra frequencies associated with motor unit recruitment strategies. *Journal of Applied Physiology, 68(3),* 1177–1185. DOI: 10.1152/jappl.1990.68.3.1177.

25 Klaver-Krol, E.G., Hermens, H.J., Vermeulen, R.C., et al. (2021). Chronic fatigue syndrome: Abnormally fast muscle fiber conduction in the membranes of motor units at low static force load. *Clinical Neurophysiology, 132(4),* 967–974. DOI: 10.1016/j.clinph.2020.11.043.

26 McArdle, W.D., Katch, F.I., & Katch, V.L. (2006). Essentials of exercise physiology (3rd ed.). *Lippincott Williams & Wilkins.*

27 Markus, I., Constantini, K., Hoffman, J.R., et al. (2021). Exercise-induced muscle damage: Mechanism, assessment and nutritional factors to accelerate recovery. *European Journal of Applied Physiology, 121(4),* 969–992. DOI: 10.1007/s00421-020-04566-4.

28 Souron, R., Nosaka, K., & Jubeau, M. (2018). Changes in central and peripheral neuromuscular fatigue indices after concentric versus eccentric contractions of the knee extensors. *European Journal of Applied Physiology, 118(4),* 805–816. DOI: 10.1007/s00421-018-3816-0.

29 Michaut, A., Pousson, M., Babault, N., et al. (2002). Is eccentric exercise-induced torque decrease contraction type dependent? *Medicine and Science in Sports and Exercise, 34(6),* 1003–1008. DOI: 10.1097/00005768-200206000-00016.

30 Martin, V., Millet, G.Y., Lattier, G., et al. (2005). Why does knee extensor muscles torque decrease after eccentric-type exercise? *Journal of Sports Medicine and Physical Fitness, 45(2),* 143–151.

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Meta analysis of the effects of resistance training on the lower limb muscle strength of basketball players

The objective of the study is to comprehensively evaluate the effects of resistance training on the improvement of lower limb motor function of basketball players. During the study the following methods were applied: Elsevier, SCI-E, CNKI and other databases were searched to collect the relevant randomized controlled experiments on the effects of resistance training on the lower limb muscle strength of basketball players. The search time was set to March 2020, and the references of the included literatures were retrospectively searched. The quality of the literature was evaluated. Statistical analysis was conducted using RevMan 5.3 software to compare the effects of training programs and intensity on the sports performance of basketball players using odds ratio and 95 % confidence interval as effect indicators. As a result, a total of 14 literatures and 313 experimental samples were included. Compared with the control group, the results showed that resistance training could significantly improve the running height of basketball players (SMD=-4.92, 95 %CI (-6.31, -3.54), P<0.00001). The resistance training could significantly improve the longitudinal jumping of basketball players (SMD=-1.69, 95 %CI (-2.11, -1.28), P<0.00001). The resistance training could improve the speed of basketball players at 20m sprints (SMD=0.24, 95 %CI (0.04, 0.43), P=0.02). The resistance training could significantly improve the standing long jump of basketball players (SMD=-11.46, 95 %CI (-18.09, -4.83), P=0.0007). It was concluded that resistance training can improve the lower limb movement ability of basketball players.

Keywords: basketball, resistance training, strength exercise, plyometrics, strength of lower limb muscles.

Introduction

Invented in 1891, basketball has evolved into one of the world's most popular and widely viewed sports. There is a great amount of basketball leagues all over the world, such as China's CBA league, NBA league in the US, EuroLeague, etc. In recent years, 3X3 basketball games have become popular all over the world. As the improvement of competition level, the players are required to have more excellent athletic ability; it is largely dependent on the ability to produce maximum neuromuscular strength [1]. Therefore, the players shall achieve a relatively high level of strength, and turn it into achievements to the greatest extent. The player's good lower limb muscle strength and function are the key factors of their basketball performance [2–4], and it is the guarantee for their daily activities and training [5, 6], so the scientific and rich anti-group training program to help athletes achieve the best athletic ability has been given attention [1, 7, 8]. Some coaches and researchers have experimented that heavy load resistance training [9, 10], explosive resistance training [11, 12], electrical stimulation training [12], vibration training [13], plyometric training, etc. are more effective methods to improve jumping ability and leg muscle strength [14–16]. In contrast, there are also some authors who believe that these training modalities do not significantly improve lower limb athletic ability [17–21], and some of them even report negative effects [22]. Moreover, there are few studies on the improvement or improvement of basketball players' lower limb muscle strength and athletic ability by resistance training methods in China, and there are some controversies about the formulation of basketball players' lower limb muscle strength training plan. In view of this, this paper uses Meta-analysis method to quantitatively and comprehensively analyze the literatures at home and abroad on different resistance training methods to improve the lower limb muscle strength of basketball players; discusses the possible heterogeneity and bias of the included literatures, and quantitatively analyzes the results to obtain more scientific and regular effect results. This paper also analyzes the influence of different resistance training methods on basketball players' achievements, such as running height, longitudinal jumping, 20-m sprints and standing long jump. It is expected to provide theoretical basis and practical scheme for the improvement of basketball players' lower limb muscle strength and sports performance.

Methods and materials

1. Document Retrieval

The computer retrieval databases are as follows: Elsevier, SCI-E, and CNKI databases. The Chinese search words are "篮球、运动员、抗组训练、肌力训练、下肢肌力、运动功能", etc., the English search words are "basketball, athletes, sportsman, strength training, lower limbs, FMA", etc. For different databases, the corresponding combination of subject words, free words and keywords are selected. A total of 36,199 literatures were obtained. After deduplication and research direction preliminary screening, 18,902 literatures were remained. Further reading the title and abstract, 842 literatures were retained, and after reading the full text and excluding conferences and reviews, articles unrelated to basketball, 87 literatures were remained. Finally, after excluding no data and specific indicators and non-lower limb muscle strength influence indicators, 14 literatures were finally included for Meta-analysis (Figure 1) [23–36].

1.1 Literature review criteria

The included literatures would have a direct impact on the reliability and validity of the Meta-analysis results. In order to include scientific research, strict included criteria are required: 1) The included research shall be Chinese and English literatures of randomized controlled trials of basketball players' resistance training; 2) The experimental subjects shall be basketball players, and the experimental data include the basic conditions and training indexes of the subjects before and after the experiment; 3) Exercise intervention shall be greater than or equal to 2 times/week. The total duration of the experiment shall be at least 6 weeks.

1.2 Data information extraction

The standardized procedures and forms are strictly followed, and the basic information, sample size, age of subjects, experimental design, intervention time, overall intervention time, attrition rate, etc. of the included literatures are used as preliminary indicators of literature bias and heterogeneity. Results of index data: The mean (X) and standard differences (SD) of the indexes and effect sizes of the subjects' approach run and touch, longitudinal jump, 20-m sprints, standing long jump, etc. According to the data required in this study and the data format processing using RevMan5.3 software, the data converter in the software is used to extract the data included in the literatures and unify the format.

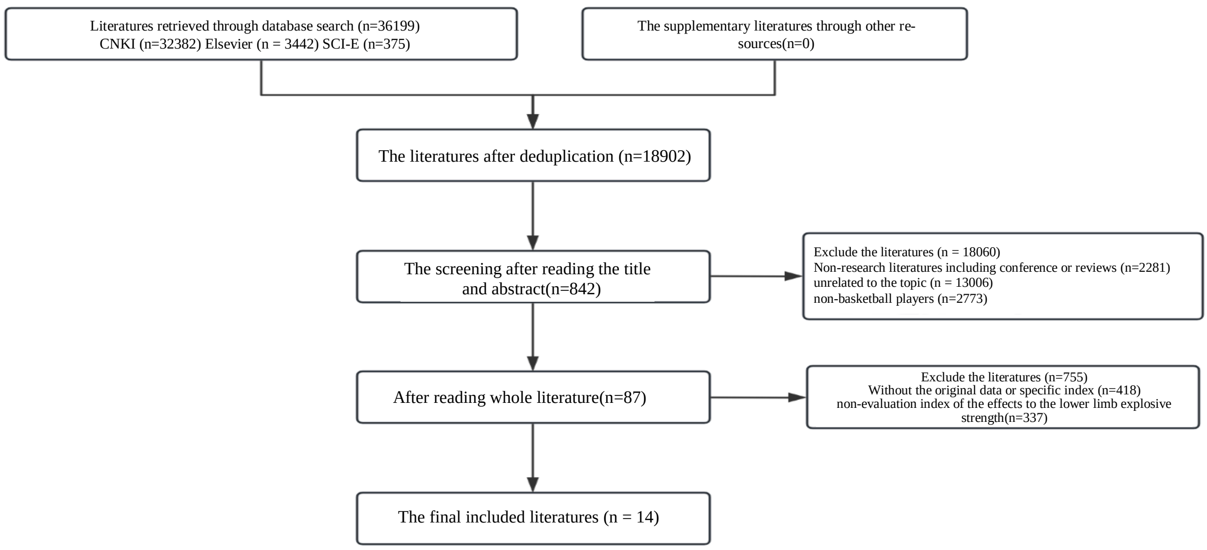

Figure 1. Literature Selection Flow Diagram

1.3 Quality evaluation

The quality of the included literature was evaluated according to the Literature Quality Evaluation Criteria Manual recommended in Cochrane Manual 5.1.0.

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1.4 Data statistical processing

RevMan5.3 is mainly used to evaluate publication bias and test heterogeneity, merge data and draw bias and forest maps; The data to be processed in this paper are continuous data, and the effect size MD (Mean Differences) fixed and random effect models have 95 % confidence intervals. The judgment of heterogeneity is mainly based on I^2, and when $I^2 < 50$ %, the fixed effect model is adopted; When $I^2 \geq 50$ %, the random effects model is adopted. The significance level $\alpha = 0.05$.

Results and Discussion

2 Basic information and quality discussion of the included literatures

In total, 36,199 literatures were obtained. After preliminary elimination of duplicates, 18,902 records remained. Further reading of the title and abstract excluded 18,060 studies that did not meet the inclusion criteria. After preliminary screening, 87 literatures were retained. After the full-text review and quality evaluation, 14 literatures were finally included, consisting of 10 Chinese and 4 English studies.

Table 1 shows the basic information of the included literature in the Meta-analysis, and the sample size is 313 participants in the included literature, and the subjects are all basketball players; All included studies examined resistance training. In particular, plyometric training, which is commonly used in foreign studies, involves rapid and powerful contraction after muscle elongation. This muscle activity method is named as the “Stretch-Shortening Cycle (SSC)”. This training method will make the muscles stretch quickly, thus stimulating the proprioceptors of the muscle spindle, allowing them to transmit information to the central nervous system and make reflexes, thus prompting more muscle fibers to deliver more energy. Studies have pointed out that the time of resistance training should be 2-3 times a week for each large muscle group.

Table 1

Basic Information Included Research

The included literature (first author)	Number of sample	Age	Gender	Training method	Duration (weeks)	Training volume	Quality Score (PEDro)
1	2	3	4	5	6	7	8
Approach run and touch							
Gan Liju	6	21.08±1.41	Male	HISRT+LBFRT Comprehensive Training	8	3 times/week	4
Gan Liju	6	21.08±1.41	Male	HISRT training	8	3 times/week	4
Yin Wei	7	19.71±0.37	Female	Core strength training	12	3 times/week	4
Yin Wei	7	19.86±0.37	Female	General resistance training	12	3 times/week	4
Zhao Qichao	6	21.00±0.894	Male	Single leg resistance training	10	3 times/week	4
Zhao Qichao	6	21.00±1.265	Male	Two legs resistance training	10	3 times/week	4
Hu Chengye	12	19.08±1.03	NA	Rapid telescopic compound training	8	3 times/week	3
Li Shaosong	8	18~22	Male	Single leg flexion hard stretch	6	2 times/week	3
Li Shaosong	8	18~22	Male	Two legs flexion hard stretch	6	2 times/week	3
Yang Zhongjun	8	18.75±1.58	Male	Maximum resistance training	8	3 times/week	4
Yang Zhongjun	8	19.38±1.77	Male	Sub-Maximum resistance training	8	3 times/week	4
Yan Yufeng	8	18.8±1.35	Male	Resistance training	8	2 times/week	4
Li Ning	12	20.79±0.64	Male	Plyometric training	12	3 times/week	4
Ma Tianze	14	16±0	Male	Lower limb burst training	8	3 times/week	4
General average	8.29	19.26	NA	NA	8.86	2.79 times/week	NA
20M sprints							
Gan Liju	6	21.08±1.41	Male	HISRT+LBFRT Comprehensive Training	8	3 times/week	4
Gan Liju	6	21.08±1.41	Male	HISRT training	8	3 times/week	4
Bogdanis	33	8.1±0.7	Female	Plyometric training	8	3 times/week	5
Zhang Xiaodong	13	14.5±0.5	Female	Video resistance training	6	2 times/week	4
Zhang Xiaoqing	13	14.5±0.5	Female	Supervised resistance training	6	2 times/week	4
Li Ning	12	20.79±0.64	Male	Plyometric training	12	3 times/week	4
General average	13.83	11.15	NA	NA	8.00	2.67 times/week	NA

Continuation of Table 1

1	2	3	4	5	6	7	8
Longitudinal jump							
Bogdanis	33	8.1±0.7	Female	Plyometric training	8	3 times/week	5
Ziv	15	NA	Female	Plyometric training	NA	NA	3
Zhang Xiaodong	13	14.5±0.5	Female	Video resistance training	6	2 times/week	4
Zhang Xiaodong	13	14.5±0.5	Female	Monitoring resistance training	6	2 times/week	4
Verma	22	10~11	Female	Plyometric training	6	3 times/week	4
Verma	14	10~11	Male	Plyometric training	6	3 times/week	4
Verma	22	14~15	Female	Plyometric training	6	3 times/week	4
Verma	14	14~15	Male	Plyometric training	6	3 times/week	4
Cheng	8	17.1±0.8	Male	Plyometric training	8	2 times/week	4
Li Shaosong	8	18~22	Male	Single leg flexion hard stretch	6	2 times/week	3
Li Shaosong	8	18~22	Male	Two legs flexion hard stretch	6	2 times/week	3
Ma Tianze	14	16±0	Male	Lower limb burst training	8	3 times/week	4
General average	15.33	10.08	NA	NA	8.00	2.67 times/week	NA
Standing long jump							
Li Shaosong	8	18~22	Male	Single leg flexion hard stretch	6	2 times/week	3
Li Shaosong	8	18~22	Male	Two legs flexion hard stretch	6	2 times/week	3
Hu Chengye	12	19.08±1.03	NA	Rapid telescopic compound training	8	3 times/week	3
Zhao Qichao	6	21.00±0.894	Male	Single leg resistance training	10	3 times/week	4
Zhao Qichao	6	21.00±1.265	Male	Two legs resistance training	10	3 times/week	4
Li Ning	12	20.79±0.64	Male	Plyometric training	12	3 times/week	4
Ma Tianze	14	16±0	Male	Lower limb burst training	8	3 times/week	4
Bogdanis	33	8.1±0.7	Female	Plyometric training	8	3 times/week	5
General average	12.38	15.44	NA	NA	8.50	2.75 times/week	NA

2.1 Literature bias evaluation

The PEDro scale was used to access the literature quality [37, 38], which is a randomized controlled study quality evaluation form with a scoring design of 11 items. Each criterion is scored as “yes” or “no”, with total scores on the PEDro scale ranging from 0 to11 points. The items are as follows:

1. The included criteria of subjects clearly described
2. Randomly assigned
3. Assignment hidden
4. Similar baselines for key indicators
5. Subject blinding
6. Therapist blinding
7. Evaluator blinding
8. > 85 % of subjects performed at least one primary outcome measure
9. Subjects with measurement results shall follow the protocol treatment or undergo intention-to-treat analysis
10. The statistics among groups for at least one primary outcome reported
11. The point estimates and confidence intervals for at least one primary outcome reported

2.2 Meta-analysis results

2.2.1 Meta-analysis of the effect size of running height

A total of 14 controlled trial experiments were included in the study on the effect size of running height of basketball players before and after intervention in the resistance training [34, 29, 30, 33, 27, 28, 36, 32, 31], among which Yin Wei, Li Shaosong, Yang Zhongjun, Gan Liju, Zhao Qichao’s literatures contain 2 resistance training programs; Figure 2 represents a Forest Map of the Meta-analysis results of the ef-

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fect size of running height. The low heterogeneity in the study can be seen from Figure 2 (X^2 = 16.69, I^2 = 22 %, P = 0.21), therefore, the Meta-analysis shall adopt the fixed effects model. The analysis results show that resistance training intervention has a significant effect on basketball players' running height [SMD =-4.92, 95 % CI(-6.31, -3.54), P < 0.00001].

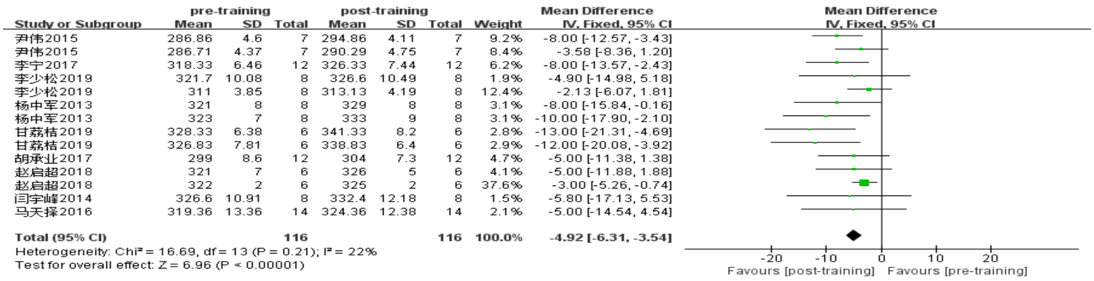

Figure 2. Forest Map Of Efficient Response Volume Of Approach Running Meta-Analysis

2.2.2 Meta-analysis of the effect size of longitudinal jumping

A total of 12 trial experiments were included in the study on the effect size of longitudinal jumping of basketball players before and after intervention in the resistance training [23, 24, 25, 26, 30, 31, 35], among which Bogdanis, Cheng, Zhang Xiaodong, Li Shaosong's literatures contain 2 resistance training programs, Vema's literature contains 4 training groups including the male and female of 2 age groups; In Figure 2, it shows a Forest Map of the Meta-analysis results of the effect size of longitudinal jumping. The low heterogeneity in the study can be seen from Figure 3 (X^2 = 18.06, I^2 = 39 %, P = 0.08), therefore, the Meta-analysis shall adopt the fixed effects model. The analysis results show that resistance training intervention has a significant effect on basketball players' longitudinal jumping [SMD =-1.69, 95 % CI(-2.11, -1.28), P < 0.00001].

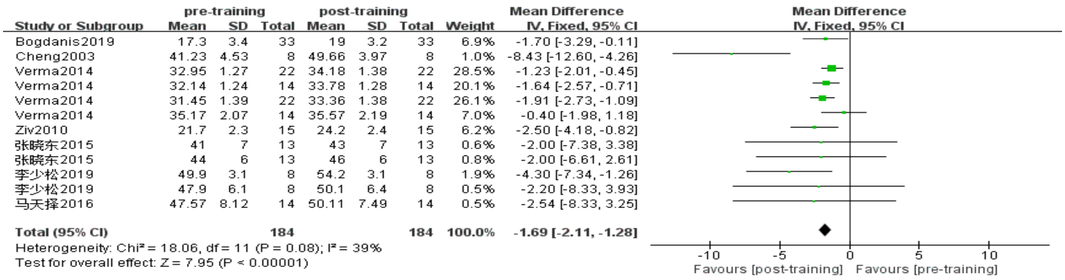

Figure 3. Forest Map of Meta-Analysis of Longitudinal Jump Effector

2.2.3 Meta-analysis of the effect size of 20-m sprints

A total of 6 trial experiments were included in the study on the effect size of 20-m sprints of basketball players before and after intervention in the resistance training [23, 35, 29, 27], among which the studies by Zhang Xiaodong, Gan Liju contained two resistance training programs; Figure 4 demonstrates a Forest Map of the Meta-analysis results of the effect size of 20-m sprints. The heterogeneity in the study can be seen from Figure 4 (X^2 = 30.17, I^2 = 83 %, P < 0.0001), therefore, the Meta-analysis shall adopt the random effects model. The analysis results show that resistance training intervention has a significant effect on basketball players' 20-m sprints [SMD =0.24, 95 % CI(0.04, 0.43), P = 0.02].

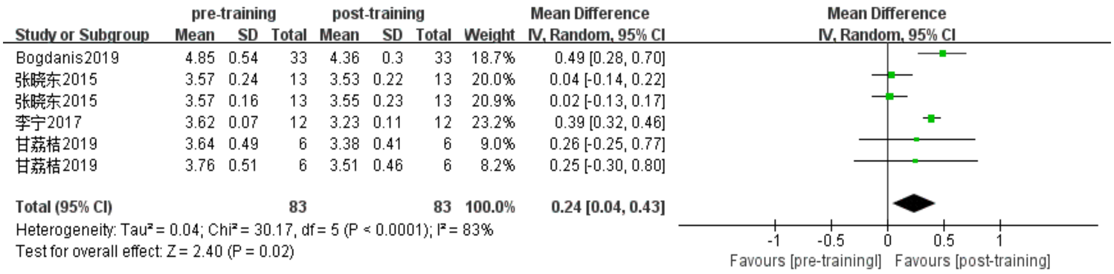

Figure 4. Funnel Map Of Meta Analysis On Effect Size Of 20m Acceleration Run

2.2.4 Meta-analysis of the effect size of standing long jump

A total of 8 trial experiments were included in the study on the effect size of standing long jump of basketball players before and after intervention in the resistance training [23, 30, 28, 36, 31], among which the studies by Li Shaosong, Zhao Qichao contained two resistance training programs; Figure 5 shows a Forest Map of the Meta-analysis results of the effect size of standing long jump. The heterogeneity in the study can be seen from Figure 5 ($X^2 = 33.45$, $I^2 = 79$ %, $P < 0.0001$), therefore, the Meta-analysis shall adopt the random effects model. The analysis results indicate that resistance training intervention has a significant effect on basketball players' standing long jump performance [SMD =-11.46, 95 % CI(18.09, -83), P < 0.0007].

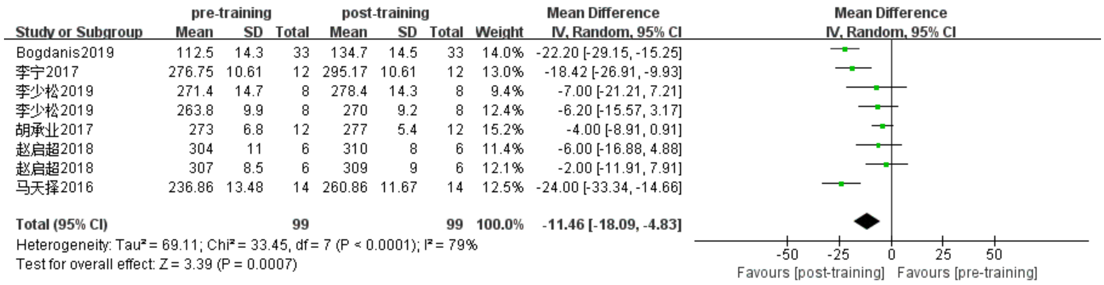

Figure 5. Funnel Map Of Standing Long Jump Effect Size Meta-Analysis

2.2.5 Subgroup analysis

Because of the heterogeneity between the 20-m sprints and standing long jump groups included in the study, and because of the large age gap in the longitudinal jumping, the subgroup analysis is conducted. The ages of longitudinal jumping are divided into ≤ 11 years old, 11 years old < resistance training group ≤ 15 years old, and > 15 years old; Figure 6 indicates the subgroup analysis results of the combined longitudinal jumping effect size data for the age resistance training group ≤ 11 years old, 11 years < resistance training group ≤ 15 years old, and 15 < resistance training groups. It can be seen from Figure 8 that there is heterogeneity in longitudinal jumping data analysis of age ≤ 11 years old ($X^2 = 1.93$, $I^2 = 0$ %, $P < 0.00001$), the 95 % confidence interval total effect size [SMD =-1.54, 95 % CI(-0.08, -1.01), P < 0.0001]; The analysis heterogeneity of age 11-15 ($X^2 = 2.82$, $I^2 = 0$ %, $P = 0.42$), the 95 % confidence interval total effect size [SMD =-1.16, 95 % CI(-2.32, -0.90), P < 0.00001]; The analytical heterogeneity of age > 15 ($X^2 = 4.28$, $I^2 = 30$ %, $P = 0.23$), the 95 % confidence interval total effect size [SMD =-4.88, 95 % CI(-7.00, -2.76), P < 0.00001]. It can be seen that resistance training has significant effect on the longitudinal jumping effect of different age groups.

Figure 7 shows the subgroup analysis results of the combined 20m sprints effect size data for the age resistance training group 1, resistance training group 2, and the trial experiments group. It can be seen from Figure 9 that the heterogeneity of 20m sprints data analysis between the training group (resistance training group 1 and resistance training group 2 are collectively referred to as the training group) and the trial experiments group ($X^2 = 1.59$, $I^2 = 0$ %, $P < 0.00001$), 95 % confidence interval total effect size [SMD = 0.22, 95 % CI(0.15, 0.29), P < 0.00001]; Resistance training group 1 and resistance training group 2 analysis heterogeneity ($X^2 = 0.17$, $I^2 = 0$ %, $P = 0.68$), 95 % confidence interval total effect size [SMD = 0.03, 95 % CI(-0.13, 0.20), P = 0.7].

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Figure 8 demonstrates the subgroup analysis results of the combined standing long jump effect size data for the age resistance training group 1, the age resistance training group and the trial experiments group. It can be seen from Figure 10 that the heterogeneity of 20m sprints data analysis between the training group and the trial experiments group (X^2 = 3.17, I^2 = 37 %, P = 0.21), 95 % confidence interval total effect size [SMD =-8.06, 95 % CI(-11.50, -4.61), P < 0.00001]; Resistance training group 1 and resistance training group 2 analysis heterogeneity (X^2 = 0.91, I^2 = 0 %, P = 0.34), 95 % confidence interval total effect size [SMD =-3.97, 95 % CI(-11.42, 3.49), P = 0.30].

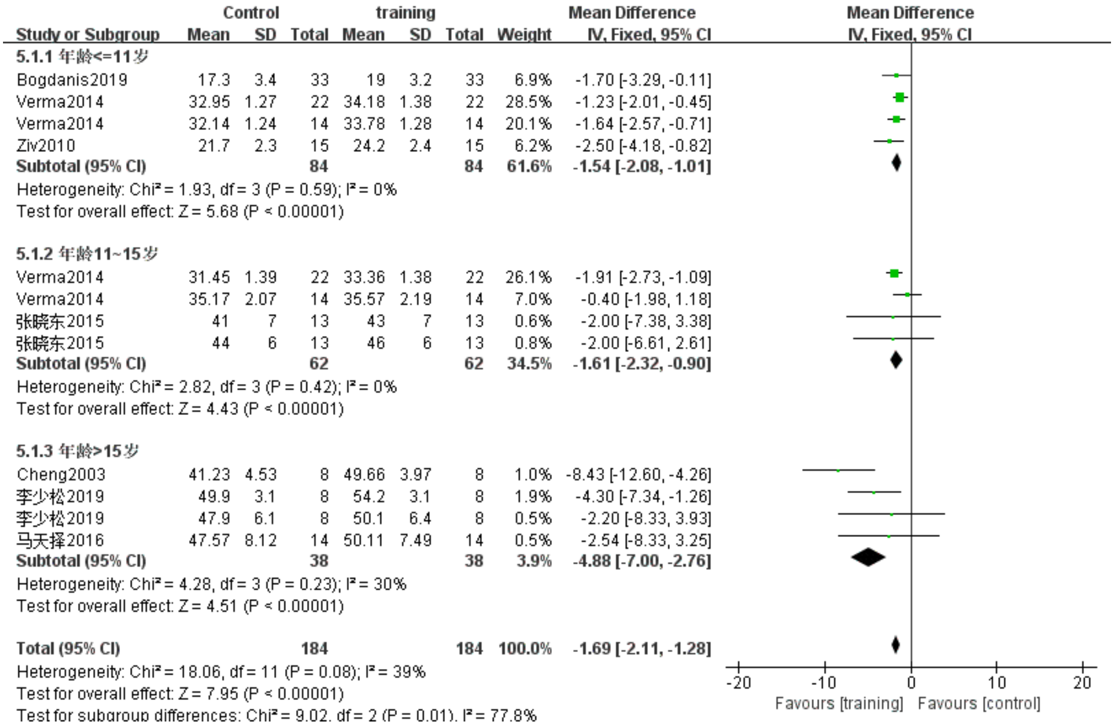

Figure 6. Subgroup Forest Map Of Longitudinal Jump Effect Size

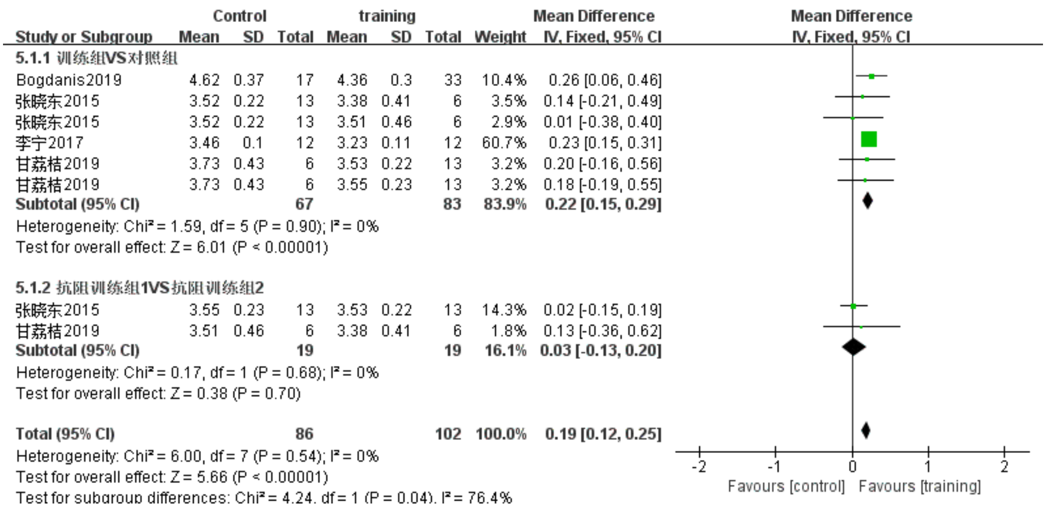

Figure 7. 20m Acceleration Effect Subgroup Forest Diagram

Note. Group 1 of Zhang Xiaodong 2015 is the supervised resistance training, and Group 2 is the video resistance training; Group 1 of Gan Liju 2019 is HISRT resistance training, and Group 2 is HISRT + LBFRT comprehensive training.

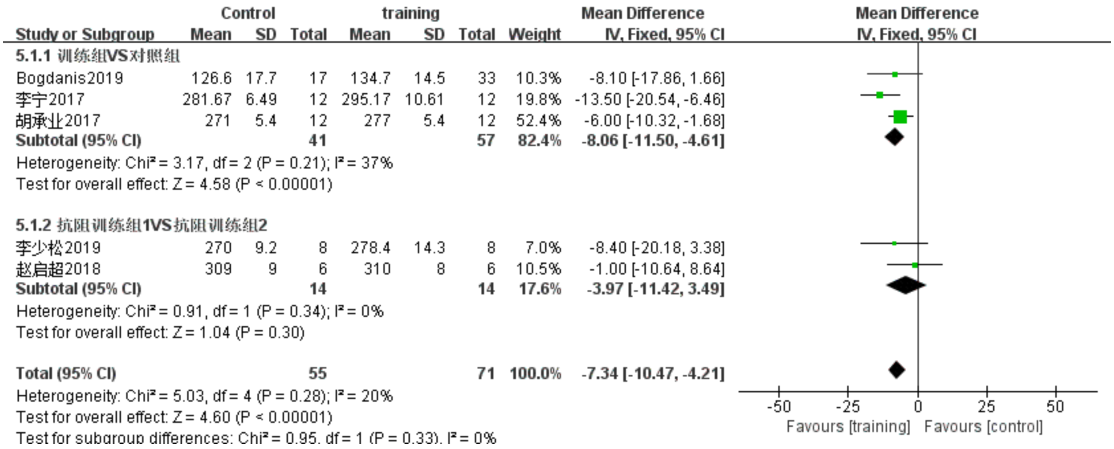

Figure 8. Forest Map Of Standing Long Jump Effect Size Subgroup

Note. Group 1 and Group 2 of Li Shaosong 2019 and Zhao Qichao 2018 are both two legs resistance training and single leg resistance training.

Conclusions

Because of the restriction of basketball court and rules, basketball players are required to obtain greater body acceleration in a short time and space to improve their bounce and air superiority ability. Therefore, the requirements for the strength quality of basketball players, especially the strength of lower limb muscles, are particularly critical. Therefore, in the literature included in this paper, the running height, the longitudinal jumping, the 20-m sprints and the standing long jump are selected as the intervention and evaluation indexes of Meta-analysis. Through the Meta-analysis of the literature included in this paper, it is confirmed that the 8-week resistance training is conducive to the improvement of athletes' ability to run up and touch height ($P < 0.05$); Among them, before and after training and the comparison of components showed that different forms of resistance training interventions for 6 weeks had significant effects on the explosive force of basketball players' lower limbs. In addition, the effect of plyometric resistance training is particularly significant for the improvement of athletes' longitudinal jumping and touching ability of different ages ($P < 0.05$).

The analysis of the research results of 20-m sprints in the training group and the trial group showed that 8 weeks of resistance training significantly improved the ability of 20-m sprints ($P < 0.05$); HISRT resistance training and HISRT + LBFRT Comprehensive Resistance Training is not significant ($P > 0.05$) to improve the ability of 20-m sprints.

The analysis of the results of the study on the standing long jump in the training group and the trial group shows that, 8 weeks of resistance training had a significant effect on the training intervention to improve the stationary long jump ability ($P < 0.05$); HISRT resistance training and HISRT + LBFRT comprehensive resistance training is not significant ($P > 0.05$) on the training intervention to improve the stationary long jump. However, because of the small sample size and study inclusion, the comparison results are treated cautiously and different resistance effects all improve lower limb muscle strength.

To sum up, more high-quality resistance training intervention studies are required to provide reliable basis for effective intervention programs for lower limb muscle strength of basketball players, so as to consolidate and expand the results of this Meta-analysis. It is suggested that future research may quantify the variation law of training intensity and interval time corresponding to resistance training methods. The results of this study support that resistance training lasting for more than 6 weeks, 2-3 times per week, is an effective training strategy to improve the lower limb muscle strength and athletic performance of basketball players.

References

1 Cormie, P., McGuigan, M.R., & Newton, R.U. (2011). Developing maximal neuromuscularpower: part 2 — training considerations for improving maximal power production. *Sports Med., 41(2).*

2 Canavan, P.K., & Vescovi, J.D. (2004). Evaluation of power prediction equations: peak vertical jumping power in women. *Med Sci Sports Exerc, 36:*1589–93.

3 Potteiger, J.A., Lockwood, R.H., Haub, M.D., et al. (1999). Muscle power and fiber characteristics following 8 weeks of plyometric training. *J Strength Cond Res,13:* 275–79.

4 Bobbert, M.F. (1990). Drop jumping as a training method for jumping ability. *Sports Med, 9:7–22*.

5 Kraemer, W.J., Mazzetti, S.A., Nindl, B.C., et al. (2001). Effect of resistance training on women's strength/power and occupational performances. *Med Sci Sports Exerc, 33:*1011–25.

6 Bassey, E.J., Fiatarone, M.A., O'Neill, E.F., et al. (1992). Leg extensor power and functional performance in very old men and women. *Clin Sci (Lond), 82:321–7*.

7 Newton, R.U., & Kraemer, W.J. (1994). Developing explosive muscular power: implicationsfor a mixed methods training strategy. *Strength Cond,16(5).*

8 Verkhoshansky, Y., & Tatyan, V. (1973). Speed-strength preparation of future champions, *Legkaya Athletika, 2, 6*. Ebben WP.

9 Wilson, G.J., Murphy, A.J., & Giorgi, A. (1996). Weight and plyometric training: effects on eccentric and concentric force production. *Can J Appl Physiol, 21:301–15*.

10 Wilson, G.J., Newton, R.U., Murphy, A.J., et al. (1993). The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc, 25:1279–86.*

11 Adams, K., O'Shea, J.P., O'Shea, K.L., et al. (1992). The effect of six weeks of squat, plyometric and squat-plyometric training on power production. *J Appl Sport Sci Res, 6:36–41*.

12 Malatesta D., Cattaneo F., Dugnani S., et al. Effects of electromyostimulation training and volleyball practice on jumping ability. J Strength Cond Res 2003;17:573–9.

13 Cardinale, M., & Bosco, C. (2003). The use of vibration as an exercise intervention. *Exerc Sport Sci Rev, 31:3–7*.

14 Ebben, W.P., & Blackard, D.O. (2001). Strength and conditioning practices of National Football League strength and conditioning coaches. *J Strength Cond Res, 15:48–58*.

15 Ebben, W.P., Carroll, R.M., & Simenz, C.J. (2004). Strength and conditioning practices of National Hockey League strength and conditioning coaches. *J Strength Cond Res, 18:889–97.*

16 Simenz, C.J., Dugan, C.A., & Ebben, W.P. (2005). Strength and conditioning practices of National Basketball Association strength and conditioning coaches. *J. Strength Cond Res, 19:495–504.*

17 Herrero, J.A., Izquierdo, M., Maffiuletti, N.A., et al. (2006). Electrostimulation and plyometric training effects on jumping and sprint time. *Int J Sports Med, 27:533–9*.

18 Turner, A.M., Owings, M., & Schwane, J.A. (2003). Improvement in running economy after 6 weeks of plyometric training. *J Strength Cond Res, 17:60–7*.

19 Miller, M.G., Berry, D.C., Bullard, S., et al. (2002). Comparisons of land-based and aquaticbased plyometric programs during an 8-week training period. *J Sport Rehabil, 11:268–83*.

20 Young, W.B., Wilson, G.J., & Byrne, C. A. (1999). comparison of drop jump training methods: effects on leg extensor strength qualities and jumping performance. *Int J Sports Med, 20:295–303.*

21 Adams, T.M. (1984). An investigation of selected plyometric training exercises on muscular leg strength and power. *Track Field Q Rev, 84:36–9.*

22 Luebbers, P.E., Potteiger, J.A., Hulver, M.W., et al. (2003). Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *J Strength Cond Res, 17:704–9.*

23 Bogdanis, G.C., Donti, O., Papia, A., Donti, A., Apostolidis, N., & Sands, W.A. (2019). Effect of Plyometric Training on Jumping, Sprinting and Change of Direction Speed in Child Female Athletes. *Sports. 7.* DOI: 10.3390/sports7050116.

24 Cheng, Ching-Feng, & Lin, Lien-Chieh, & Lin, Jung. (2003). Effects of Plyometric Training on Power and Power-Endurance in High School Basketball Players. *Annual Journal of Physical Education and Sports Science, 3,* 41-52.

25 Verma, Chhaya, & Subramanium, Lakshmi, & Krishnan, Vijaya. (2015). Effect of plyometric training on vertical jump height in high school basketball players: A randomised control trial. *International Journal of Medical Research & Health Sciences, 4,* 7. DOI: 10.5958/2319-5886.2015.00002.8.

26 Ziv, G., & Lidor, R. (2010). Vertical jump in female and male basketball players—A review of observational and experimental studies. *Journal of Science and Medicine in Sport, 13, 3*, 332–339, ISSN 1440-2440, https://doi.org/10.1016/j.jsams.2009.02.009.

27 Gan, Liju, & Hui, Jun (2019). "An Empirical Study on the Effect of 'HISRT+LBFRT" Comprehensive Training on the Explosive Power of Male College Basketball Players in China". *Journal of Shenyang Sport University, 38(01):* 116-122.

28 Hu, Chengye (2017). Experimental Study on the Effect of Plyometric Training on Lower Limb Explosive Power in College Basketball Majors. *Xi'an Physical Education University*.

29 Li, Ning (2017). Study on the Effect of Plyometric Training on Explosive Power in Basketball Players. Guangzhou Sport University.

30 Li, Shaosong (2019). The Effects of Single-Leg Romanian Deadlift and Double-Leg Romanian Deadlift on Lower Limb Explosive Power in Male College Basketball Players. Beijing Sport University.

31 Ma, Tianze (2016). Research on Lower Limb Explosive Power Training Programs for Young Male Basketball Players in Hebei Province. Hebei Normal University.

32 Yan, Yufeng (2014). Experimental Study on the Influence of Barbell Power Clean Strength on Jumping Ability in Male College Basketball Players. Beijing Sport University.

33 Yang, Zhongjun (2013). Research on the Effects of Different Combined Strength Training Methods on Lower Limb Explosive Power in Basketball Players. Beijing Sport University.

34 Yin, Wei (2015). "Experimental Study on Core Strength Training to Improve the Technical Level of Young Female Basketball Players in Shandong Province". *Shandong Sports Science & Technology, 37(04):* 26-29.

35 Zhang, Xiaodong (2015). "Experimental Study on the Effect of Online Video-Based Resistance Training on Improving Physical Fitness in Adolescent Basketball Players". *Journal of Shandong Sport University, 31(04):* 90-95.

36 Zhao, Qichao (2018). A Comparative Study of Single-Leg and Double-Leg Resistance Training on Lower Limb Explosive Power Development in Basketball Players. Beijing Sport University.

37 Maher, C.G., Sherrington, C., Herbert, R.D., et al. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther, 83:713–21*.

38 Bauer, P., Uebellacker, F., Mitter, B., Aigner, A.J., Hasenoehrl, T., Ristl, R., et al. (2019). Combining higher-load and lower-load resistance training exercises: A systematic review and meta-analysis of findings from complex training studies, *Journal of Science and Medicine in Sport, 22,* 7.

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Ways to prevent men's cardiovascular diseases during training at the gym

The article presents a significant cause of male mortality and the results of empirical observations of a group of 7 men working out in the gym under the supervision of a trainer. Men are more susceptible to cardiovascular diseases earlier and more than women. Wellness training and psycho-emotional stability have a preventive effect on the development of cardiopathology. Men's regular gym-based training for 3–6 months, 3 times a week for 1.5 hours in the gym, increased personal self-esteem and satisfaction, improved body composition, but at the same time, prenosological diagnostics of the functional parameters of the cardiovascular system of the examined patients gave unsatisfactory results. To reduce the risk of diseases of the cardiovascular system in men, it is necessary to carry out a prenosological diagnosis of the functional state with subsequent correction of the structure of the training load, perform individually dosed cardio in a sufficient and safe range of heart rate and breathing exercises.

Keywords: men's health, cardiovascular system, strength training, functional tests, dosed aerobic load.

Introduction

According to the World Health Organization (WHO), cardiovascular diseases are the leading cause of mortality among the adult population in the world, including in Kazakhstan [1]. Numerous studies have shown that men are prone to developing heart diseases 10–15 years earlier than women, starting at about the age of 25 [2–5].

Today, the government places significant emphasis on the early diagnosis and treatment of cardiovascular diseases. Advanced high-tech cardiac surgeries are being implemented to treat patients with severe chronic heart failure.

At the same time, global experience proves that preventive measures are more effective than a clinical approach to solving the problem. Positive changes in the current situation can be expected only with the activation of the disease prevention and health promotion system — changes in a person's lifestyle, where key roles are played by health-improving training and psycho-emotional resilience.

Currently, there is a wide network of wellness centers that successfully promote fitness programs of various orientations, but men tend to participate less in group classes and prefer working out in the gym. Moreover, not all of them seek guidance from a trainer to develop a personalized training program; many independently determine their training load on their own.

Based on the aforementioned, it was decided to assess how much regular gym exercises protect the body from health disorders and to evaluate the preventive effect in terms of reducing cardiovascular risk factors in men.

Methods and materials

To achieve the stated objective, a group of 7 people who regularly exercised at the gym (3 times a week for 1.5 hours for 3–6 months) was examined.

The individual training load was assigned by the trainer, who also conducted ongoing pedagogical observations to ensure correct exercise performance.

The gym is equipped with a variety of fitness equipment for strength training. In addition, during the workout, the participants received a dosed aerobic load on a treadmill.

The age of the observed people: 6 people between 22–27 years and 1 person aged 50 years old. Functional indicators were measured before training.

The study used simple, accessible methods of prenosological diagnostics of basic functional indicators:

- blood pressure — BP,
- heart rate — HR,
- stroke volume — SV, was calculated using Starr's formula
- cardiac output — CO = SV*HR
- circulatory efficiency coefficient — CEC
- Breath Holding test (Stange's test) — BHT,
- modified Romberg maneuver — static balancing — SB,
- Kerdo's vegetative index assessment — KVI
- Baevsky's adaptation potential — AP

The following average normative values were used as criteria: BP — 120/80 mmHg, HR — 60-80 beats per minute, SV — 60 mL, BHT — 50 seconds, SB — 15 seconds.

To assess the mental state, anxiety levels were tested using the Spielberger-Hanin scale, and levels of Physical Satisfaction Score (PSS), Social Satisfaction Score (SSS), and Mental Satisfaction Score (MSS) were determined according to I.A. Gundarov's method (on a 100-point scale) [6].

The results are shown below.

Results and Discussion

An analysis of the cardiovascular system indicators (Table 1) shows that the HR in two participants (25.6 %) exceeds the norm (60–80 beats per minute). Diastolic pressure was elevated in six out of the seven participants. Stroke volume did not reach the normative value in any of the participants.

Table 1

Cardiovascular system indicators of men training at the gym

№	**Name**	**Age (in years)**	**HR (bpm)**	**BP (mmHg)**	**SV (mL)**	**CO (mL)**	**AP (points)**	**CEC**
1	P.A.	22	89	165-135	21,8	1940,2	3,651	2670
2	G.D.	20	76	120-90	50	3800	2,238	3040
3	K.A.	25	72	120-80	58	4176	2,319	2880
4	O.I.	50	72	120-90	32	2304	2,713	2160
5	A.R.	27	84	125-90	48,3	4057,2	2,737	2940
6	G.A.	23	72	120-90	48,2	3470,4	2,281	2160
7	A.B.	24	72	110-90	42,6	3067,2	2,137	2160

The definition of adaptive potential (AP) according to R.M. Baevsky was used as a criterion for the adaptive capabilities of a whole organism. According to Baevsky's research, the higher the numerical value of AP, the lower the level of functional (adaptive) capabilities of the human body [7]. A reference point of 2.11 points is used, above which indicates strain in the adaptation mechanisms, and below that — a satisfactory level of adaptation. As shown in Table 1, all participants exhibited varying degrees of strain in their adaptation mechanisms.

Normally, the circulatory efficiency coefficient (CEC) in a healthy individual ranges from 2000 to 2600. An increase in this indicator suggests impaired cardiac function and reduced adaptive capacity of the cardiovascular system, which was observed in four out of the seven participants.

We would like to pay special attention to the indicators of 22-year-old patient №1 P.A.: heart rate, blood pressure, both systolic and diastolic are elevated (165-135 mmHg), there are low systolic (21.8 ml with

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a norm of 60-80 ml), and minute blood volumes, tension of adaptation mechanisms, and a slightly increased CEC.

Overall, regardless of the participants' age, their indicators reflect an unsatisfactory functional state of the cardiovascular system.

Table 2 presents the results of the Stange's test (BHT), static balancing (SB), and Kerdo's vegetative index (KVI).

A Breath Holding time of 50–60 seconds is considered a good result for untrained people, 40–49 seconds is satisfactory, and less than 39 seconds is unsatisfactory. For trained people, a good result ranges from 60 to 90 seconds or more.

As shown in the table below (Table 2), 6 participants demonstrated good Breath Holding results, and one — № 5 A.R. showed a satisfactory result, notably, participant № 1 P.A., who is in the risk group, had a high score.

In the assessment of SB, maintaining the pose for 15 seconds is considered a satisfactory result, indicating the participant's ability to maintain body equilibrium — a result demonstrated by all participants.

The results of the Kerdo's Vegetative Index (KVI) assessment (Table 2) indicate a predominance of the sympathetic division of the autonomic nervous system (ANS) among the participants, since when the sympathetic and parasympathetic divisions of the ANS are balanced, the KVI = 0, and if the KVI is less than 0, the parasympathetic division of the ANS predominates.

In our case, the KVI of the all participants is more than 1, moreover, the greatest predominance of the sympathetic nervous system was noted in №1 P.A.(1,51).

Table 2

Indicators of the functional capabilities of the respiratory system and static balancing in men training at the gym

№	Name	BW (kg)	H (cm)	BHT (sec)	SB (sec)	KVI
1	P.A.	94	178	75	20	1,51
2	G.D.	70	182	51	15	1,18
3	K.A.	89	186	55	25	1,1
4	O.I.	82	183	50	19	1,25
5	A.R.	90	175	41	33	1,07
6	G.A.	72	179	53	20	1,25
7	A.B.	67	176	66	18	1,25

Many researchers emphasize the special role of personal self-assessment of well-being in evaluating health status. For this purpose, various subjective health characteristics are proposed: "the ability to live a full life in close connection with what I love", "I am healthy when I am in balance, when I am able to do what I want", "it is the choice of a lifestyle that allows me to enjoy my health" [8].

I.A. Gundarov (1993) proposed a method for determining the "health quality", including an assessment of a person's physical, mental and social satisfaction, which can be easily measured and quantified [6]. Such an assessment can be carried out either through a survey or by filling out a standard questionnaire. The "health quality" reflects not the living conditions or the state of the body, but the individual's satisfaction with their bodily condition in relation to their living conditions and various aspects of life. This group of indicators includes the results that characterize a person's well-being, activity, and mood.

The social and psychological aspects of health determine the harmonious process of developing a person's inner world (self-acceptance — understanding, accepting, analyzing, controlling, loving) and relationships with others, adaptation in society [9]. Subjective self-assessment of health is no less important than objective health indicators. To assess the mental state and satisfaction, a survey was conducted using the Spielberger-Khanin's scale and the level of physical, social and mental satisfaction according to Gundarov (Table 3).

Table 3

Assessment of personal anxiety — according to Spielberger-Khanin scale and satisfaction level according to Gundarov

№	Name	PSS (points)	SSS (points)	MSS (points)	PA (points)
1	P.A.	70,0	100,0	99,7	43,0
2	G.D.	80,0	100,0	99,8	47,0
3	K.A.	80,0	100,0	99,3	45,0
4	O.I.	90,0	100,0	99,8	35,0
5	A.R.	60,0	100,0	99,8	34,0
6	G.A.	80,0	90,0	99,9	39,0
7	A.B.	80,0	100,0	99,5	44,0

According to the results represented in Table 3, the satisfaction levels of the men training at the gym are high (PSS 77,1±10,0, SSS 98,6±3,3, MSS 99,7±0,2), with the exception of № 5 A.R., whose PSS score was an average value of 60.0.

Moreover, in the group of men training at the gym, we identified the following: a lower anxiety level 41,0±4,3, and higher social (SSS — 98,6±3,3) and mental satisfaction (MSS 99,7±0,2).

It should be noted that all the surveyed participants rated their physical, social and mental satisfaction significantly higher than average, compared to the period before starting their training at the gym.

A significant indicator of the effectiveness of training is an increase in muscle mass, an increase in bone density, reduction of visceral fat. According to the results of a study of body composition by bioimpedance measurement using a TANITA multi-frequency analyzer, the majority of the surveyed were younger in body composition than their calendar age [10].

However, when comparing the functional state and the compositional age, the results did not align. It turned out that being slim is not a guarantee of good health.

The cardiovascular system reflects the body's reactions to external and internal factors, and its indicators are primary for the prenosological assessment of the overall functional state of the body.

Certainly, prenosological diagnostics do not replace medical supervision, but it helps prevent the development of disorders that lead to the onset of diseases.

The conducted research demonstrated that regular strength training for 3–6 months in the gym had a positive impact on the psycho-emotional state of men, body composition, but did not have a positive effect on the studied functional indicators of the cardiovascular system. This, apparently, indicates insufficient aerobic load for effective cardiovascular training.

Conclusions

- to solve the problems of health-improving training — reducing the risk of cardiovascular diseases in men, it is necessary to conduct a prenosological diagnostics of the functional state followed by the correction of the training load structure.

-it is important to get cardio training in a sufficient and safe range of heart rate (HR). This range is different for each person. The safe pulse zone (BPZ) for cardio training can be calculated using the formula: 220 — age and perform aerobic exercises at a heart rate of 60–80 % of the result for 30 minutes per workout.

-to pay attention to dosed aerobic loads and breathing exercises for a positive effect on the state of the cardiovascular system.

-pay attention to breathing exercises for a positive effect on the state of the cardiovascular system.

References

1 WHO. Cardiovascular diseases. (n.d.). *www.who.int.* Retrieved from https://www.who.int/ru/health-topics/cardiovascular-diseases#tab=tab_1.

2 Kurbanova, G.D., Tnimova, G.T., & Seksenov, V.A. (2020). Subektivnaia otsenka zdorovia muzhchinami i zhenshchinami [Subjective health assessment by men and women]. Proceedings from The Interuniversity Scientific and Practical Conference with International Participation dedicated to the 75th Anniversary of the Victory of the Soviet People in the Great Patriotic War (*7 maia*

 ISSN 3081-0531 (Print) ISSN 3081-054X (Online)

2020 goda): "Socio-Hygienic and Clinical Problems of Modern Medicine" (pp. 51-53). A.I. Evdokimov Moscow State University of Medicine and Dentistry [in Russian].

3 Drapkina, O.M., Kupreishvili, L.V., & Fomin, V.V. (2017). Kompozitsionnyi sostav tela i ego rol v razvitii metabolicheskikh narushenii i serdechno-sosudistykh zabolevanii [Body composition and its role in development of metabolic disorders and cardiovascular diseases]. *Kardiovaskuliarnaia terapiia i profilaktika — Cardiovascular Therapy and Prevention, 16(5),* 81–85 [in Russian].

4 Apanasenko, G.L., & Popova, L.A. (2000). Meditsinskaia valeologiia [Medical valeology]. *Rostov na-Donu: Feniks, 248* (4) [in Russian].

5 Voitenko, V.P. (1991). Zdorove zdorovykh. Vvedenie v sanologiiu [The Health of the Healthy: Introduction to Sanology]. Kyiv: Zdorovia, 246.

6 Gundarov, I.A., & Polesskii, V.A. (1993). Aktualnye voprosy prakticheskoi valeologii [Current issues of Practical Valeology]. In *Valeology: Diagnostics, Means and Practice of Health Maintenance.* Saint Petersburg, 25–32 [in Russian].

7 Baevskii, R.M., & Berseneva, A.P. (1990). Adaptatsionnyi potentsial sistemy krovoobrashcheniia i voprosy donozologicheskoi diagnostiki [Adaptation potential of the circulatory system and issues of prenosological diagnostics]. *Problemy adaptatsii detei i vzroslogo organizma v norme i patologii — Problems of Adaptation of Children and Adults in Normal and Pathological Conditions*. Moscow: IGMI, 172 [in Russian].

8 Solodkov, A.S., & Sologub, E.B. (2001). Fiziologiia cheloveka. Obshchaia. Sportivnaia. Vozrastnaia [Human Physiology: General, Sports, and Age-related]. Moscow: Olimpiia Press [in Russian].

9 Kornienko, D.S., Kozlov, A.I., & Otavina, M.L. (2016). Vzaimosviaz samootsenok zdorovia i psikhologicheskogo blagopoluchiia u prakticheski zdorovykh i imeiushchikh khronicheskie zabolevaniia molodykh liudei [Differences in self-assessment of health and psychological well-being between healthy and unhealthy young adults]. *Hygiene & Sanitation (Russian Journal), 95(6),* 577–581. DOI: 10.18821/0016-9900-2016-95-6-577-581 [in Russian].

10 Tanita Vesy i analizatory sostav tela [Tanita. Scales and Body Composition Analyzers]. *(n.d.). medves.ru.* Retrieved from http://medves.ru/f/tanita_2016_2.pdf [in Russian].

References

1 WHO. Cardiovascular diseases. (n.d.). *www.who.int.* Retrieved from https://www.who.int/ru/health-topics/cardiovascular-diseases#tab=tab_1.

2 Курбанова Г.Д., Тнимова Г.Т., Сексенов В.А. Субъективная оценка здоровья мужчинами и женщинами // Материалы межвузовской научно-практической конференции с международным участием, посвящённой 75-й годовщине Победы советского народа в Великой Отечественной войне «Социально-гигиенические и клинические проблемы современной медицины». — ФГБОУ ВО Московский государственный медико-стоматологический университет им. А.И. Евдокимова. — 7 мая 2020. — С. 51–53.

3 Драпкина О.М. Композиционный состав тела и его роль в развитии метаболических нарушений и сердечно-сосудистых заболеваний / О.М. Драпкина, Л.В. Купрейшвили, В.В. Фомин // Кардиоваскулярная терапия и профилактика. – – 2017. — 16(5). — С. 81–85.

4 Apanasenko, G.L., & Popova, L.A. (2000). Meditsinskaia valeologiia [Medical valeology]. *Rostov na-Donu: Feniks, 248* (4) [in Russian].

5 Войтенко В.П. Здоровье здоровых: Введение в санологию / В.П. Войтенко. — К.: Здоровья, 1991. — 246 с.

6 Гундаров И.А. Актуальные вопросы практической валеологии / И.А. Гундаров, В.А. Полесский // Валеология: диагностика, средства и практика обеспечения здоровья. — СПб., 1993. — С. 25–32.

7 Баевский Р.М. Адаптационный потенциал системы кровообращения и вопросы донозологической диагностики / Р.М. Баевский, А.П. Берсенева // Проблемы адаптации детей и взрослого организма в норме и патологии. М.: ИГМИ, 1990. — с. 172.

8 Солодков А.С. Физиология человека. Общая. Спортивная. Возрастная: учеб. / А.С. Солодков, Е.В. Сологуб // М.: Олимпия Пресс, 2001.

9 Корниенко Д.С. Взаимосвязь самооценок здоровья и психологического благополучия у практически здоровых и имеющих хронические заболевания молодых людей / Д.С. Корниенко, А.И. Козлов, М.Л. Отавина // Гигиена и санитария. — 2016. — 95(6). — С. 577–581. DOI: 10.18821/0016-9900-2016-95-6-577-581.

10 Tanita Весы и анализаторы состав тела [Электронный ресурс]. — Режим доступа: http://medves.ru/f/tanita_2016_2.pdf.

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Gender differences in integral indicators of adaptation of athletes' bodies to training in different energy modes

Adaptation to intense muscle activity leads to an increase in athletic performance. The task is not to bring an athlete to the stage of failure of adaptation mechanisms during training, which is accompanied by a drop in performance and other negative consequences, hence the need to have accessible and informative markers of the athlete's body condition in order to correct the training process. The study was conducted at the Olympic Training Center (OTC), city of Karaganda. The participants were athletes without health complaints. To determine the physical performance of athletes, a submaximal PWC $_{170}$ test was used, and the MOC was calculated by an indirect method. Based on the measurement of the main indicators of the cardiovascular system (HR, SBP, DBP) and the calculation of derivative indices (PP, SBV, MCV, DP, KEC) adopted in sports medicine and adaptology (ShI, IFC), a comparative analysis of the adaptation of the body of high-class athletes (46 people) to training in different energy modes (aerobic, anaerobic-aerobic, anaerobic) was performed. The study showed differences in the adaptation indicators of the cardiovascular system of the athletes depending on the energy mode of training and gender. Measurement and subsequent calculation of accessible and informative indicators of adaptation of the cardiovascular system of the athlete's body to training loads in different energy modes allows not only to monitor its current state, but also to identify the stress preceding the breakdown of adaptation mechanisms.

Keywords: athlete, gender, energy training regime, cardiovascular system adaptation, stress, adaptation failure, indices.

Introduction

The state of the system can be assessed by the final result of its action, by the output. At the output of the system, first of all, energy is released, due to which the impact on the environment is carried out. The amount of this energy correlates with viability, which, in turn, is associated with the concept of adaptability. In addition, the energy potential is an integral indicator of the system's operation; it can be calibrated and reflected in the integral indicators of the system's state [1]. In connection with the above, the integral indicators of the athlete's body adaptation (training) can be working capacity, as well as indicators of his physical development, assessed by the method of standards and the method of indices [2, 3].

The ability to adapt to an influencing factor (in our case, to intense muscular activity) without breaking down the adaptation mechanisms is possible only with sufficient adaptation potential. The "cost of adaptation" is determined primarily by the costs of maintaining the required level of functioning of the cardiovascular system [4].

The purpose of this study is to identify gender-specific features of the adaptive capabilities of the cardiovascular system of athletes training in various energy modes using generally available methods accepted in sports medicine and adaptology.

Materials and methods

The survey was conducted at the beginning of the annual training cycle at the Olympic Training Center (OTC), Karaganda. The surveyed high-class athletes (masters of sports, candidate masters of sports) were divided into 3 groups: 21 people training mainly in aerobic mode, 7 people in anaerobic mode, 18 people in mixed, aerobic-anaerobic mode. The study groups included athletes without health complaints. The following indicators were measured using standard methods: HR (heart rate), SBP (systolic blood pressure), DBP (diastolic blood pressure), PP (pulse pressure) were measured by generally accepted methods.

Based on the data obtained, the following integral indices were calculated: SBV — systolic blood volume; MCV — minute circulatory volume; KEC — Kvass endurance coefficient (the ratio of HR to PP, multiplied by 10); DP — “double product”, characterizes the systemic work of the heart; ShI — Shaptala index, reflects the adaptive capabilities of the cardiovascular system; IFC — index of functional changes [4].

To determine the physical performance of athletes, the submaximal PWC $_{170}$ test was used, and maximal oxygen consumption (MOC) was calculated using an indirect method [3].

The digital material obtained as a result of a comprehensive instrumental study was processed using the method of variation statistics with standard programs. In statistical processing of the obtained results, the method of finding the indicator of a significant difference from the arithmetic mean (M), the value of the square deviation (σ), and the average error (m) was used. The degree of reliability between the compared values was determined by the Student’s t reliability criterion (Sepetliev D., 1968). Differences were assessed as reliable if the probability value P corresponded to a value of less than 0.05 (95 %).

Results

The results of the parameters of the cardiovascular system are presented in Table 1. The heart rate (HR) of men and women training in the same energy mode showed no significant differences. In the group of athletes training in the anaerobic mode, HR was 71.0±7.5 beats/min in men and 72.0±4.2 beats/min in women. In the anaerobic-aerobic mode, HR values were 64.0±2.1 and 62.0±2.5 beats/min, respectively, while in the aerobic mode they were 63.1±2.8 and 62.0±2.5 beats/min (Table 1).

Table 1

Cardiovascular parameters of elite athletes training in different bioenergetic modes (M±m)

Training mode	Heart rate, d /min	SBP, mm Hg	DBP, mm Hg	PP, mm Hg	DP, conventional units.
men					
Anaerobic	71.0±7.5	123.3±4.2	80.0±1.0	43.3±4.2	87.7±9.3
Anaerobic-aerobic	64.0±2.1	116.7±1.8	74.2±3.5	42.5±4.4	74.5±2.5
Aerobic	63.1±2.8	126.2±3.3	82.5±2.0	42.1±3.3	76.0±4.6
women					
Anaerobic	72.0±4.2	117.5±8.6	72.5±2.8	40.0±5.7	81.0±5.9
Anaerobic-aerobic	62.0±2.5	103.3±4.2	70.0±8.4	33.3±12.6	64.0±2.5*
Aerobic	62.0±2.5	110.0±8.4	86.7±6.3	43.3±2.1	68.0±2.5*

*Note**. Changes are statistically significant ($p < 0.05$) compared to the anaerobic training regimen (women). HR — heart rate, SBP — systolic blood pressure, DBP — diastolic blood pressure, PP — pulse pressure, DP — double product.

The relatively high pulse rate of athletes training in an anaerobic mode is noteworthy. A slowdown in the pulse rate at rest in athletes in the other two groups is a typical adaptation response to repeated physical exertion. As a result of systematic sports training, the central tone of the vagus nerve increases, which is known to be the main parasympathetic nerve innervating the heart. The balance between sympathetic and parasympathetic control over the activity of the sinus node of the heart changes towards the predominance of parasympathetic, slowing influences — bradycardia develops. At the same time, signs of fatigue in an athlete’s body are considered to be a state when the pulse rate at rest exceeds 80–85 beats per minute.

The measurement of arterial pressure in the examined groups showed that the average figures of both systolic (SBP) and diastolic (DBP) pressure correspond to the standards accepted for athletes (Table 1). Thus, at present, it is accepted to consider the values of maximum pressure in athletes to be normal if they fluctuate in the range from 105 to 129 (mm Hg). The normal range for minimum BP is 60–89 (mm Hg). The values of SBP and DBP measured by us in female athletes are somewhat lower than in the examined male athletes.

Pulse pressure (PP), calculated as the difference between systolic and diastolic pressure, was approximately the same in all groups, from 40.0 to 43.3 (mm Hg). The exception was the group of athletes training in an anaerobic-aerobic mode, whose PP value was equal to 33, 3 mm Hg. The obtained value of PD is explained by the low figure of SBP (103, 3 mm Hg), registered in this group. According to various authors, arterial hypotension in athletes occurs in 10–16 % of cases and in women twice as often as in men [2]. With the growth of athletic skill and experience, the frequency of hypotonic conditions related to the physiological norm increases [3].

Calculation of the DP (double product), reflecting the systemic work of the heart, showed the following (Table 1). The highest value of this indicator was found in male athletes training in the anaerobic mode (87.7 ± 9.3). The DP of athletes training in mixed and aerobic modes is lower by 18 % and 15 %, respectively, but the difference is not statistically confirmed. A similar pattern is observed in female athletes, but the difference between the compared groups is more pronounced. In female athletes training in a mixed mode, the DP is significantly lower by 26 % ($p < 0.05$), and in aerobic mode — by 19 % ($p < 0.01$). In general, the DP figures calculated by us are lower in women than in men. It should be noted that the lower the specified index at rest, the higher the maximum aerobic capabilities of the athlete's body [5–8].

For a more in-depth characterization of the cardiovascular system's response to training loads with different energy characteristics, we calculated a number of indices characterizing adaptive shifts in the heart and blood vessels.

Thus, the systolic blood volume (SBV) in men and women of the examined groups (Table 2) fluctuated, on average, from 59.5±0.59 ml (in athletes training in anaerobic mode) to 65.4±9.1 ml (in athletes training for endurance), which corresponds to the average standards.

It is known that healthy untrained people may have this indicator with some changes within 40–90 ml, and athletes — in the range of 50–100 ml [3]. In our case, there is a tendency for the systolic blood volume to increase. This fact is explained, on the one hand, by the anthropometric characteristics of the athlete, since this indicator is directly proportional to the body weight and height of the athlete, and on the other hand on by general physical performance, which is most pronounced in athletes training for endurance. In our case, these are male athletes training mainly in aerobic mode. These athletes have the highest average SV, equal to 65.4 ±9.1 ml.

T a b l e 2

Integral indicators of the cardiovascular system of high-class athletes training in various bioenergetic modes (M±m)

Training mode	SBV, ml	MBV, l /min	ShI, conditional units	KEC, conditional units	FCI, points
men					
Anaerobic	59.5±0.59	3.27±0.5	21.7±1.6	16.4±0.7	2.22±0.13
Anaerobic-aerobic	64.3±2.4	3.12±0.47	15.8±2.3	15.5±3.9	2.15±0.05
Aerobic	65.4±9.1	3.47±0.3	17.9±2.9	9.5±0.9	2.50±0.3
women					
Anaerobic	62.3±1.7	3.31±0.2	16.6±2.4	19.6±2.7	2.04±0.19
Anaerobic-aerobic	62.7±10.1	2.69±1.2	12.9±5.7	21.7±8.8	1.78±0.09
Aerobic	64.5±1.5	3.33±0.3	10.7±3.5	12.5±0.8*	1.77±0.58

*Note**. Changes are statistically significant compared to men in this group ($p < 0.025$). SBV — systolic blood volume, MBV — minute blood volume, ShI — Chaptal index, KEC — endurance coefficient, FCI — functional change index.

The main hemodynamic indicator is cardiac output measured by MBV coefficient. It characterizes the level of tissue blood supply and the associated delivery of oxygen to cells and removal of carbon dioxide from them. Under resting conditions, the body's need for blood supply is relatively low. In healthy untrained people, this indicator (recorded in an upright body position) most often fluctuates between 2.5 and 5 l/min. In athletes, MBV value varies in a wider range, from 3 to 10 l/min. In approximately 60 % of athletes, MBV values correspond to normal standards recorded in healthy untrained people [3, 5].

The MBV values calculated in our study can be represented within the range of figures typical for athletes, with the highest values of MBV observed in men training for endurance (3.47±0.3 l/min), and the lowest in women training in an aerobic-anaerobic mode (2.69±1.2 l/min).

Shaptala Index (ShI) reflects the "mobilization readiness" of the cardiovascular system. We have not found any studies interpreting the ShI in high-class athletes. Thus, the value of this index in healthy young people before the exam was 23.1 ± 0.8 for boys and 14.2 ± 0.9 for girls. Psycho-emotional stress led to an increase in the ShI by 12 and 21 %, respectively [9]. We obtained ShI values at rest that are close to these values (Table 2). Thus, in athletes training mainly in an anaerobic mode, the ShI is, on average, 21.7 ± 1.6 for men and 16.6 ± 2.4 for women. A mixed training regimen leads to significantly lower ShI values: in men — 15.8 ± 2.3, which is 37 % lower than in the previous group ($p < 0.1$); in women — 12.9±5.7. Aerobic training is also accompanied by low values of the ShI, both in men (17.9±2.9) and in women (10.7±3.5) (Table 2).

The endurance coefficient (KEC) calculated in our study for all the examined groups of athletes, to a certain extent, reflects the functional capabilities of the cardiovascular system and should not exceed 16 conventional units at rest. Calculations showed that men in all three groups have the KEC which does not exceed the specified value: the average values were 16.4 ± 0.7 in anaerobic athletes, 15.5 ± 3.9 in the anaerobic-aerobic athletes, and 9.5 ± 0.9 in the aerobic athletes (all in conventional units). Women have higher values of this indicator compared to male athletes by 19 % (anaerobic mode), 40 % (aerobic-anaerobic mode) and 31 % (aerobic mode) ($p < 0.025$). To interpret the obtained data on the ShI and KEC, additional measurements using testing physical load are required.

It is known that there is a certain relationship between the values of the systolic blood volume (SBV) and the level of performance of an athlete, while the value of the MCV at rest is practically not related to athletic performance. This is explained by the fact that the MCV depends not only on the value of the systolic volume, but also on the heart rate. Both of these components, which determine the value of the MCV, are differently related to the level of physical performance. There is a direct proportional relationship between the level of physical performance and the systolic blood volume, and an inverse relationship between the value of physical performance and the heart rate. As a result of such multidirectional trends, the value of the MCV does not depend on the level of physical performance [9, 10]. Thus, judging by the hemodynamic data described above, in high-class athletes who train mainly in aerobic mode, the economization of the heart's work is more pronounced, in female athletes of the same group — to a greater extent.

Next, we measured the index of functional changes (IFC) in the examined athletes, proposed by Berseneva A.P. for the general population [4]. The advantage of this approach is the identification of the preclinical state of the organism, which, in turn, manifests itself in the following stages: 1-expressed functional stress, 2-acute functional stress, 3-overstrain of regulatory mechanisms. Only then does a breakdown of adaptation occur with exhaustion and breakdown of the regulatory systems of the organism.

The IFC reflects the relationship between myocardial-hemodynamic and structural-metabolic homeostasis. As a sensitive indicator of the adaptive reactions, the cardiovascular system is the first to respond to the action of intensive muscular loads; a regulator of the internal environment of the organism, maintaining the homeostasis of its organs and systems by their adequate blood supply.

The obtained IFC values in the athletes of the studied groups are shown in Table 2. Thus, in the group of athletes training mainly in the anaerobic mode, the average IFC value in men was 2.22±0.13 points, in women — 2.04±0.19 points. In martial artists, the IFC was also similar: 2.15±0.05 points, in women of the same group, the functional change index was 1.78±0.09 points, which is significantly lower than in men by 21 % ($p < 0.002$). The same average IFC value was demonstrated by female athletes training in the aerobic mode: 1.77±0.58 points. The average IFC figure for male athletes training in the aerobic mode was 2.50±0.3 points.

According to the authors, the level of functioning of the cardiovascular system (adaptation potential) according to the IFC up to 2.59 points reflects satisfactory adaptation, from 2.60 to 3.09 — tension of adaptation mechanisms, 3.10–3.49 — unsatisfactory adaptation, 3.50 and above — failure of adaptation [4]. We can state that the IFC values in female athletes are significantly lower than in men, and these IFC values reflect satisfactory adaptation. The IFC value for characterizing the adaptive capabilities of an athlete is relevant when considering individual indicators, which is reflected in Table 3 using the example of athletes training in an aerobic mode.

In this group, we recorded the highest values of performance and maximum oxygen consumption (Table 3). Thus, athlete A has a PWC_{170} test result of 2728 kgm /min, and MOC is 5878 ml/min, although the relative values of these indicators are higher for athlete P.: 30.0 kgm /min x kg $^{-1}$ and 66.9 ml/min x kg $^{-1}$, respectively.

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Table 3

Individual performance indicators, maximal oxygen consumption and adaptation potential of high-class athletes training in aerobic mode

№	Gender	PWC 170 kgm min -1	PWC 170 kgm min 1 kg -1	MOC ml min -1	MOC ml min -1 kg -1	IFC, points
Aerobic energy supply						
1	Woman	1452	17.5	3705	44.7	2.53
2	Woman	1097	18.6	3105	52.6	1.63
3	Man	2728	28.1	5878	60.6	3.25
4	Man	2343	29.3	5224	65.3	2.20
5	Man	2340	30.0	5218	66.9	2.30
6	Man	2593	28.2	5649	61.4	3.46
7	Woman	1176	18.1	3239	49.8	2.15

Calculation of the index of adaptation changes (IAC) showed that two athletes (A. and L.), who showed the first two results in absolute values of the PWC $_{170\ test}$ and MOC, are in the stage of unsatisfactory adaptation, their IFC is 3.25 and 3.16 points, respectively. It should be noted that deviations from the average statistical values of the measured indicators in these athletes were also noted by us in other measurements. The remaining athletes have sufficient adaptation potential according to the IAC.

Conclusion

The studies showed that the values of both systolic and diastolic pressure measured by us in female athletes were slightly lower than those of the examined male athletes, while female athletes training in an anaerobic-aerobic mode had arterial hypotension. The figures of DP, reflecting the systemic work of the heart, were lower in women than in men in all energy modes of training, which indicates higher aerobic capabilities of the athletes’ body. At the same time, the average value of the systolic blood volume (SBV) was the highest in male athletes training mainly in an aerobic mode. We also noted that the highest values of the minute blood volume (MBV), characterizing the level of tissue blood supply and gas exchange, are observed in men training for endurance, the lowest — in women training in an aerobic-anaerobic mode.

The Shaptala Index (ShI) reflects the “mobilization readiness” of the cardiovascular system, is within the statistical norm for athletes, both men and women, and the endurance coefficient (KEC), reflecting the functional capabilities of the cardiovascular system, was higher for women in all training modes. This is confirmed by the calculated values of the IFC, which reflect satisfactory adaptation of the body of the examined athletes, however, for female athletes the figures are significantly lower than for men. Also, reserve capacity of the cardiovascular system (according to the DP and KEC indices) in female athletes in all energy modes is higher compared to male athletes. It should be added that we have not encountered any comprehensive studies of the adaptation of the cardiovascular system in athletes in the gender aspect, training in different energy modes.

Thus, measurement and subsequent calculation of integral indicators of adaptation of the cardiovascular system to training loads allows not only to judge its current state, but also to identify the tension of adaptation mechanisms in the process of monitoring the state of the athlete's body, taking into account its gender.

References

1 Bae, D., Matthews, J.J.L., Chen, J.J., & Mah, L. (2021). Increased exhalation to inhalation ratio during breathing enhances high-frequency heart rate variability in healthy adults. *Psychophysiology, 58,* e13905.

2 Fincham, G.W., Strauss, C., Montero-Marin, J., & Cavanagh, K. (2023). Effect of breathwork on stress and mental health, A meta-analysis of randomized-controlled trials. *Sci. Rep., 13,* 432.

3 Migliaccio, G.M., Di Filippo, G., Russo, L., Orgiana, T., Ardigò, L.P., Casal, M.Z., et al. (2022). Effects of Mental Fatigue on Reaction Time in Sportsmen. *Int. J. Environ. Res. Public Health, 19,* 14360.

4 Baevsky, R.M., & Bersenyeva, A.P. (1997). Assessment of the adaptive capabilities of the organism and the risk of disease development. *Moscow.*

5 Buchanan, T.L., & Janelle, C.M. (2021). Fast breathing facilitates reaction time and movement time of a memory-guided force pulse. *Hum. Mov. Sci.*, *76*, 102762.

6 Ivanov, V.A., & Petrov, A.K. (2010). Aerobic and anaerobic respiration in athletes: physiological mechanisms and their importance in the training process. *Journal of Sports Medicine and Physiology.* Moscow, 20(5), 123-128.

7 Toleubekov, M.K., & Abdrakhmanova, S.Zh. (2018). Gemodinamikalyk korsetkishter zhane olardyn sportshylardyn densaulygyna aseri [Hemodynamic indicators and their impact on the health of athletes]. *Kazak kardiologiia zhane ishki aurular journaly — Kazakh cardiology and Internal Deseases,* Almaty, 15(3), 45–50 [in Kazakh].

8 Zhumabaev, N.R., & Syzdykov, A.D. (2020). Germodinamikalyk korsetkishterdin fizikalyk zhuktemelerge reaktsiiasy [Response of Hemodynamic Indicators to physical loads]. *Proceedings of International Conference on Cardiology and Physiology Issues in Kazakhstan* (pp. 120–125) [in Kazakh].

9 Samokhina, A.A., & Tnimova, G.T. (2016). The influence of physical activity on hemodynamic parameters in athletes / *Journal of Sports Medicine and Physiology.* Moscow, 22(3), 45–49.

10 Kuspanov, D.J., & Alimbaev, T.K. (2019). Sportshylardagy kannyn minuttyk kolemi: fiziologiialyk mekhanizmder zhane zhattygu aseri [Minute Blood Volume in athletes: physiological mechanisms and training effects]. *Kazakh sports medicine magazines.* Almaty, 14(2), 8–83 [in Kazakh].

References

1 Bae D. Increased exhalation to inhalation ratio during breathing enhances high-frequency heart rate variability in healthy adults / D. Bae, J.J.L. Matthews, J.J. Chen, L. Mah // Psychophysiology. — 2021. — 58. — e13905.

2 Fincham G.W. Effect of breathwork on stress and mental health, A meta-analysis of randomized-controlled trials / G.W. Fincham, C. Strauss, J. Montero-Marin, K. Cavanagh // Sci. Rep. — 2023. — 13. — P. 432.

3 Migliaccio G.M. Effects of Mental Fatigue on Reaction Time in Sportsmen / G.M. Migliaccio, G. Di Filippo, L. Russo, T. Orgiana, L.P. Ardigò, M.Z. Casal et al. // Int. J. Environ. Res. Public Health. — 2022. — 19. — 14360.

4 Baevsky R.M. Assessment of the adaptive capabilities of the organism and the risk of disease development / R.M. Baevsky, A.P. Bersenyeva. — Moscow, 1997.

5 Buchanan T.L. Fast breathing facilitates reaction time and movement time of a memory-guided force pulse / T.L. Buchanan, C.M. Janelle // Hum. Mov. Sci. — 2021. — 76. — 102762.

6 Ivanov V.A. Aerobic and anaerobic respiration in athletes: physiological mechanisms and their importance in the training process / V.A. Ivanov, A.K. Petrov // *Journal of Sports Medicine and Physiology.* Moscow. — 2010. — 20(5). — P. 123–128.

7 Төлеубеков М.К. Гемодинамикалық көрсеткіштер және олардың спортшылардың денсаулығына әсері / М.К. Төлеубеков, С.Ж. Абрахманова // Қазақ кардиология және ішкі аурулар журналы. — Алматы, 2018. — 15(3). — Б. 45–50.

8 Жұмабаев Н.Р. Гемодинамикалық көрсеткіштердің физикалық жүктемелерге реакциясы / Н.Р. Жұмабаев, А.Д. Сыздықов // Қазақстандағы кардиология және физиология мәселелеріне арналған халықаралық конференцияның материалдары. — Нұр-Сұлтан, 2020. — Б. 120–125.

9 Samokhina A.A. The influence of physical activity on hemodynamic parameters in athletes / A.A. Samokhina, G.T. Tnimova // Journal of Sports Medicine and Physiology. Moscow, 2016. — 22(3). — P. 45–49.

10 Құспанов Д.Ж. Спортшылардағы қанның минуттық көлемі: физиологиялық механизмдер және жаттығу әсері / Д.Ж. Құспанов, Т.К. Әлімбаев // Қазақ спорт медицинасы журналы. — Алматы, 2019. — 14(2). — Б. 78–83.

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Fatigue Recovery and Exercise Performance after Contrast Water Therapy- Meta-analysis

Fatigue recovery plays a critical role in athletic performance. Contrast Water Therapy (CWT) has been widely applied, but its effectiveness remains controversial across different exercise types. Methods applied in the study: A systematic review and meta-analysis were conducted using PubMed, Web of Science, and Elsevier databases. Seventeen trials involving 368 participants were included. Two researchers independently screened and extracted data, including subjective indicators (DOMS, RPE) and objective markers (CMJ, sprint, CK, lactate, CRP, IL-6). Results: Meta-analysis showed that CWT significantly alleviated DOMS and RPE, particularly after team-based sports like football. CWT was also effective in reducing lactate levels immediately post-exercise. However, no significant improvements were found in CMJ or sprint performance for most sports. Cold Water Immersion (CWI) showed superior results in reducing CK and lactate at 24–48h post-exercise compared to CWT. Discussion: CWT can reduce perceived muscle soreness and fatigue, especially in team sports, though its impact on objective performance is limited. CWI may be more effective for physiological recovery. Further studies are needed to explore protocol-specific and sport-specific outcomes.

Keywords: contrast water therapy, cold water immersion, fatigue recovery, muscle soreness, ratings of perceived exertion, creatine kinase, lactate, countermovement jump, team sports, recovery strategies.

Introduction

Fatigue recovery is crucial for athletes to sustain performance and reduce injury risks, making effective recovery modalities a key area of sports science research. Contrast Water Therapy (CWT) is a widely used recovery technique involving alternating immersion in cold water (≤20 °C) and hot water (≥36 °C) [1], typically for 1–3 minutes per cycle [2]. This alternating protocol is believed to promote vasoconstriction and vasodilation, thereby enhancing blood circulation and accelerating the removal of metabolic by-products such as lactate. As a result, CWT is popular for its potential to reduce lactic acid accumulation [3], inflammation, edema, pain, and muscle stiffness [1], ultimately alleviating Delayed-Onset Muscle Soreness (DOMS) and improving fatigue recovery.

In contrast, Cold Water Immersion (CWI) involves immersing the body in cold water without alternating temperature changes. CWI is thought to reduce muscle inflammation and edema by inducing vasoconstriction and decreasing tissue temperature. Several studies have directly compared CWT and CWI, yielding mixed results. Some findings indicate that CWI may be more effective in reducing muscle temperature and inflammation due to its ability to sustain vasoconstriction and lower tissue temperature [4–6]. Other studies designate that CWT, due to its alternating vasoconstriction and vasodilation mechanism, may be more effective than CWI in alleviating muscle soreness and reducing creatine kinase levels [7].

While several studies have investigated the effects of CWT and CWI on post-exercise recovery, the findings remain inconsistent. These inconsistencies may stem from variations in experimental designs, exercise protocols, and the lack of systematic integration of key recovery indicators. To comprehensively assess the effects of CWT on fatigue recovery, this review focuses on commonly used subjective indicators, such as DOMS and Rating of Perceived Exertion (RPE), and objective markers [8], including Sprint time, Countermovement Jump (CMJ), Creatine Kinase (CK), lactate, IL-6, and C-reactive protein (CRP) [9, 10]. These indicators are widely recognized for their relevance in evaluating both perceived and physiological recovery after exercise.

By systematically integrating these subjective and objective indicators, this review aims to clarify the effects of CWT on subjects fatigue recovery across different post-exercise time points, providing a more comprehensive understanding of its efficacy.

Based on the available literature, the present study hypothesizes that:

1. CWT can alleviate exercise-induced fatigue and promote subsequent exercise performance.

2. CWT and CWI have similar effects on fatigue recovery and promote subsequent exercise performance.

3. The efficacy of CWT varies depending on immersion depth, exercise types, and experimental designs.

Methods and materials

2.1 Literature Search Strategies

This meta-analysis was conducted from January 2023 to July 2023 according to the guidelines of PRISMA [11]. PubMed, Web of Science, and Elsevier were used as the primary databases for the literature search. The search terms included "Contrast Water Therapy" OR "Contrast water immersion" OR "CWT", "Exercise performance" OR "Sports performance" OR "Athletic performance", and "Fatigue" OR "Recovery". Only articles published in English between 2002 and 2022 were considered. This timeframe was chosen to focus on studies conducted within the past two decades, as it reflects the evolution of contemporary practices, methodologies, and technologies in Contrast Water Therapy (CWT), ensuring the inclusion of recent and up-to-date research. All searches were conducted by two researchers (XFY, JL), with a third researcher (ZH) performing a review for accuracy and completeness.

2.2 Literature inclusion and exclusion criteria

Following the PICOS criteria outlined in Cochrane systematic reviews, the inclusion criteria for the literature were as follows: (1) Participants: General population without specific gender restrictions and free from any diseases. The inclusion criteria did not specifically limit participants to athletes, nor did it impose restrictions on age range, as the focus was on the intervention outcomes rather than participant characteristics; (2) Intervention: Post-exercise CWT intervention, with cold water temperature ≤20 °C and hot water temperature ≥36 °C, this temperature was selected based on prior studies [12]. The inclusion criteria did not impose specific restrictions on the duration of immersion cycles in CWT interventions, as the focus of this review was on the overall effects of CWT rather than the optimization of immersion time. The immersion depth included whole-body immersion up to the umbilicus or shoulders, while studies involving partial immersion, such as hot-cold showers, were excluded to maintain consistency in the intervention protocols; (3) Experimental Design: Both independent samples (between-group designs) and repeated measures (within-group designs) were included, provided they met the inclusion criteria. To ensure valid comparisons, all studies were required to have a clearly defined control group, which performed either passive recovery or low-intensity active recovery. Studies without a control group or those using inappropriate comparison groups (e.g., partial immersion or alternative recovery methods) were excluded; (4) Exercise Type: No specific restrictions were imposed on the type of prior exercise performed by participants; (5) Outcome Measures: Subjective recovery characteristics (DOMS, RPE) and/or objective recovery features (Sprint time, CMJ, CK, lactate, CRP, and IL-6).

The following studies were excluded from consideration: (1) Participants with specific major illnesses affecting exercise performance; (2) Studies with inadequate experimental design; (3) Duplicate publications; (4) Animal experiments; (5) Articles published in languages other than English.

2.3 Variable Selection

The primary outcome measures included subjective recovery characteristics (DOMS, RPE) and objective recovery features (Sprint time, CMJ, CK, lactate, CRP, and IL-6). DOMS and RPE were assessed using validated scales, while Sprint time and CMJ were used to evaluate physical performance. Biochemical markers, such as CK and lactate were included to assess muscle damage and metabolic recovery, respectively. Measurements were taken at multiple time points post-intervention: immediately (0h), 1 hour (1h), 24 hours (24h), and 48 hours (48h) after CWT intervention. The systematic search strategy and literature selection process are illustrated (Fig. 1).

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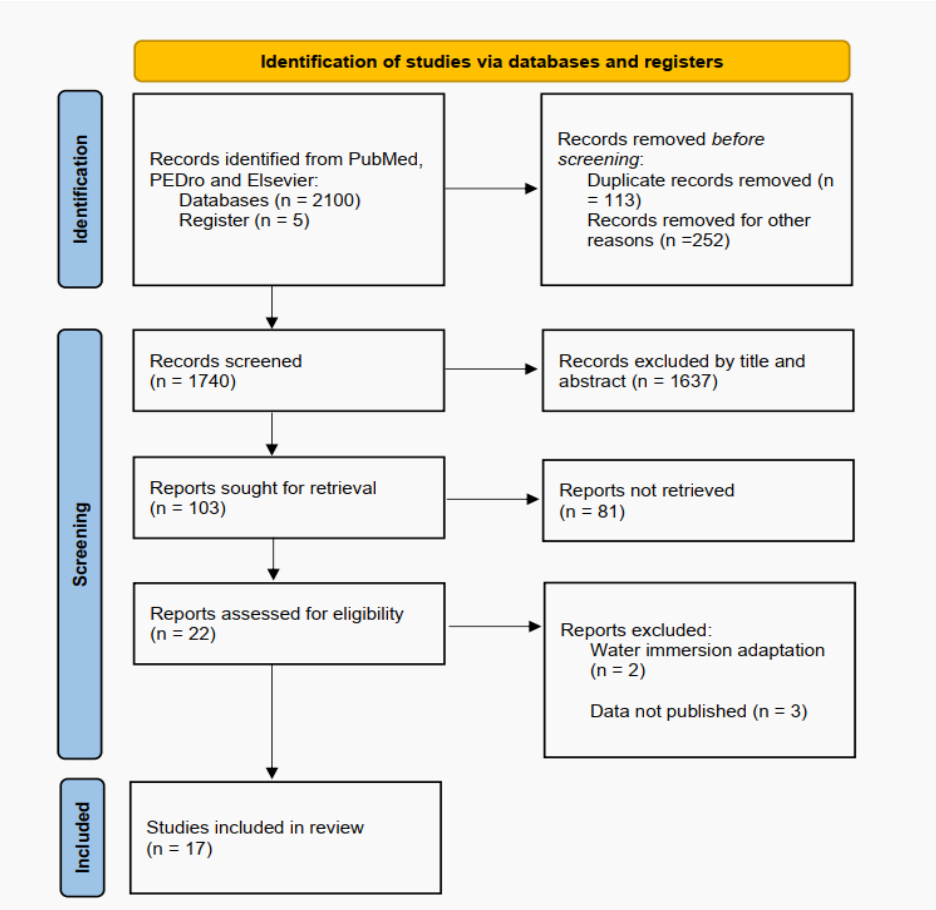

Figure 1. Systematic review procedure

2.4 Data Extraction

Basic information from the literature was extracted by two researchers and subsequently cross-verified. A secondary verification of the extracted data was performed. The included literature underwent a quality risk assessment. In case of discrepancies, a third researcher intervened, and a consensus was reached among all researchers regarding the accuracy of the data extraction. The primary contents extracted included the first author of the literature, publication year, sample size, age, and gender of the study participants, experimental design, post-exercise intervention methods, outcome assessment indicators, and corresponding data.

2.5 Statistical processing

The heterogeneity analysis, data synthesis, subgroup analysis, forest plot generation, and publication bias analysis were conducted using RevMan 5.4 software. When the units were consistent, the Mean Difference (MD) was selected for statistical analysis. When there were variations in measurement units or methods, the Standardized Mean Difference (SMD) was chosen. The I^2 statistic was utilized to assess heterogeneity among studies, where I^2 values of 0 %, ≥25 %, ≥50 %, and ≥75 % represent no heterogeneity, low, moderate, and high heterogeneity, respectively. In the presence of moderate to high heterogeneity ($I^2 \geq$ 50 %), a random-effects model was applied; otherwise, a fixed-effects model was used. If heterogeneity was observed, subgroup and sensitivity analyses were performed. After excluding studies with abnormal results, the analyses were repeated to observe whether heterogeneity persisted.

2.6 Risk of bias

The Cochrane risk of bias tool was used to assess all included articles independently by two authors. Each article was scored in the following aspects: random sequence generation, allocation concealment, blinding participants, blinding personnel, blinding outcome assessors, incomplete outcome data, and other sources of bias. Each item was classified as either high risk, unclear risk or low risk [13]. Any disagreements were discussed with a third reviewer (ZH).

2.7 Subgroup analysis

Subgroup analyses were conducted based on different body parts (shoulders, umbilicus), different experimental types (randomized controlled trials (RCTs), cross-over Trials, and other types of Trials) and different types of exercise when performing CWT intervention.

Results

3.1 Risk of bias of the included literature

The risk of bias assessment for the included studies is shown in Figures 2 and 3.

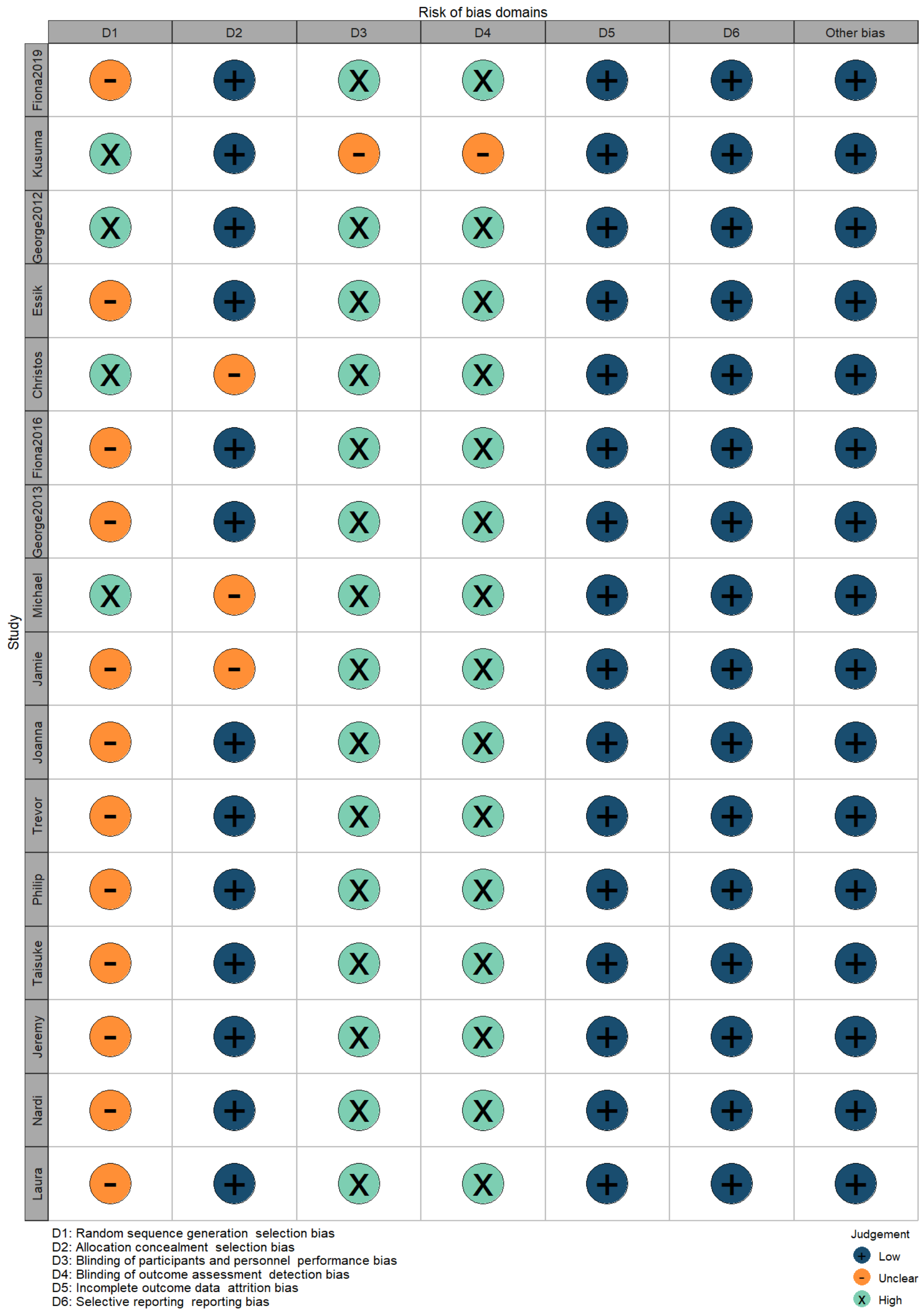

Figure 2. Risk of bias graph for all included studies

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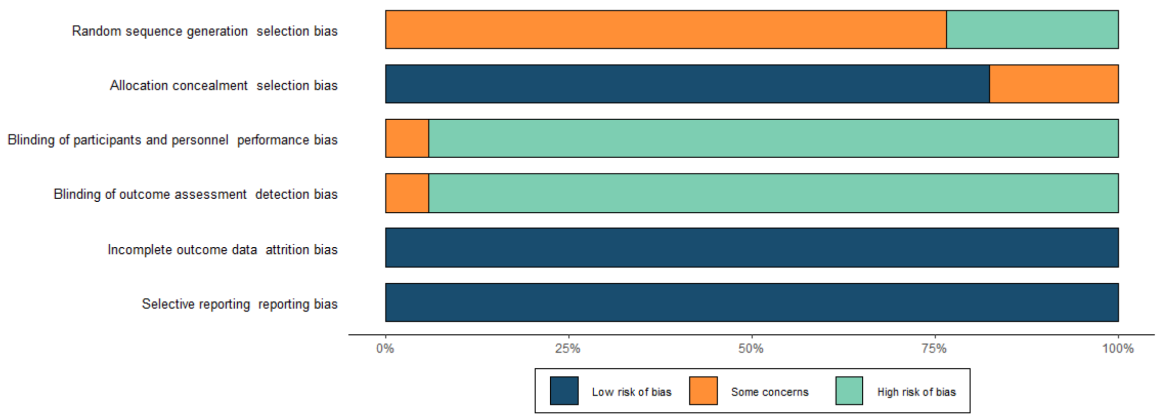

Figure 3. Risk of bias summary for all included studies

3.2 Basic characteristics of the included literature

In this review, a total of 17 studies were included, providing the primary data source for this analysis [6, 12, 14–28]. These trials initially recruited 368 healthy participants (338 males and 30 females). However, due to individual dropouts (e.g., personal reasons or inability to complete the intervention), only 338 participants completed the trials and were included in the final analysis (Table 1).

Table 1

Summary of the included studies

Study, year	**Characteristics of participants (training status, sex (m: f), age)**	**Enviroment condition (Tm±S; RHm±S)**	**Exercise protocol**	**Classification of the exercise**	**[CWT duration and temperature] ×number**	**Control group**	**Outcome variables and time of measurement post exercise(h)**
1	2	3	4	5	6	7	8
Fiona A Crowther et al., 2019	Recreational avtive healthy males (14:0); 26±6 yrs	24.3-25.8°C; 56.7-61.0 %RH	Simulated ruby tournament	High intensity	[1 min at 15°C+1 min at38°C]×7	14 min passive recovery	DOMS (0;1); CMJ(0;1); Sprint time(0;1)
Kusuma, M. Nanang et al., 2021	Elite athletes(30:0); 18.23±1.17 yrs		Sub-maximal intensity of circuit training	Sub-maximal intensity	15°C&38°C total 15 min	15 min static stretching	Lactate (0); DOMS(0)
George P. Elias et al., 2012	Australian Footballers(14:0); 20.9±3.3 yrs		AF training	High intensity	[1 min at 12°C+1 min at 38°C]×7	14 min passive recovery	DOMS (0;1;24;48); Fatigue(0;1;24;48); CMJ(0;24;48); Sprint time(0;24;48)
Essi K. Ahokas et al., 2019	Physically active men(9:0); 26±3.7 yrs		Short term exercise with maximal effort		[1 min at 10°C + 1 min at 38°C]×5	10 min active recovery	Lactate (0); DOMS(1;24;48); CK(24;48)
Christos K. Argus et al., 2016	Healthy males(13:0); 26±5 yrs		Single full-body resistance training session	High intensity	[1 min at 15°C + 1 min at 38°C]×7	14 min passive recovery	DOMS(0;1); Fatigue(0;1)
Fiona Crowther et al., 2017	Recreational avtive healthy males(34:0); 27±6 yrs	22.6-23.9°C; 71.9-73.9 %RH	Simulated team-game circuit	High intensity	[1 min at 15°C + 1 min at 38°C]×7	14 min passive recovery	DOMS (1;24;48); CMJ(1;24;48); Sprint time(1;24;48); TQR(1;24;48)
George P. Elias et al., 2013	Elite footballers (24:0); 19.9±2.8 yrs	25.8°C; 63 %RH	AF match	High-intensity	[1 min at 12°C+1 min at 38°C]×7	14 min passive recovery	DOMS (0;1;24;48); Fatigue(0;1;24;48); CMJ(0;24;48); Sprint time(0;24;48)
Michael J. Hamlin et al., 2007	Junior representative rugby players(17:3); 19 ± 1 yrs		Repeated sprint test	High-intensity	[1 min at 8-10°C+1 min at 38°C]×3	6 min slow jogging	Lactate(0)

Continuation of Table 1

1	2	3	4	5	6	7	8
Jamie Stanley et al., 2012	Well-trained cyclists(18:0); 27±7 yrs	25.1±0.8℃	60 min high intensity cycling	High-intensity	[1 min at 14.2±0.6℃+2 min at 35.5±1.1℃]×3	10 min passive recovery	DOMS(0); Fatigue(0)
Joanna M. Vaile et al., 2007	Recreational athletes(4:9); 26.2±5.8 yrs		5 sets of 10 eccentric bilateral leg press contractions	High-intensity	[1 min at 8-10℃+2 min at 40-42℃]×5	15 min passive recovery	DOMS(0;24;48); CK(0;24;48)
Trevor Higgins et al., 2012	Well-trained rugby players(24:0); 19.5 ± 0.8 yrs		Simulated game of rugby union	High-intensity	[1 min at 10-12℃+1 min at 38-40℃]×5	15 min passive recovery	Fatigue(48)
Philip D. Glasgow et al., 2014	Healthy participants(32:18); 18-35 yrs		Eccentric hamstring contractions to fatigue	High-intensity	[1 min at 10℃+1 min at 38℃]×3	10 min passive recovery	DOMS(24;48;72); CK(24;48;72)
Taisuke Kinugasa et al., 2009	28 young soccer players; 14.3±0.7 yrs		90 min soocer match	High-intensity	[1 min at 12℃+2 min at 38℃]×3	9 min active recovery	TQR(0;24)
Joanna Vaile et al., 2008	Strength trained males(38:0)		5 sets of 10 eccentric bilateral leg press contractions	High-intensity	[1 min at 15℃+1 min at 38℃]×7	14 min passive recovery	Lactate(0;24;48); CK(0;24;48); IL-6(0;24)
Jeremy Ingram et al., 2009	Athletes(11:0); 27.5±6.0 yrs	19.8±1.5℃; 41±12 %RH	Simulated team sports exercise	High-intensity	[2 min at 10℃+2 min at 40℃]×3	15 min passive recovery	DOMS(0;24;48); CK(0;24;48) CRP(0;24;48)
M. De Nardi et al., 2011	18 young soccer players 15.5±1.0 yrs	31.9±1.7℃; 87.5±2.9 %RH	140 min low intensity training	Low-intensity	[2 min at 15±0.5℃+2 min at 28±0.5℃]×2	8 min passive recovery	Fatigue(0;24;48); CMJ(0;24;48); Sprint time(0;24;48)
Laura E. Juliff et al., 2014	Elite netball athletes(0:10); 20±0.6 yrs		Netball specific circuit	High-intensity	[1 min at 15℃+1 min at 38℃]×7	14 min passive recovery	Fatigue(0;24)

3.2.1 Type of literature

The types of literature include single-group pre-post comparison studies [12, 15, 16, 21], cross-sectional studies [24], randomized controlled trials [14, 17, 18, 20, 25], and cross-over studies [6, 19, 22, 23, 26–28].

3.2.2 Type of exercise

Type of exercise included team sports such as simulated rugby matches [16, 29], soccer training [6] and matches [17, 23], netball-specific circuit training [22], simulated team-game circuit training [15, 21], high-intensity cycling [26], sub-maximal intensity exercise [24], low-intensity training [25], short-term exercise [12, 19], and eccentric exercise [18, 27, 28] (Table 1).

3.2.3 Characteristics of CWT

During CWT interventions, the immersion depth varied, including water reaching the level of the navel or below [18–21, 24, 25, 28], as well as water reaching the level of the shoulders or below [6, 12, 14–17, 22, 23, 26, 27]. The temperature of the hot water during CWT interventions ranged from 28±0.5 °C to 42 °C, and the cold water temperature ranged from 8 °C to 15±0.5 °C, with immersion durations of 6 to 15 minutes per session (Table 1).

3.2.4 Characteristics of CON

The common control (CON) methods include passive recovery, typically lasting 8–15 minutes [6, 15–18, 26, 28–33], as well as static stretching [24], jogging [19], and active recovery [12, 23], with varying durations of 6−15 minutes. The reason for choosing these forms as control groups is that subjects during rest periods in competitions are not just passively waiting [34], but also engage in low-intensity warm-up activities to maintain body temperature. Therefore, low-intensity active recovery has also been included in this review (Table 1).

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3.3 CWT versus CON

3.3.1 DOMS

CWT significantly reduced DOMS at 1h, 24h, and 48h post-exercise compared to CON (1h: SMD -0.59, 95 %CL -0.89 to -0.29, 6 trials); (24h: SMD -0.56, 95 %CL -0.86 to -0.27, 7 trials); (48h: SMD -0.39, 95 %CL -0.68 to -0.10, 7 trials). Heterogeneity was observed at 24h and 48h, but the use of a random-effects model did not change the significance of the results (Fig. 4).

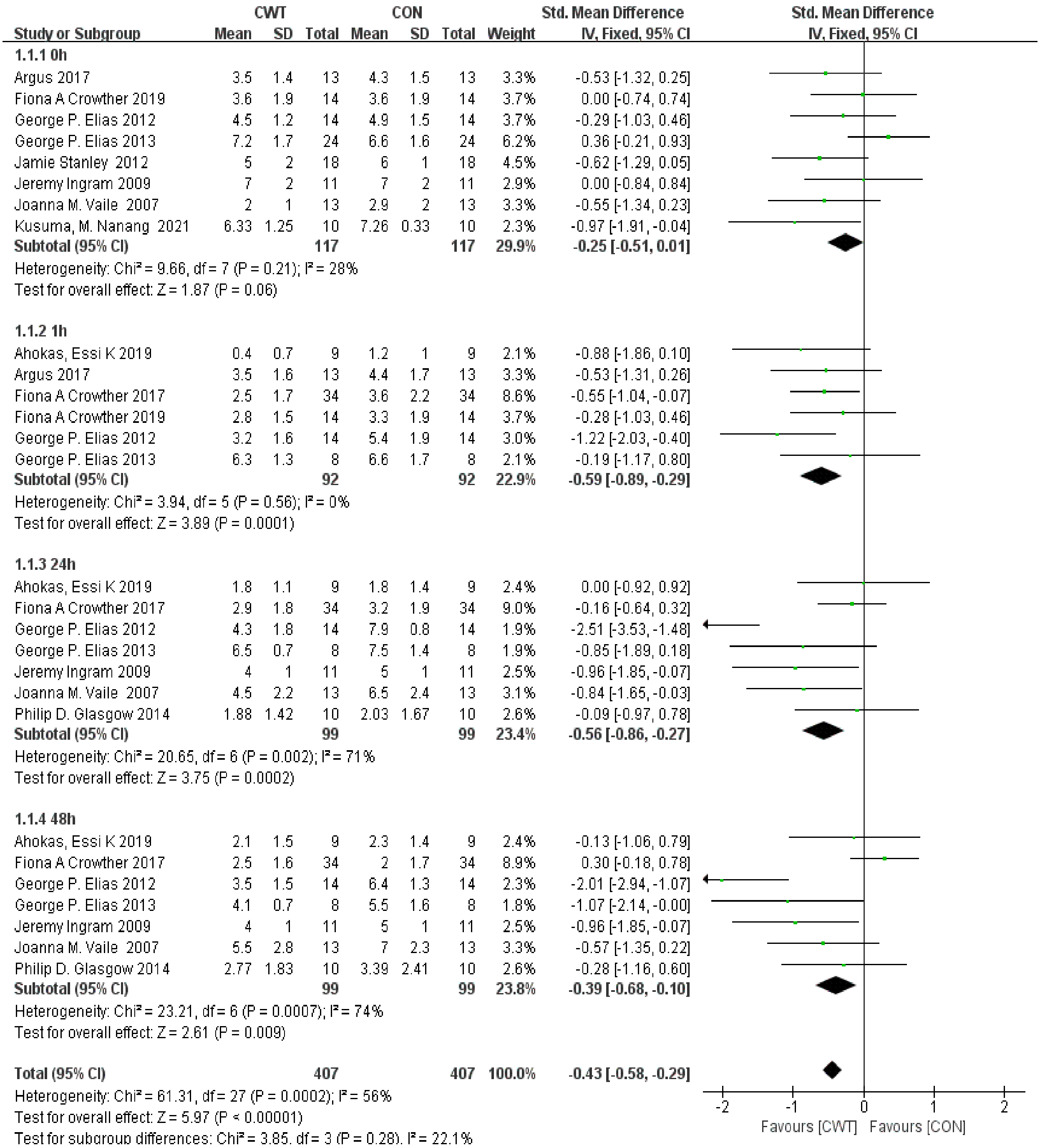

Figure 4. Forest plot of the comparison of CWT versus CON for measurement of DOMS
CWT=Contrast water therapy, CON= Control, DOMS= Delayed-onset muscle soreness.

Sensitivity analyses were conducted to investigate whether heterogeneity was caused by individual studies. Heterogeneity decreased when George et al. [6] was excluded at 24h ($Chi^2 = 5.57$, df = 5 (P= 0.35); $I^2 = 10$ %), suggesting that this literature may be responsible for the heterogeneity.

CWT subgroup analysis was performed based on different immersion depth to further explore potential sources of heterogeneity. There was no significance between the subgroups of the shoulder and umbilical immersion groups (24h Test for subgroup differences: Chi2=0.11, df=1(P=0.74); I^2=0 %); (48h Test for subgroup differences: Chi2=0.02, df=1(P=0.89); I^2=0 %), indicating that the difference immersion depth of CWT was not responsible for the heterogeneity. Subgroup analyses were performed according to the type of experiment, but no statistically significant difference was observed (Test for subgroup differences: 24h: Chi2=2.33, df=2(P=0.31); I^2=14.0 %; 48h: Chi2=1.83, df=2(P=0.40); I^2=0 %).

3.3.2 Perceived fatigue

Perceived fatigue was significantly reduced at 0h, 1h, 24h, and 48h after CWT compared to CON (0h: SMD -0.43, 95 %CL -0.77 to -0.08, 6 trials); (1h: SMD -0.81, 95 %CL -1.30 to -0.31, 3 trials); (24h: SMD -0.71, 95 %CL -1.18 to -0.24, 4 trials); (48h: SMD -0.48, 95 %CL -0.96 to -0.00, 4 trials) (Fig. 5). Heterogeneity was low across time points, and sensitivity analysis confirmed the stability of the results.

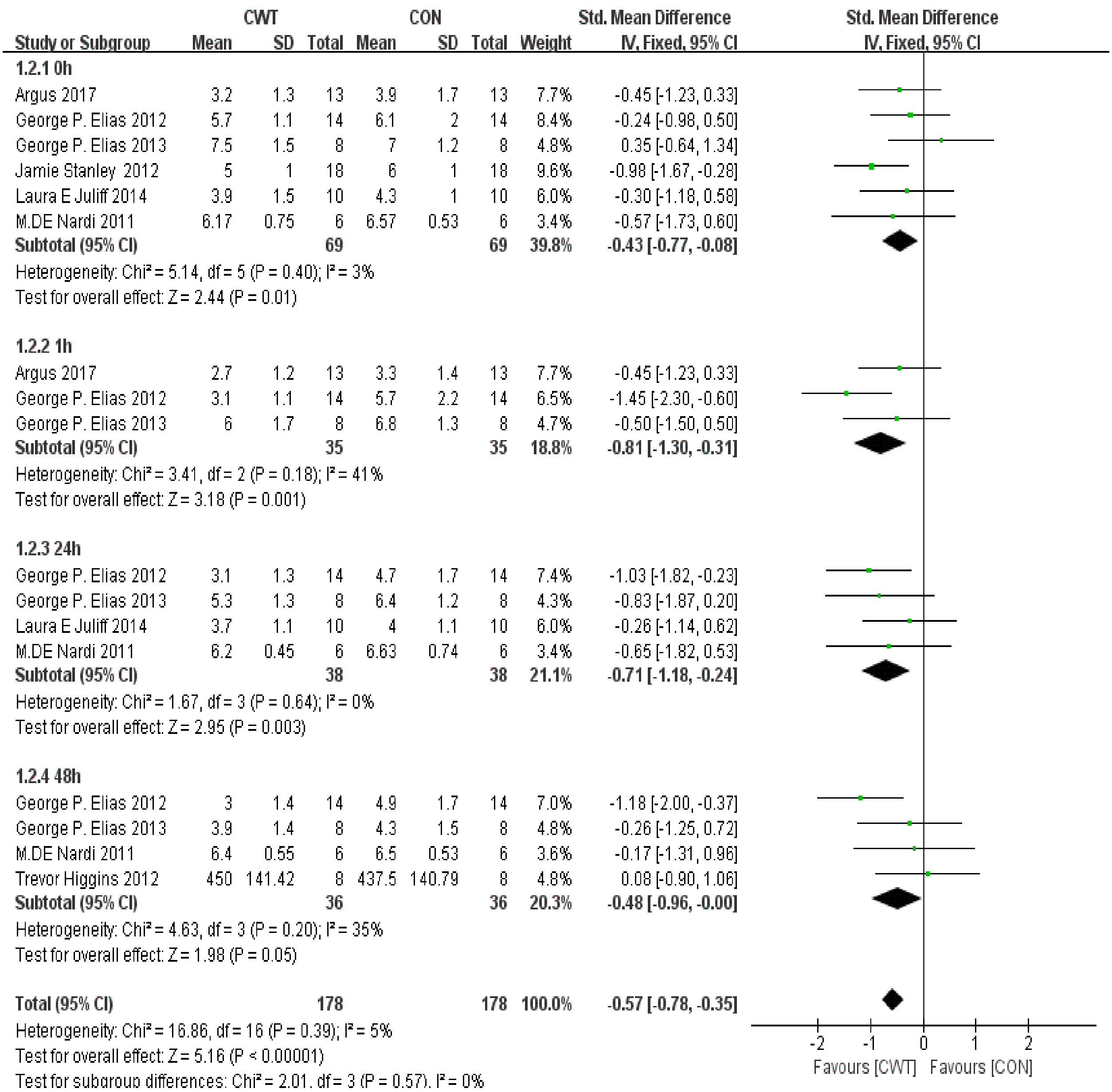

Figure 5. Forest plot of the comparison of CWT versus CON for measurement of Fatigue
CWT=Contrast water therapy, CON= Control, Fatigue= Perceived fatigue.

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3.3.3 CMJ

No significant difference in CMJ were observed at any time point post CWT in comparison to the CON (0h: SMD -0.02, 95 %CL -0.44 to 0.41, 4 trials); (1h: SMD -0.15, 95 %CL -0.55 to 0.25, 2 trials); (24h: SMD -0.03, 95 %CL -0.38 to 0.32, 4 trials); (48h: SMD -0.01, 95 %CL -0.41 to 0.39, 3 trials). The results indicate that the CWT intervention did not enhance CMJ immediately after exercise or at the 1h, 24h, and 48h post-exercise (Fig. 6).

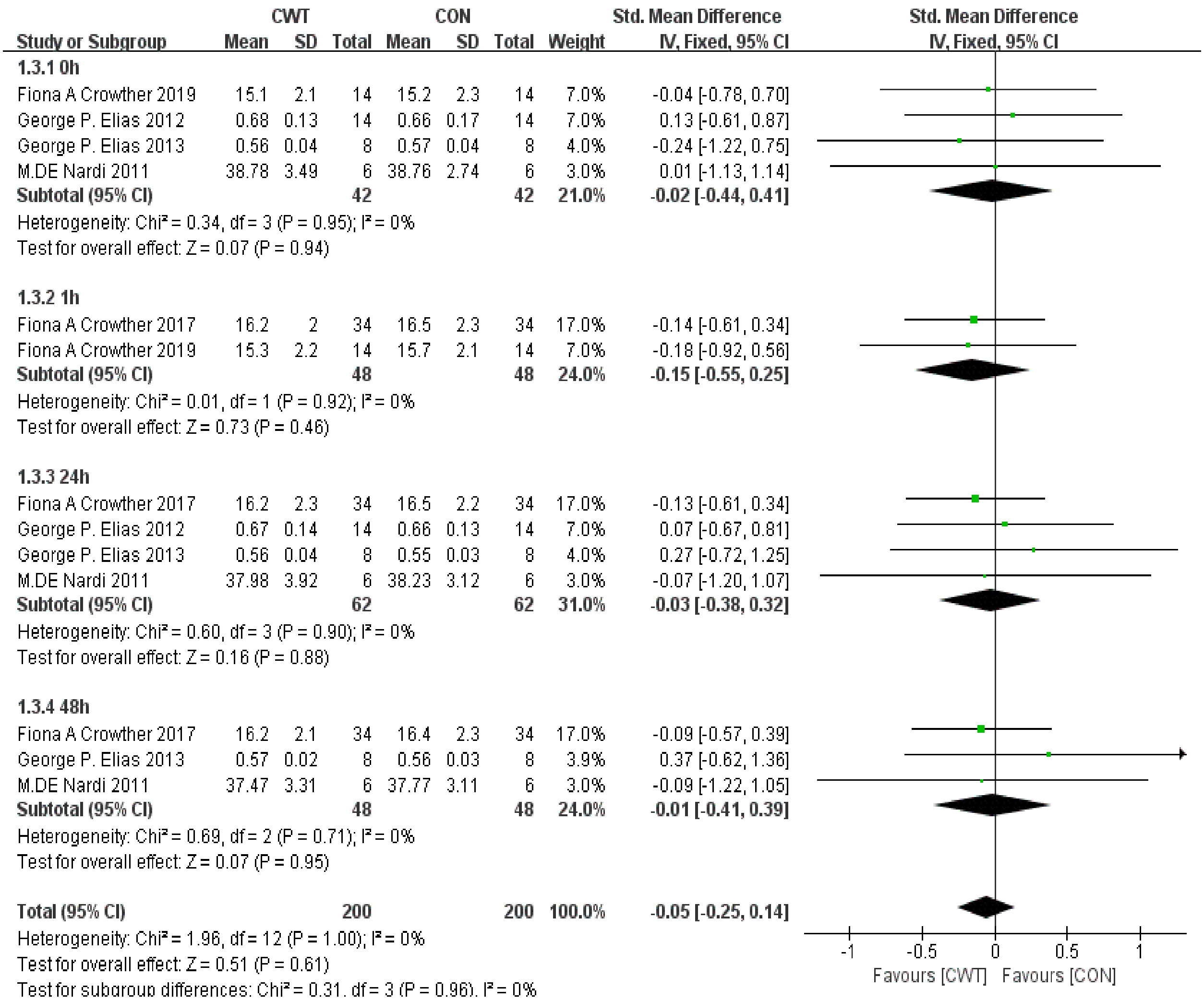

Figure 6. Forest plot of the comparison of CWT versus CON for measurement of CMJ
CWT=Contrast water therapy, CON= Control, CMJ=Countermovement jump.

3.3.4 Sprint time

As the figure shows, the sprint time after CWT intervention was not significantly different from the CON group at 0h, 1h, 24h, and 48h (0h: SMD 0.13, 95 %CL -0.30 to 0.56, 4 trials); (1h: SMD 0.10, 95 %CL -0.30 to 0.50, 2 trials); (24h: SMD -0.20, 95 %CL -0.56 to 0.16, 4 trials); (48h: SMD -0.04, 95 %CL -0.39 to 0.32, 4 trials). However, the data showed heterogeneity at 24h (I^2=62 %). There was still no significant difference between the two groups after the random effects model was used (24h: SMD -0.30, 95 %CL -0.96 to 0.36, 4 trials) (Fig. 7).

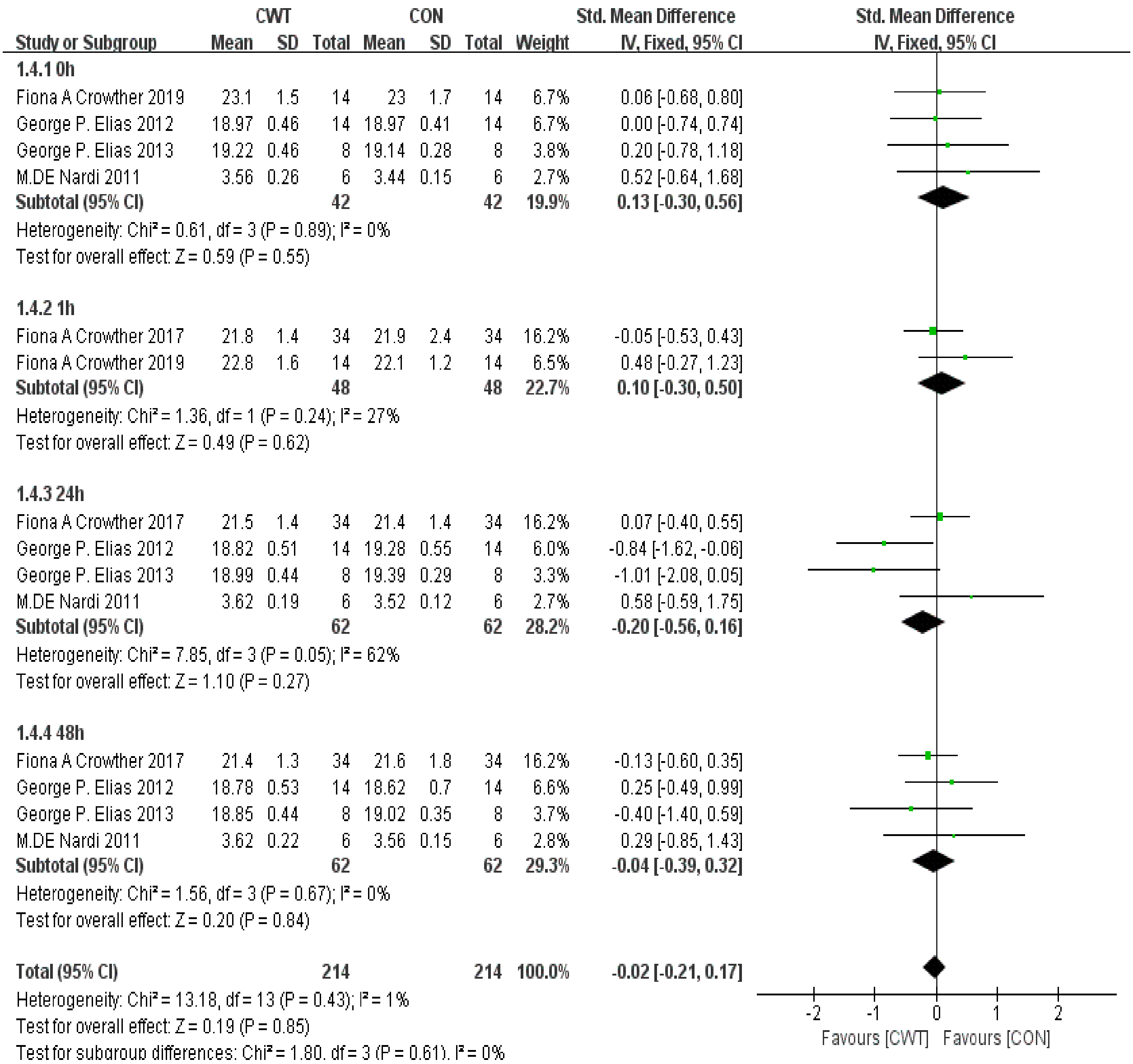

Figure 7. Forest plot of the comparison of CWT versus CON for measurement of Sprint time
CWT=Contrast water therapy, CON= Control.

Sensitivity analyses were conducted to determine the causes of heterogeneity. Eliminating the literature one by one did not change the heterogeneity between the data. To thoroughly examine the heterogeneity, the subgroup analysis was conducted based on the varied water positions during CWT. The results indicate no significant difference between the subgroups (Test for subgroup differences: Chi2=0.36, df=1(P=0.55); I^2=0 %), suggesting that difference in water immersion at either shoulder or umbilical level do not contribute to heterogeneity in sprint times at 24h post-CWT. During the subgroup analysis of various trial types, no significant difference was found (Test for subgroup differences: Chi2=1.16, df=1(P=0.28); I^2=13.7 %), indicating that trial type variations do not have a significant impact on the observed heterogeneity in sprint time outcomes at 24h after CWT.

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3.3.5 Lactate

Compared to CON, there was no significant difference in lactate in the CWT group at 0h, 24h or 48h (0h: SMD -0.20, 95 %CL -0.60 to 0.20, 4 trials); (24h: SMD 0.16, 95 %CL -0.43 to 0.76, 1 trials); (48h: SMD 0.34, 95 %CL -0.26 to 0.94, 1 trials). There was heterogeneity among the data at 0h (I^2=60 %), hence a random effects model was used. However, the results were still not significantly different (0h: SMD -0.34, 95 %CL -0.99 to 0.32, 4 trials), indicating that the results were stable (Fig. 8).

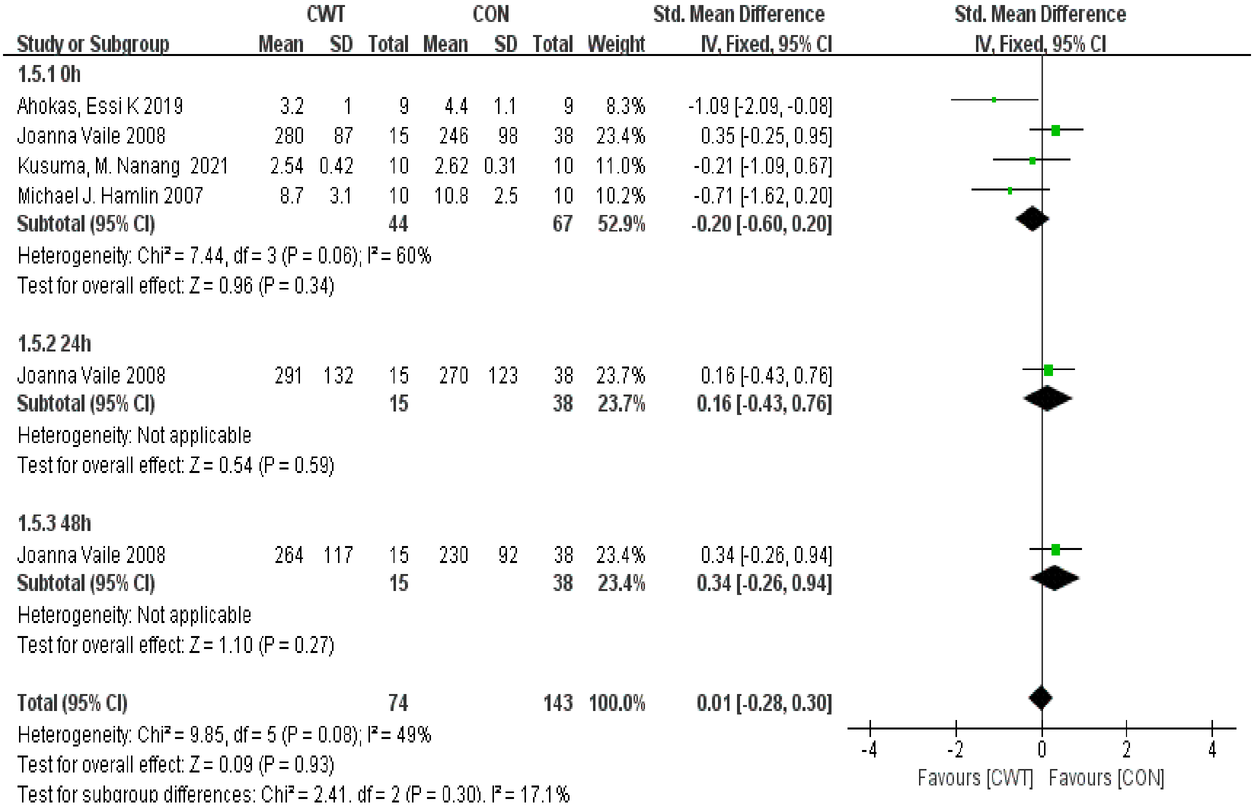

Figure 8. Forest plot of the comparison of CWT versus CON for measurement of Lactate
CWT=Contrast water therapy, CON= Control.

Sensitivity analyses to identify sources of heterogeneity revealed that there was no heterogeneity between the data when the Joanna Vaile, 2008 literature was deleted (Chi2=1.71, df=2(P=0.43); I^2=0 %), so it is probable that this literature was the source of heterogeneity between the data. Meanwhile, after this literature was deleted, significant difference between the CWT group and the CON group was identified (SMD -0.63 95 %CL -1.17 to -0.10, 3 trials). This suggests that the results of the original meta-analysis were susceptible to significant changes due to changes in the number of studies.

In order to investigate the source of heterogeneity in lactate levels at 0h, subgroup analyses were conducted. There has no significant difference between the shoulder and umbilicus subgroups of CWT (Test for subgroup differences: Chi2=0.03, df=1(P=0.86); I^2=0 %), which suggest that alterations in water positions during CWT were not responsible for the variability in lactate levels at 0h. In addition, subgroup analyses were performed based on the type of trials. There was no significant difference among subgroups of varying trial types (Test for subgroup differences: Chi2=0.50, df=1(P=0.48); I^2=0 %), suggesting that difference in type of trials were not a source of 0h lactate heterogeneity.

3.3.6 CK

As shown, there was no significant difference in CK between the CWT group and the CON group at 0h, 24h, and 48h (0h: SMD -0.17, 95 %CL -0.58 to 0.24, 3 trials); (24h: SMD -0.05, 95 %CL -0.40 to 0.29, 5 trials); (48h: SMD 0.00, 95 %CL -0.35 to 0.35, 5 trials). And there was no heterogeneity between the results, suggesting that CWT was not effective in improving CK compared to CON (Fig. 9).

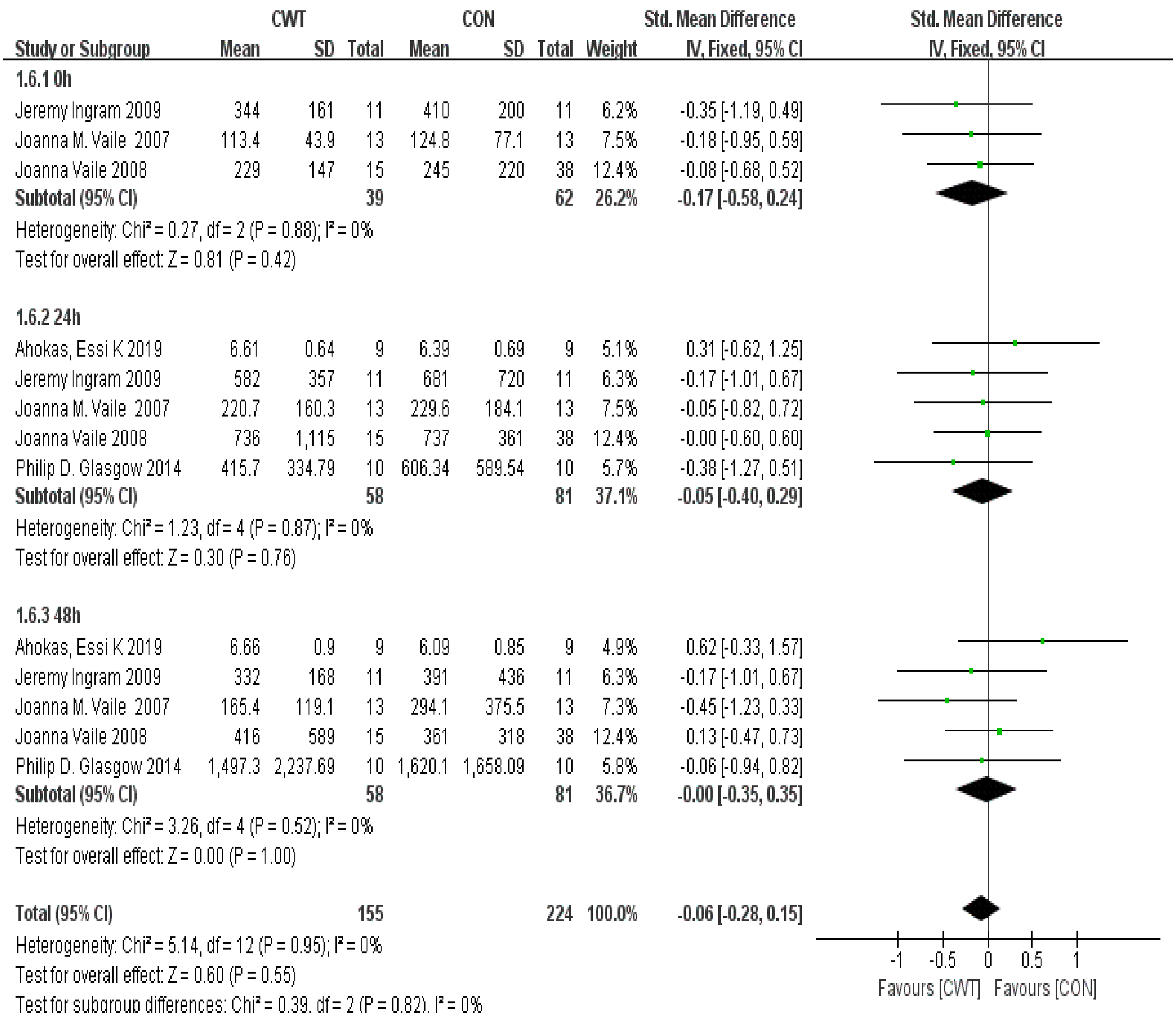

Figure 9. Forest plot of the comparison of CWT versus CON for measurement of CK
CWT=Contrast water therapy, CON= Control, CK=creatine kinase.

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3.3.7 CRP

Analysis of the effects of post-exercise CWT and CON on CRP revealed no significant difference at 0h, 24h, and 48h, indicating that no improvement in CRP could be achieved after CWT. Meanwhile, only one piece of literature was included in the CRP group for meta-analysis, which was insufficient literature to adequately explain the results (Fig. 10).

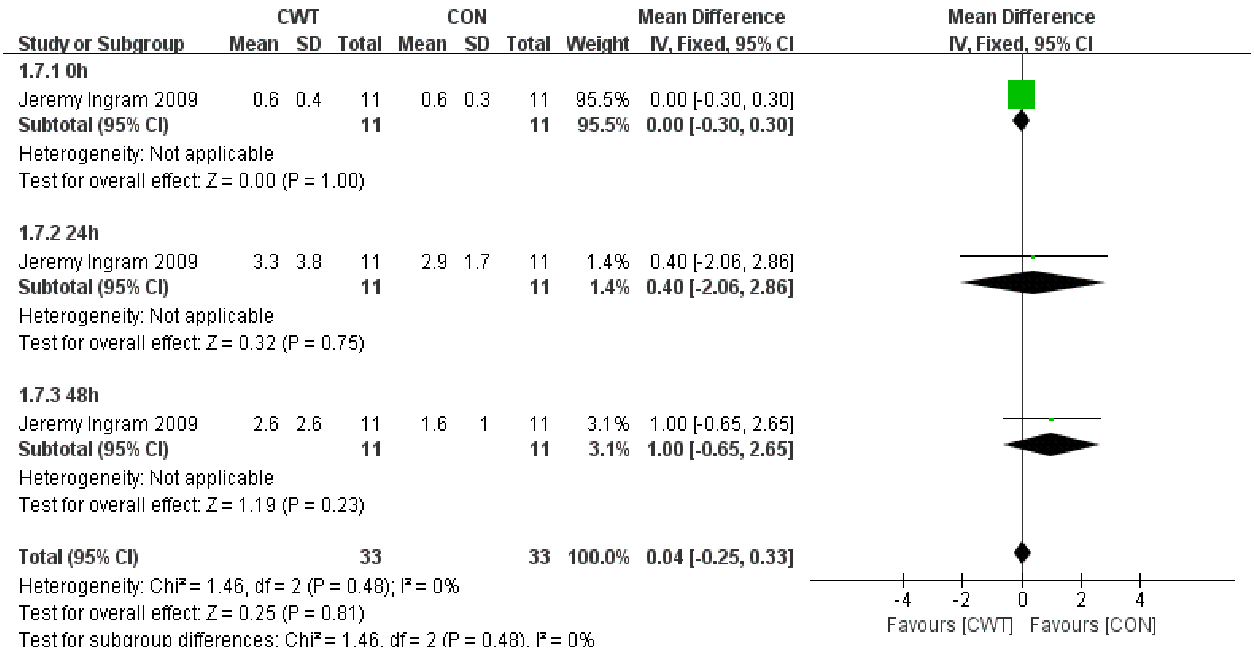

Figure 10. Forest plot of the comparison of CWT versus CON for measurement of CRP
CWT=Contrast water therapy, CON= Control, CRP=C-Reactive Protein.

3.3.8 IL-6

There was no significant difference in IL-6 between the CWT group and the CON group at 0h and 24h, indicating that post-exercise CWT was not able to optimize IL-6 in human blood. Meanwhile, this result is not representative due to the insufficient amount of literature (Fig. 11).

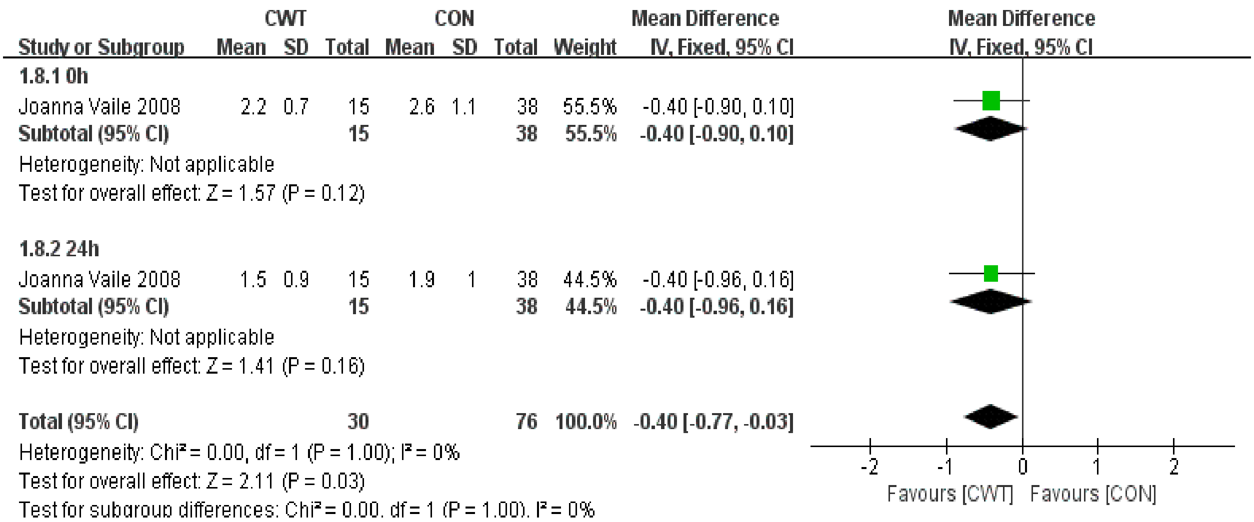

Figure 11. Forest plot of the comparison of CWT versus CON for measurement of IL-6
CWT=Contrast water therapy, CON= Control, IL-6= Interleukin 6.

3.4 CWT versus CWI

3.4.1 DOMS

The data presented in the figure indicates that there was a statistical difference only at 48h (48h: SMD 0.34, 95 %CL 0.03 to 0.65, 6 trials). Heterogeneity present at 1h, 24h, and 48h (1h: I^2=50 %; 24h: I^2=70 %; 48h: I^2=52 %), there was no statistical significance after selecting the random effects model at 1h, 24h, 48h. This result suggesting that the findings at 48h were not stable enough. Meanwhile, there was no difference in the effect of CWT or CWI intervention on post-exercise soreness (Fig. 12).

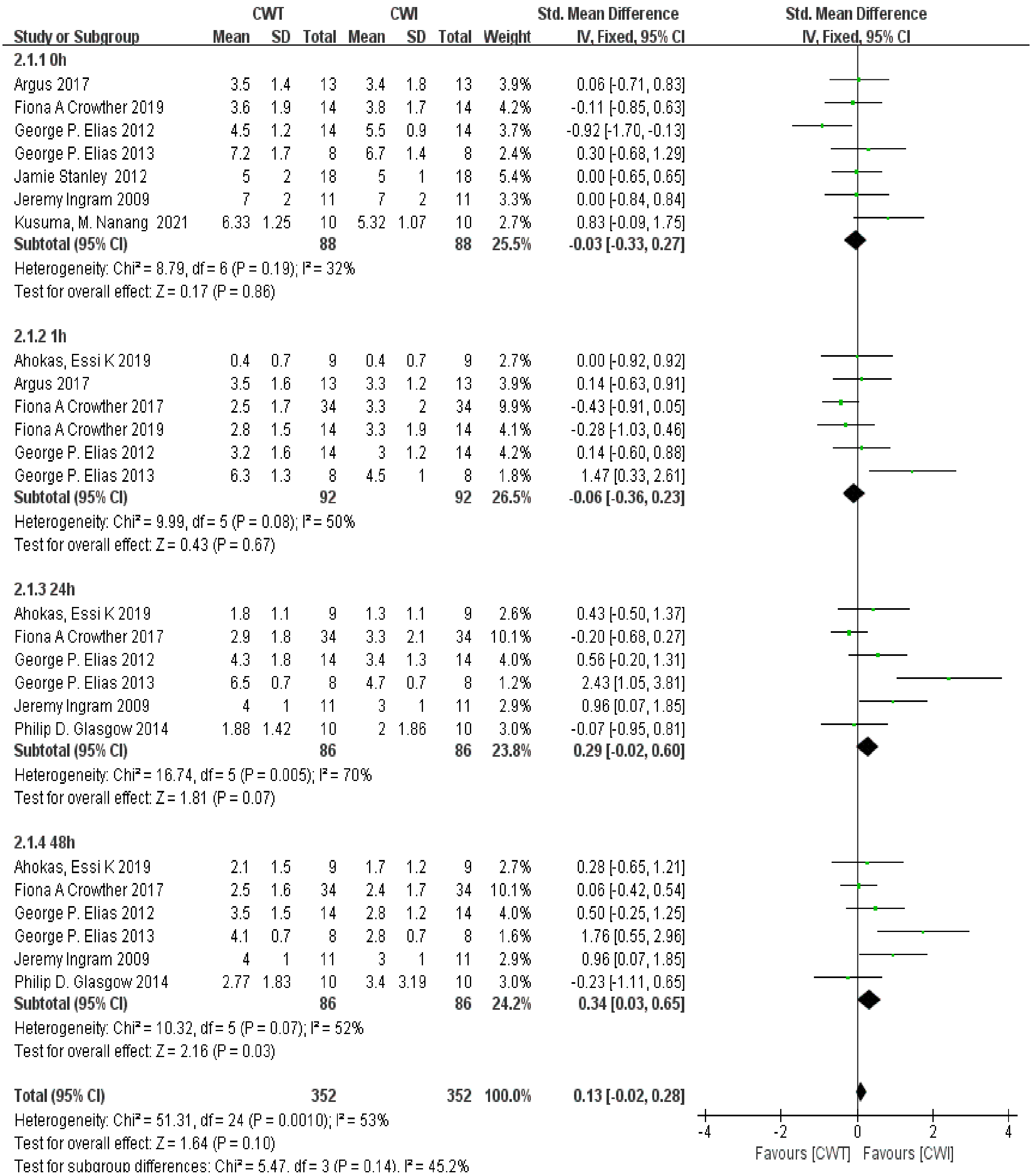

Figure 12. Forest plot of the comparison of CWT versus CWI for measurement of DOMS
CWT=Contrast water therapy, CWI=Cold water immersion, DOMS=delayed-onset muscle soreness.

3.4.2 Perceived fatigue

No significant difference was found among the perceived fatigue metrics at 0h, 1h, 24h, and 48h post-exercise with either the CWT or CWI interventions (0h: SMD -0.02, 95 %CL -0.39 to 0.34, 5 trials); (1h: SMD -0.14, 95 %CL -0.61 to 0.34, 3 trials); (24h: SMD 0.33, 95 %CL -0.21 to 0.87, 3 trials); (48h: SMD 0.44, 95 %CL -0.03 to 0.91, 4 trials). There was no heterogeneity (0h: I^2=0 %; 1h: I^2=7 %; 24h: I^2=22 %; 48h: I^2=0 %), hence a fixed effects model was used. The results revealed that there was no distinction in the impact of CWT or CWI interventions on perceived fatigue (Fig. 13).

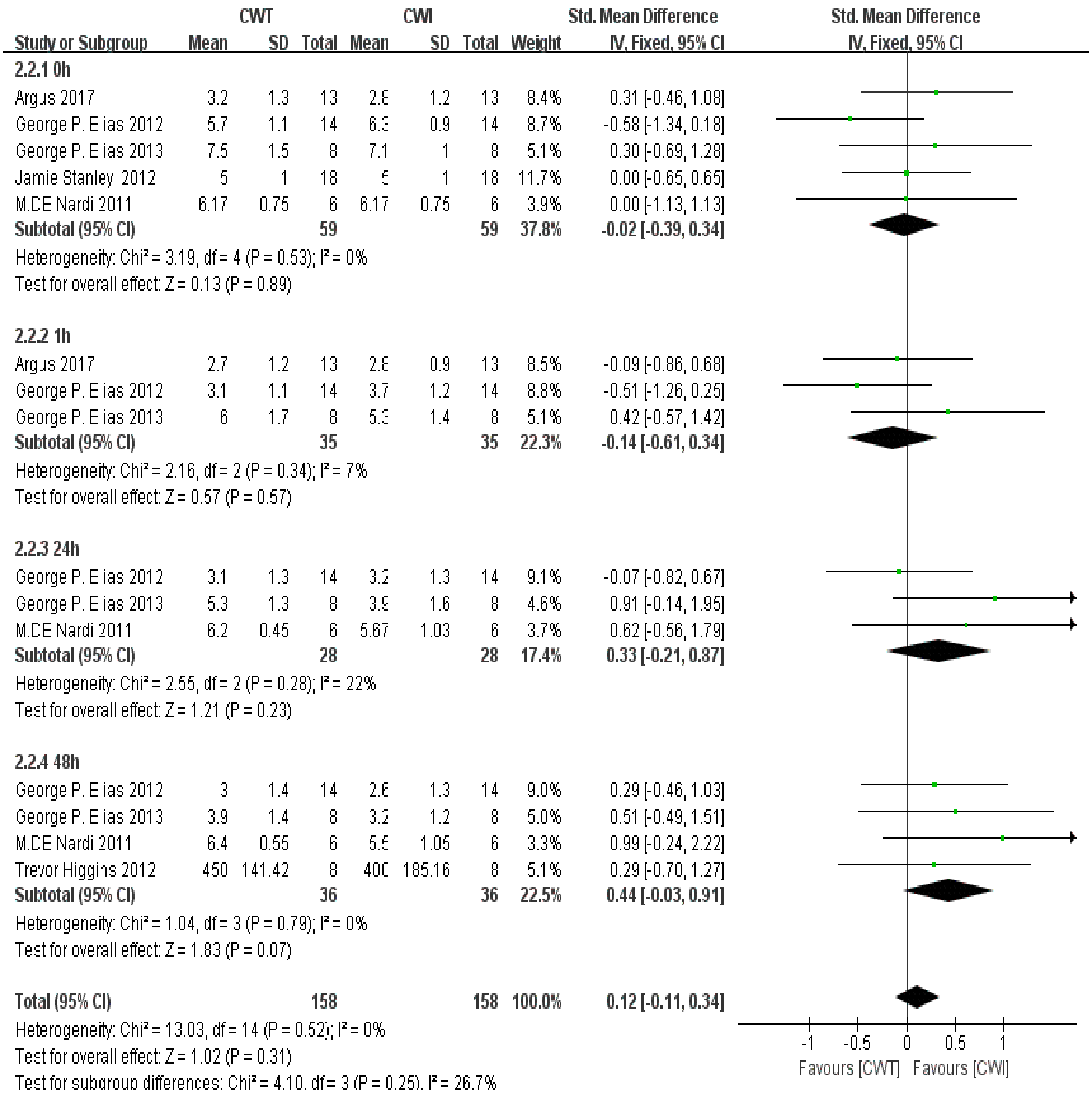

Figure 13. Forest plot of the comparison of CWT versus CWI for measurement of Fatigue
CWT=Contrast water therapy, CWI=Cold water immersion, Fatigue=Perceived fatigue.

3.4.3 CMJ

The results of CMJ at 0h, 1h, 24h, and 48h were not significant after CWT or CWI (0h: SMD -0.16, 95 %CL -0.59 to 0.27, 4 trials); (1h: SMD 0.13, 95 %CL -0.28 to 0.53, 2 trials); (24h: SMD -0.08, 95 %CL -0.43 to 0.27, 4 trials); (48h: SMD -0.14, 95 %CL -0.49 to 0.21, 4 trials), and there was no heterogeneity between any of the results (0h: I^2=0 %; 1h: I^2=0 %; 24h: I^2=0 %; 48h: I^2=0 %), so a fixed effects model was used. These findings demonstrate that there is no difference in the effect of either post-exercise CWT or CWI on CMJ (Fig. 14).

	CWT			CWI				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
2.3.1 0h								
Fiona A Crowther 2019	15.1	2.1	14	15.4	2.5	14	6.6%	-0.13 [-0.87, 0.62]
George P. Elias 2012	0.68	0.13	14	0.69	0.11	14	6.6%	-0.08 [-0.82, 0.66]
George P. Elias 2013	0.56	0.04	8	0.57	0.04	8	3.7%	-0.24 [-1.22, 0.75]
M.DE Nardi 2011	38.78	3.49	6	39.9	2.2	6	2.8%	-0.35 [-1.50, 0.79]
Subtotal (95% CI)			**42**			**42**	**19.6%**	**-0.16 [-0.59, 0.27]**
Heterogeneity: Chi² = 0.19, df = 3 (P = 0.98); I² = 0%								
Test for overall effect: Z = 0.75 (P = 0.45)								
2.3.2 1h								
Fiona A Crowther 2017	16.2	2	34	15.9	2.1	34	15.9%	0.14 [-0.33, 0.62]
Fiona A Crowther 2019	15.3	2.2	14	15.1	2.7	14	6.6%	0.08 [-0.66, 0.82]
Subtotal (95% CI)			**48**			**48**	**22.5%**	**0.13 [-0.28, 0.53]**
Heterogeneity: Chi² = 0.02, df = 1 (P = 0.88); I² = 0%								
Test for overall effect: Z = 0.61 (P = 0.54)								
2.3.3 24h								
Fiona A Crowther 2017	16.2	2.3	34	16.3	2.1	34	16.0%	-0.04 [-0.52, 0.43]
George P. Elias 2012	0.67	0.14	14	0.68	0.09	14	6.6%	-0.08 [-0.82, 0.66]
George P. Elias 2013	0.56	0.04	8	0.57	0.03	8	3.7%	-0.27 [-1.25, 0.72]
M.DE Nardi 2011	37.98	3.92	6	38.08	3.34	6	2.8%	-0.03 [-1.16, 1.11]
Subtotal (95% CI)			**62**			**62**	**29.0%**	**-0.08 [-0.43, 0.27]**
Heterogeneity: Chi² = 0.17, df = 3 (P = 0.98); I² = 0%								
Test for overall effect: Z = 0.44 (P = 0.66)								
2.3.4 48h								
Fiona A Crowther 2017	16.2	2.1	34	16.4	2.4	34	15.9%	-0.09 [-0.56, 0.39]
George P. Elias 2012	0.68	0.15	14	0.68	0.12	14	6.6%	0.00 [-0.74, 0.74]
George P. Elias 2013	0.57	0.02	8	0.58	0.02	8	3.6%	-0.47 [-1.47, 0.53]
M.DE Nardi 2011	37.47	3.31	6	38.62	2.7	6	2.8%	-0.35 [-1.50, 0.79]
Subtotal (95% CI)			**62**			**62**	**28.9%**	**-0.14 [-0.49, 0.21]**
Heterogeneity: Chi² = 0.74, df = 3 (P = 0.86); I² = 0%								
Test for overall effect: Z = 0.78 (P = 0.43)								
Total (95% CI)			**214**			**214**	**100.0%**	**-0.07 [-0.26, 0.12]**
Heterogeneity: Chi² = 2.37, df = 13 (P = 1.00); I² = 0%								
Test for overall effect: Z = 0.70 (P = 0.48)								
Test for subgroup differences: Chi² = 1.26, df = 3 (P = 0.74), I² = 0%								

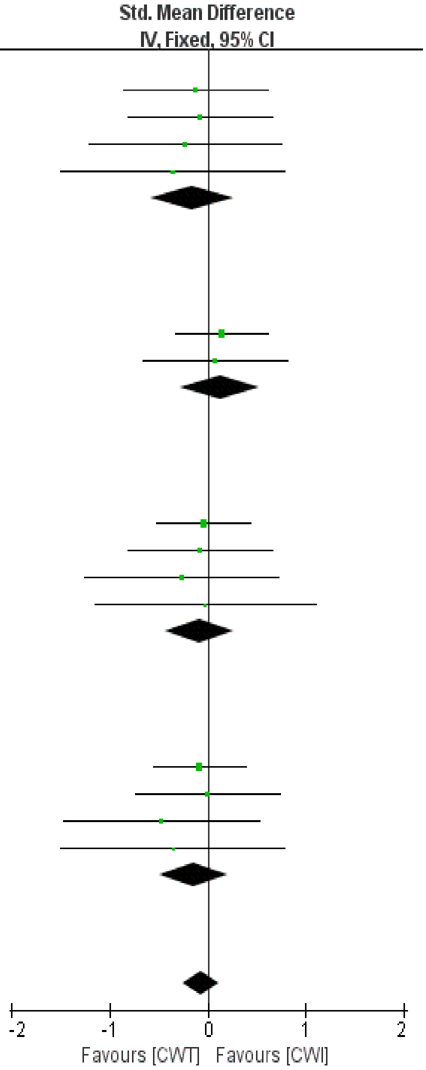

Figure 14. Forest plot of the comparison of CWT versus CWI for measurement of CMJ
CWT=Contrast water therapy, CWI=Cold water immersion, CMJ=Countermovement jump.

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3.4.4 Sprint time

The findings reveal that there was no significant difference in sprint time between the CWT and CWI interventions at 0h, 1h, 24h, and 48h (0h: SMD 0.05, 95 %CL -0.38 to 0.48, 4 trials); (1h: SMD -0.21, 95 %CL -0.61 to 0.19, 2 trials); (24h: SMD 0.22, 95 %CL -0.13 to 0.58, 4 trials); (48h: SMD 0.22, 95 %CL -0.13 to 0.58, 4 trials). The results were not heterogeneous (0h: I^2=0 %; 1h: I^2=0 %; 24h: I^2=3 %; 48h: I^2=0 %), necessitating a fixed-effects model. No evidence of a difference in the effect of either CWT or CWI intervention on exercise performance sprint time was found (Fig. 15).

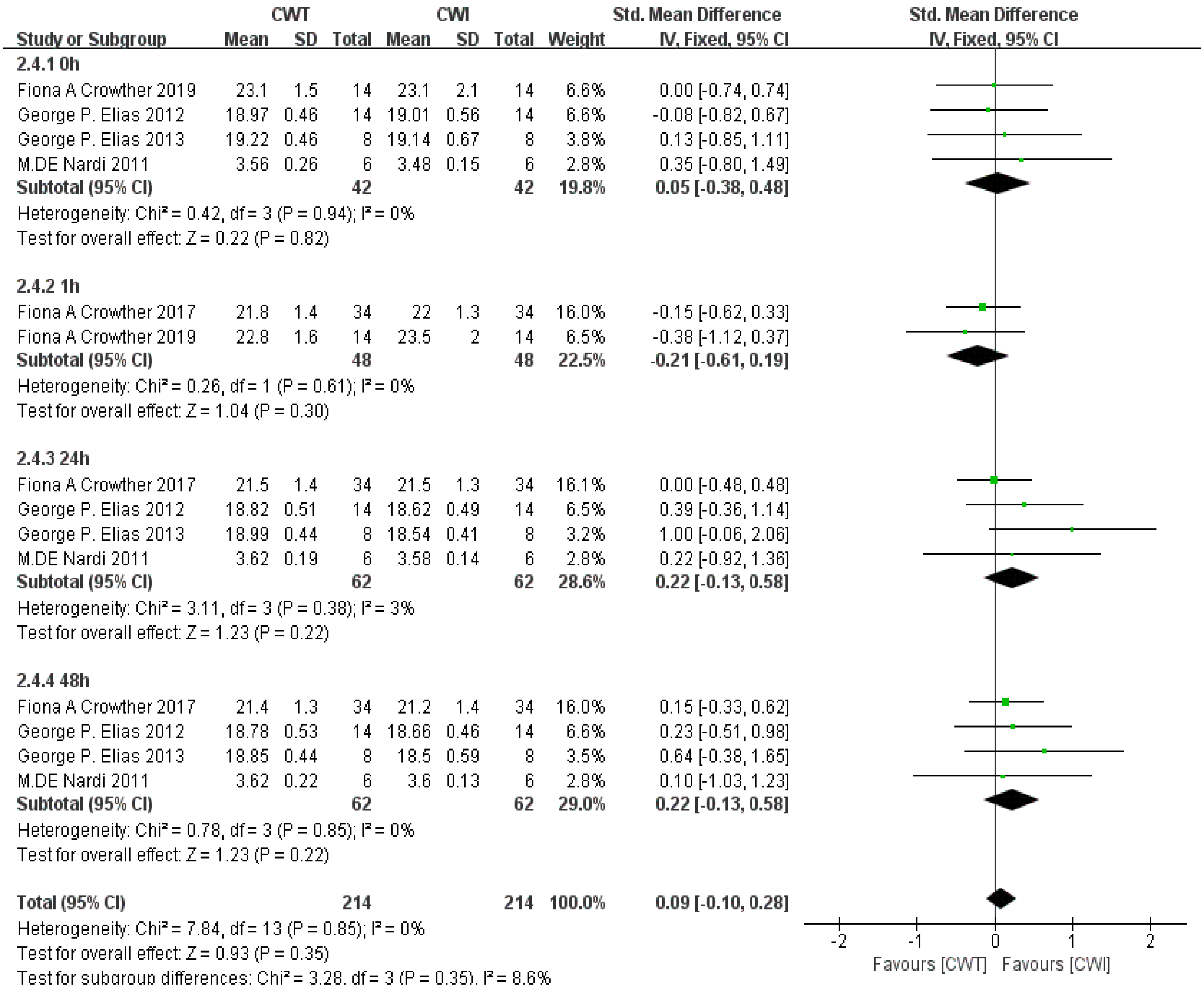

Figure 15. Forest plot of the comparison of CWT versus CWI for measurement of Sprint time
CWT=Contrast water therapy, CWI=Cold water immersion.

3.4.5 Lactate

There was no significant difference between lactate levels at 0h following CWT or CWI (0h: SMD 0.23, 95 %CL -0.27 to 0.73, 3 trials), indicating that the immediate impact on lactate levels is similar when using either CWT or CWI. The results at 24 h and 48 h showed a significant difference (24 h: SMD 0.87, 95 %CL 0.07 to 1.67, 1 trials); (48 h: SMD 0.85, 95 %CL 0.05 to 1.65, 1 trials), indicating that post-exercise with CWI intervention is more effective in removing lactate than CWT at 24 h and 48 h. It should be noted that this result is not representative as only one piece of literature was included (Fig. 16).

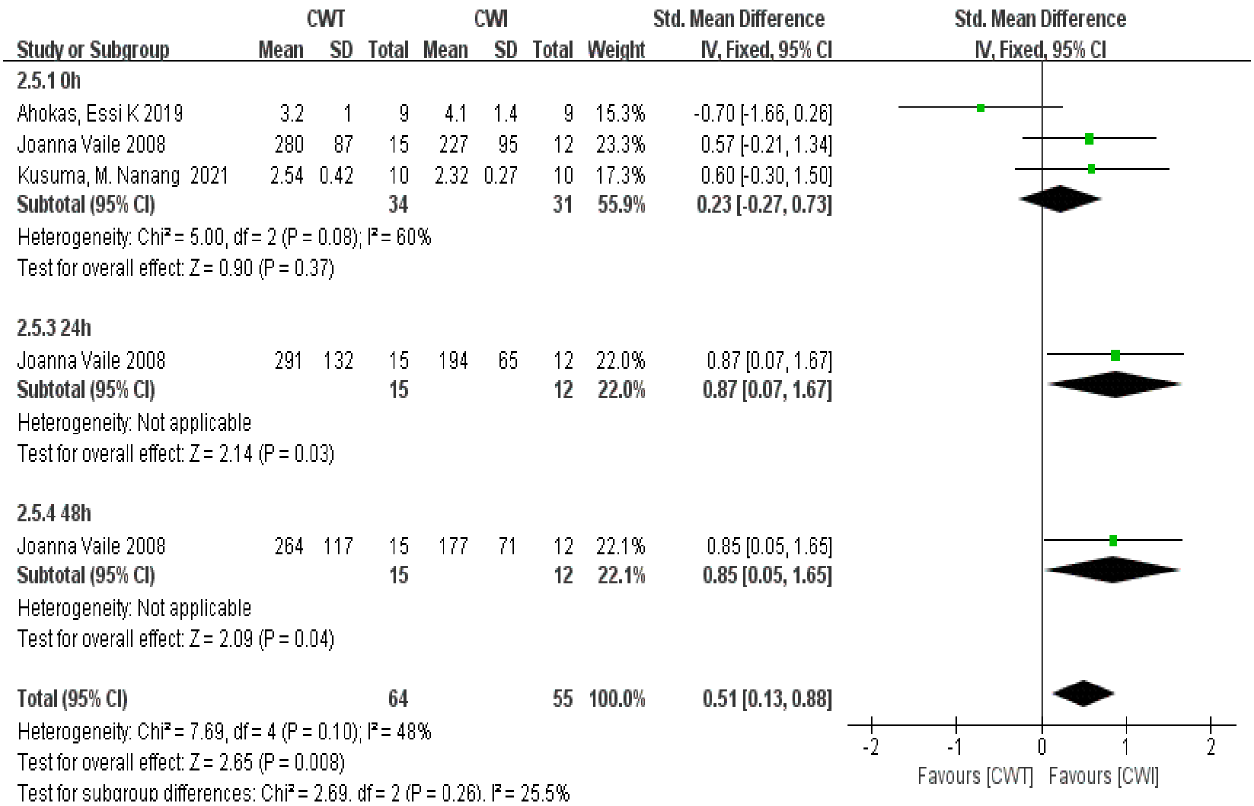

Figure 16. Forest plot of the comparison of CWT versus CWI for measurement of Lactate
CWT=Contrast water therapy, CWI=Cold water immersion.

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3.4.6 CK

Significant difference was observed between the data of CK at 24 h (24 h: SMD 0.48, 95 %CL 0.05 to 0.91, 4 trials). A fixed effects model was utilized due to the absence of heterogeneity amongst the results (0 h: I^2=0 %; 24 h: I^2=0 %; 48 h: I^2=0 %). The findings indicate that the interventions of CWT and CWI had comparable effects on CK at 0 h and 48 h. Conversely, CWI had a greater effect on CK clearance compared to CWT at 24 h (Fig. 17).

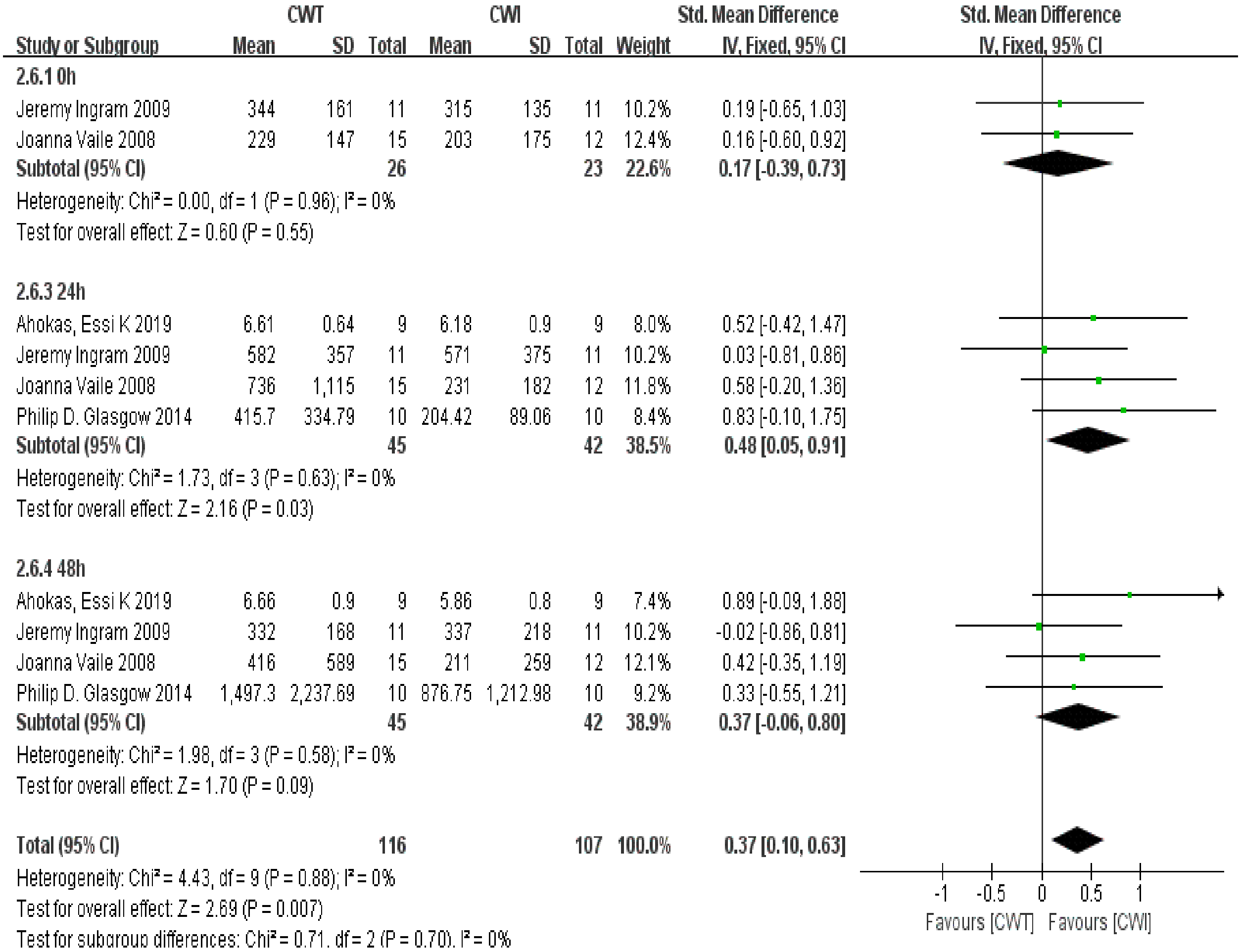

Figure 17. Forest plot of the comparison of CWT versus CWI for measurement of CK
CWT=Contrast water therapy, CWI=Cold water immersion, CK=Creatine kinase.

3.4.7 CRP and IL-6

The analysis presented in the figure reveals no statistically significant difference between the groups subjected to either CWT or CWI interventions in either the CRP or IL-6. However, due to the limited number of sources examined and the inclusion of only one study on indicators of CRP and IL-6, the findings are not representative (Fig. 18, 19).

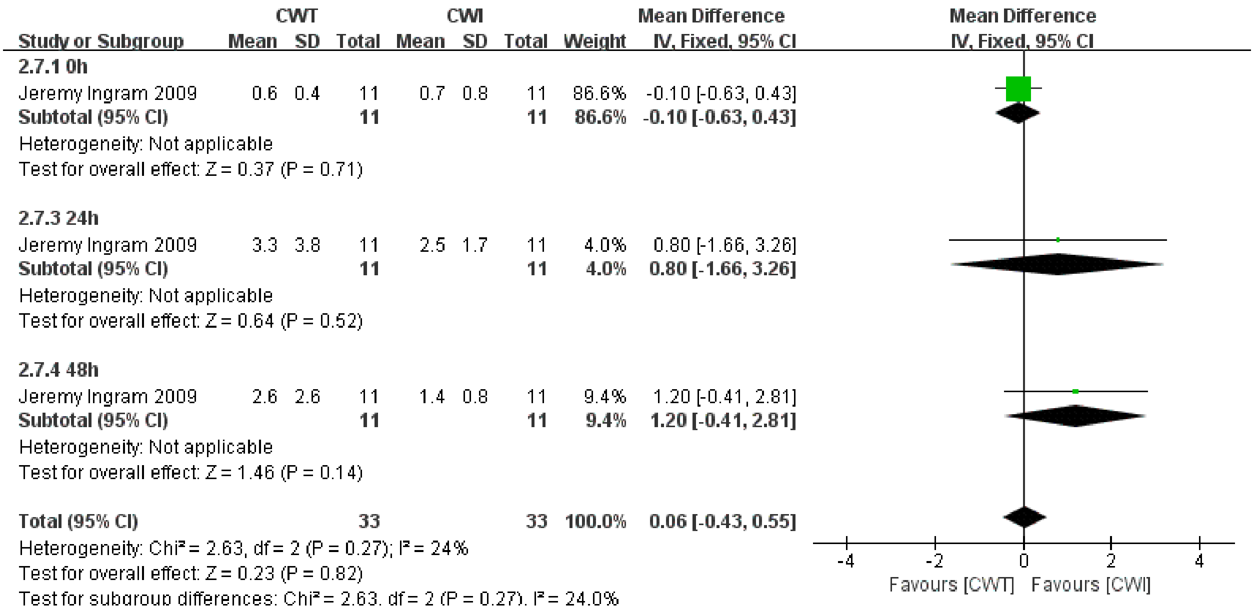

Figure 18. Forest plot of the comparison of CWT versus CWI for measurement of CRP
CWT=Contrast water therapy, CWI= Cold water immersion, CRP=C-Reactive Protein.

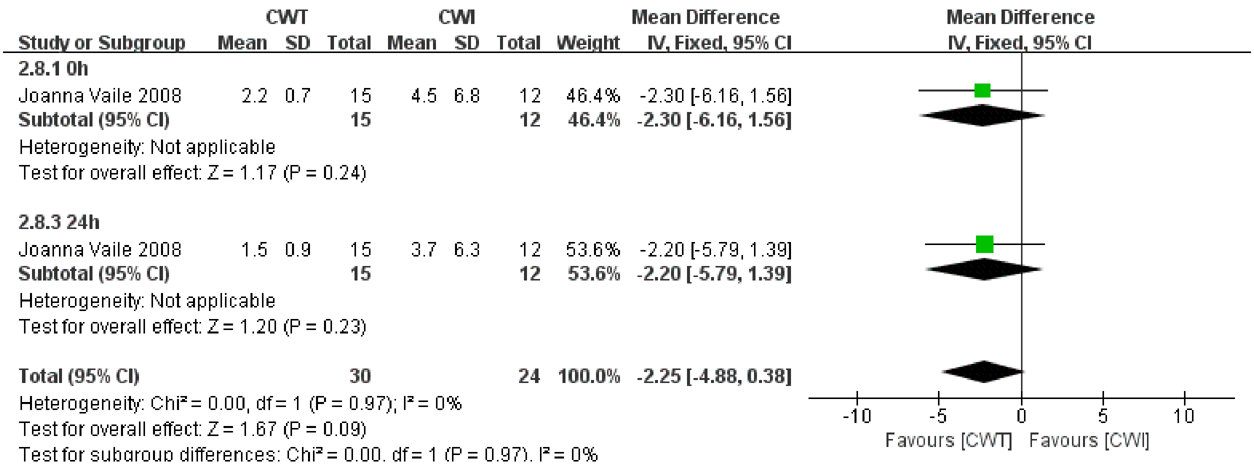

Figure 19. Forest plot of the comparison of CWT versus CWI for measurement of IL-6
CWT=Contrast water therapy, CWI= Cold water immersion, IL-6= Interleukin 6.

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3.5 Subgroup analysis

3.5.1 Position of water during CWT

In the subgroup analysis focusing on water immersion depth during CWT, participants were divided into two categories: the umbilical immersion group and the shoulder immersion group. The analysis of DOMS outcomes revealed a statistically significant reduction in the umbilical immersion group at both 24 h and 48 h (24 h: SMD -0.64, 95 %CL -1.13 to -0.15, 3 trials); (48h: SMD -0.60, 95 %CL -1.09 to -0.11, 3 trials) post-CWT. This implies that submerging the body in water up to the umbilical level is effective in reducing muscle soreness. In contrast, no significant difference was observed in the shoulder immersion group at these time intervals, indicating that immersion up to shoulder level did not significantly alter muscle soreness at 24 h and 48 h. Additionally, the shoulder immersion group showed no notable difference in sprint time performance, suggesting that water level reaching the shoulders does not influence sprinting ability 24 hours post-CWT. However, the findings pertaining to the umbilical immersion group were based on a single study, limiting the generalizability of this result. Regarding lactate levels no statistically significant difference was observed in either the umbilical or shoulder immersion groups immediately post-CWT (0 hours). This indicates that the depth of immersion, whether at the umbilicus or shoulder level, does not significantly affect lactate levels at this time point.

3.5.2 Types of trial

Subgroup analyses based on trial type were conducted, categorizing studies into RCTs, cross-over trials, and other types of trials. For DOMS, no significant difference was observed in the RCTs group at 24 h or 48h post-CWT. In the cross-over trials group, a significant reduction in DOMS was found at 24 h (SMD -1.64, 95 % CI -3.28 to -0.01, 2 trials), but not at 48 h (SMD -0.61, 95 % CI -1.38 to 0.15, 2 trials). No significant differences were observed in the other types group at either 24 h or 48 h.

Regarding sprint time, results in the RCTs group did not show improvement at 24h post-CWT (SMD: -0.49, 95 % CL: -1.38 to 0.41, across 3 trials). The literature inclusion for both the cross-over group and other types group was deemed insufficient for meta-analysis. In terms of lactate levels immediately post-CWT (0h), non-significant results were observed in both the RCTs group (SMD: -0.12, 95 % CL: -1.16 to 0.92, across 2 trials) and other types group (SMD: -0.59, 95 % CL: -1.25 to 0.07, across 2 trials). These findings indicate that neither RCTs nor other types of trials were effective in altering lactate levels at 0 hours post-CWT.

3.5.3 Types of exercise

Exploring the effects of CWT on subjects after different sport types. The results showed a significant difference in DOMS at 1h and 24h when CWT was performed after team sports (1h: SMD -0.58, 95 %CL -1.06 to -0.10, 3 trials); (24h: SMD -1.07, 95 %CL -2.05 to -0.08, 4 trials), especially following soccer, the DOMS was significant at 24h and 48h (24h: SMD -1.68, 95 %CL -3.31 to -0.06, 2 trials); (48h: SMD -1.60, 95 %CL -2.31 to -0.90, 2 trials). There was insufficient literature to analyze rugby exercise. In team sports, there was significant difference in indicator of perceived fatigue at 1h, 24h, and 48h (1h: SMD -1.01, 95 %CL -1.94 to -0.08, 2 trials); (24h: SMD -0.72, 95 %CL -1.23 to -0.21, 3 trials); (48h: SMD -0.55, 95 %CL -1.08 to -0.02, 3 trials). Additionally, it was also significant difference in the soccer group at 1 h and 24 h (1h: SMD -1.01, 95 %CL -1.94 to -0.08, 2 trials); (24h: SMD -0.95, 95 %CL -1.58 to -0.32, 2 trials). There was also a significant difference in the indicator of sprint time in the soccer group at 24 h (24h: SMD -0.90, 95 %CL -1.53 to -0.28, 2 trials).

For eccentric exercise, no significant differences were observed in DOMS, lactate, and CK at 0h, 1h, 24h, and 48h post-CWT intervention. No available data were reported for perceived fatigue, CMJ, and sprint time in this category. In short-duration exercise, lactate levels significantly decreased at 0h post-CWT intervention (SMD -0.88, 95 % CI -1.56 to -0.21, 2 trials). No significant differences were found in DOMS, perceived fatigue, CMJ, sprint time, and lactate for high-intensity, submaximal intensity, or low-intensity exercise.

Discussion

4.1 CWT versus CON (passive rest and low-intensity active recovery)

All the results of CWT vs. CON are as shown in Table 2.

Table 2

Summary of results of CWT and CON

	0H	**1H**	**24H**	**48H**
DOMS	—	↓	↓† Umbilicus↓; Cross-over↓	↓† Umbilicus↓; Type—
Fatigue	↓	↓	↓	↓
CMJ	—	—	—	—
Sprint time	—	—	—† Part—; Type—	—
Lactate	—† Part—; Type—		—	—
CK	—		—	—
CRP	—		—	—
IL-6	—		—	

Note. ↓= significantly decrease in CWT groups, compared with CON groups; ↑= significantly increase in CWT groups, compared with CON groups; — = unsignificant difference between CWT and CON groups; †= heterogeneity present between CWT and CON groups; Part= CWI of different body parts; Type= different type trial of CWT; CMJ= Countermovement jump; CK= Creatine kinase; CRP= C-Reactive protein; DOMS= Delay of Muscle Soreness; Fatigue= perceived fatigue; IL-6= Interleukin 6.

This meta-analysis demonstrated that CWT significantly alleviates DOMS and perceived fatigue compared to CON, consistent with previous findings by Dupuy et al. [35]. However, unlike the analysis conducted by Dupuy, this review incorporated subgroup and sensitivity analyses to investigate heterogeneity sources, revealing that neither immersion depth nor trial type significantly influenced recovery outcomes. Notably, the study of Dupuy included a broader range of exercise protocols and participant populations, which may explain the differences in outcomes, particularly for biomarkers like CK.

The reduction in DOMS observed with CWT can be attributed to several potential mechanisms. Hydrostatic pressure during immersion likely facilitates fluid redistribution, reducing edema and alleviating muscle soreness. Alternating vasoconstriction and vasodilation during CWT may enhance blood flow, thereby accelerating the clearance of metabolic by-products [28, 36]. Furthermore, cold water immersion reduces skin temperature and sympathetic drive, which can promote recovery by decreasing muscle inflammation and pain perception [37]. However, direct evidence supporting these mechanisms is sparse, and further research is needed to elucidate their precise roles. Additionally, the placebo effect may partly explain subjective improvements, underscoring the importance of conducting future trials with appropriate blinding.

None of the biomarkers exhibited significant changes after CWT as compared to CON. CK is a general biomarker that indirectly responds to muscle damage after strenuous exercise [38]. In contrast to the findings of Dupuy, which reported a significant reduction in CK following CWT [35], the present meta-analysis did not observe a significant effect of CWT on CK levels. The concentration of CK increases maximally when performing multiple sets of moderate to high intensity eccentric exercises [39]. Most of the studies reviewed only utilized a single exercise, which did not generate enough intensity to significantly increase CK. Consequently, there was an insignificant variation in the recovery effect among the different intervention modalities.

Lactate is a metabolite that accumulates during strenuous exercise and has traditionally been associated with muscle fatigue. However, recent evidence suggests that lactate itself may not directly cause fatigue but rather serves as an energy substrate and a buffer against acidosis [40, 41].The results are inconsistent with other studies showing that CWT effectively reduces blood lactate levels at different times. This particular study only found an immediate reduction in blood lactate after short-term exercise. This is because only one study about lactate indicators at 24 and 48 hours was included. Additionally, the short duration of CWT included in the literature may also explain the insignificant changes in blood lactate at 0h [19]. Consistent with the findings of Ingram and Vaile et al. that CWT does not affect inflammatory biomarkers [21, 27], this review did not find an effect of CWT on IL-6 and CRP. This might be due to the fact that only a few studies with indicators of IL-6 and CRP were included in the present review and therefore the results were not representative.

CWT did not enhance subsequent exercise performance compared to CON. Blood lactate was not significantly reduced after CWT, and elevated lactate can adversely affect muscle contractile processes [42]. Both CMJ and sprint time, the metrics included in this review to characterize exercise performance, require strong muscle contraction, which may explain why CWT did not improve exercise performance.

4.2 CWT versus CWI

All the results of CWT vs. CWI are as shown in Table 3.

Table 3

Summary of results of CWT and CWI

	0H	**1H**	**24H**	**48H**
DOMS	—	—†	—†	—†
Fatigue	—	—	—	—
CMJ	—	—	—	—
Sprint time	—	—	—	—
Lactate	—†		↓	↓
CK	—		↓	—
CRP	—		—	—
IL-6	—		—	

Note. ↓= significantly decrease in CWI groups, compared with CWT groups; — = unsignificant difference between CWT and CWI groups; †= heterogeneity present between CWT and CWI groups; CMJ= Countermovement jump; CK= Creatine kinase; CRP= C-Reactive protein; DOMS= Delay of Muscle Soreness; Fatigue= perceived fatigue; IL-6= Interleukin 6.

There was few statistically significant difference between CWT and CWI in terms of perceived indicators like DOMS and fatigue, biochemical markers like CRP and IL-6, and exercise performance indicators such as CMJ and sprint time. The study revealed a significant reduction in lactate levels at 24h and 48h as well as a significant reduction in CK levels at 24h with CWI compared to CWT. This suggests that CWI is an effective intervention for relieving body soreness after 24 hours of exercise. However, the long-term use of cold water immersion leads to decreased muscle temperature and impaired exercise performance. Future research aims to explore alternative recovery protocols.

4.3 Characterization of subgroup analysis

4.3.1 Immersion Depth

The recovery efficacy of CWT varied by immersion depth. Subgroup analysis based on immersion depth revealed that immersing the body to the umbilicus was more effective in reducing DOMS at 24h and 48h compared to shoulder-level immersion. This effect can be attributed to hydrostatic pressure differences [36, 43, 44]: when immersed to the umbilicus, hydrostatic pressure facilitates fluid transfer from the lower extremities to the central cavity [36], reducing edema and soreness [44]. In contrast, full-body immersion to the shoulders applies pressure to the thoracic and abdominal cavities, potentially counteracting the beneficial fluid transfer from the lower extremities.

The exercise protocols in the included studies primarily targeted lower extremity muscles, which might explain the more pronounced recovery effects with umbilical immersion. Additionally, the reduced pressure on the upper body during umbilical-level immersion may enhance comfort and relaxation [36, 44], indirectly promoting fatigue recovery.

4.3.2 Trial Type

The effectiveness of CWT in promoting recovery differed across various trial type. Subgroup analysis by trial type showed that cross-over trials were more representative of the effects of CWT on DOMS, demonstrating significant reductions at 24h post-intervention. In contrast, RCTs and other trial types did not show consistent improvements, likely due to variations in study designs and protocols.

The significant heterogeneity observed across different trial types suggests that methodological differences—such as participant selection, intervention timing, and exercise protocols—may influence the reported outcomes. Future research should adopt more standardized trial designs to improve the comparability of results.

4.3.3 Exercise Type

The recovery efficacy of CWT varied by exercise type. CWT was more effective in reducing DOMS and perceived fatigue after team sports, particularly soccer, where significant improvements were observed at 1h, 24h, and 48h post-exercise. This enhanced efficacy may be due to the high physical contact and muscle damage typically associated with team sports, making the alternating hot and cold immersion used in CWT particularly beneficial [20].

In contrast, CWT was less effective in recovery after eccentric exercises, with no significant improvements in DOMS, lactate, or CK at any time point. Additionally, while CWT was effective in reducing lactate immediately post short-duration exercise (0h), it did not show similar benefits for high-intensity, submaximal, or low-intensity exercises.

4.4 Limitations of the study design

It was not possible to blind the different interventions in the study design. Although a RCT design could have been used to try to avoid the placebo effect, RCTs are not enough in this review. When conducting such studies in the future, try to choose the same type of experiment to minimize variability. This study specifically focused on CWT due to its unique alternating hot-cold immersion protocol, which differs fundamentally in mechanism and application from single-modality methods such as Hot Water Immersion (HWI) and Thermoneutral Water Immersion (TWI). As a result, studies solely addressing HWI and TWI were excluded to maintain a targeted scope. While HWI and TWI are recognized as effective recovery modalities, their mechanisms (e.g., sustained vasodilation or neutral hydrostatic effects) are distinct and may warrant a separate systematic review.

This study did not stratify results by gender or exercise protocols, which may influence recovery responses due to physiological and biomechanical differences. Additionally, biomarkers such as lactate dehydrogenase, blood urea nitrogen, and heart rate were not analyzed, limiting a comprehensive understanding of the effects of CWT. Future research should address these limitations to provide a more nuanced understanding of recovery dynamics across different populations and exercise modalities.

The literature search was limited to studies published between 2002 and 2022 to focus on research conducted within the past two decades, reflecting contemporary practices and methodologies in CWT. While this approach ensures the inclusion of relevant and standardized studies, it may exclude earlier pioneering studies or more recent findings beyond 2022. Future reviews may expand this timeframe to incorporate additional evidence

4.5 Future directions for research

In the future, researchers can select the same experimental type for review and analysis. They can also combine multiple recovery methods as a post-exercise intervention for subjects to assess the efficacy of a combined form of these modalities in enhancing subsequent exercise performance. It remains to be seen whether different recovery modalities can be developed for different sports.

Conclusions

Post-exercise CWT interventions were effective in relieving perceived muscle soreness and perceived fatigue. Although CWT did not consistently improve subsequent exercise performance across all conditions, it showed potential benefits after specific types of exercise, such as soccer. Compared to CWT, CWI was more effective in reducing objective soreness, but both interventions demonstrated similar efficacy in overall fatigue recovery. Furthermore, the effectiveness of CWT varied depending on exercise types, with perceptual benefits being more pronounced after team sports. While immersion depth and experimental designs were considered as potential influencing factors, further research is required to confirm their roles in modulating the efficacy of CWT.

Reference

1 Hing, W.A., White, S.G., Bouaaphone, A., & Lee, P. (2008). Contrast therapy—A systematic review. *Physical Therapy in Sport: Official Journal of the Association of Chartered Physiotherapists in Sports Medicine, 9*(3), 148–161. https://doi.org/10.1016/j.ptsp.2008.06.001.

2 Higgins, T.R., Greene, D.A., & Baker, M.K. (2017). Effects of Cold Water Immersion and Contrast Water Therapy for Recovery From Team Sport: A Systematic Review and Meta-analysis. *Journal of Strength and Conditioning Research, 31*(5), 1443–1460. https://doi.org/10.1519/JSC.0000000000001559.

3 Coffey, V., Leveritt, M., & Gill, N. (2004). Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables. *Journal of Science and Medicine in Sport, 7*(1), 1–10. https://doi.org/10.1016/s1440-2440(04)80038-0.

4 Versey, N.G., Halson, S.L., & Dawson, B.T. (2013). Water immersion recovery for athletes: Effect on exercise performance and practical recommendations. *Sports Medicine (Auckland, N.Z.), 43*(11), 1101–1130. https://doi.org/10.1007/s40279-013-0063-8.

5 Poppendieck, W., Faude, O., Wegmann, M., & Meyer, T. (2013). Cooling and performance recovery of trained athletes: A meta-analytical review. *International Journal of Sports Physiology and Performance, 8*(3), 227–242. https://doi.org/10.1123/ijspp.8.3.227.

6 Elias, G.P., Varley, M.C., Wyckelsma, V.L., McKenna, M.J., Minahan, C.L., & Aughey, R.J. (2012). Effects of water immersion on posttraining recovery in Australian footballers. *International Journal of Sports Physiology and Performance, 7*(4), 357–366. https://doi.org/10.1123/ijspp.7.4.357.

7 Webb N.P., Harris N.K., Cronin J.B., & Walker C. (2013). The Relative Efficacy of Three Recovery Modalities After Professional Rugby League Matches. *The Journal of Strength & Conditioning Research, 27*(9), 2449. https://doi.org/10.1519/JSC.0b013e31827f5253.

8 Hohenauer, E., Taeymans, J., Baeyens, J.-P., Clarys, P., & Clijsen, R. (2015). The Effect of Post-Exercise Cryotherapy on Recovery Characteristics: A Systematic Review and Meta-Analysis. PLOS ONE, 10(9), e0139028. https://doi.org/10.1371/journal.pone.0139028.

9 Xiao, F., Kabachkova, A.V., Jiao, L., Zhao, H., & Kapilevich, L.V. (2023). Effects of cold water immersion after exercise on fatigue recovery and exercise performance—Meta analysis. Frontiers in Physiology, 14. https://doi.org/10.3389/fphys.2023.1006512.

10 Clyne, B., & Olshaker, J. S. (1999). The C-reactive protein11Clinical Laboratory in Emergency Medicine is coordinated by Jonathan S. Olshaker, MD, of the University of Maryland Medical Center, Baltimore, Maryland. *The Journal of Emergency Medicine, 17*(6), 1019–1025. https://doi.org/10.1016/S0736-4679(99)00135-3.

11 Moher, D., Shamseer, L., & Clarke, M. (n.d.). *Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement | Systematic Reviews.* Retrieved November 29, 2023, from https://link.springer.com/article/10.1186/2046-4053-4-1.

12 *Cochrane Handbook for Systematic Reviews of Interventions | Wiley Online Books.* (n.d.). Retrieved November 1, 2023, from https://onlinelibrary.wiley.com/doi/book/10.1002/9780470712184.

13 Argus, C.K., Broatch, J.R., Petersen, A.C., Polman, R., Bishop, D.J., & Halson, S. (2016). Cold Water Immersion and Contrast Water Therapy Do Not Improve Short-Term Recovery Following Resistance Training. International Journal of Sports Physiology and Performance.

14 Crowther, F., Sealey, R., Crowe, M., Edwards, A., & Halson, S. (2017). Influence of recovery strategies upon performance and perceptions following fatiguing exercise: A randomized controlled trial. BMC Sports Science, Medicine & Rehabilitation, 9, 25. https://doi.org/10.1186/s13102-017-0087-8.

15 Crowther, F. A., Sealey, R. M., Crowe, M. J., Edwards, A. M., & Halson, S. L. (2019). Effects of Various Recovery Strategies on Repeated Bouts of Simulated Intermittent Activity. *Journal of Strength and Conditioning Research, 33*(7), 1781–1794. https://doi.org/10.1519/JSC.0000000000002396.

16 Elias, G.P., Wyckelsma, V.L., Varley, M.C., McKenna, M.J., & Aughey, R.J. (2013). Effectiveness of water immersion on postmatch recovery in elite professional footballers. *International Journal of Sports Physiology and Performance, 8*(3), 243–253. https://doi.org/10.1123/ijspp.8.3.243.

17 Glasgow, P.D., Ferris, R., & Bleakley, C.M. (2014). Cold water immersion in the management of delayed-onset muscle soreness: Is dose important? A randomised controlled trial. *Physical Therapy in Sport, 15*(4), 228–233. https://doi.org/10.1016/j.ptsp.2014.01.002.

18 1Hamlin, M.J. (2007). The effect of contrast temperature water therapy on repeated sprint performance. *Journal of Science and Medicine in Sport, 10*(6), 398–402. https://doi.org/10.1016/j.jsams.2007.01.002.

19 Higgins, T., Greene, D., & Baker, M. (2016). The Effects of Cold Water Immersion and Contrast Water Therapy for Recovery from Team Sport: A Systematic Review and Meta-Analysis. *Journal of Strength and Conditioning Research, 31*, 1. https://doi.org/10.1519/JSC.0000000000001559.

20 Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science and Medicine in Sport, 12*(3), 417–421. https://doi.org/10.1016/j.jsams.2007.12.011.

21 Juliff, L.E., Halson, S.L., Bonetti, D.L., Versey, N.G., Driller, M.W., & Peiffer, J.J. (2014). Influence of Contrast Shower and Water Immersion on Recovery in Elite Netballers. *Journal of Strength and Conditioning Research, 28*(8), 2353–2358. https://doi.org/10.1519/JSC.0000000000000417.

22 Kinugasa, T., & Kilding, A. E. (2009). A comparison of post-match recovery strategies in youth soccer players. *Journal of Strength and Conditioning Research, 23*(5), 1402–1407. https://doi.org/10.1519/JSC.0b013e3181a0226a.

23 KUSUMA, MOH. NANANG HIMAWAN. (n.d.). Effect of cold water and contrast immersion on physiological and psychological responses of elite athletes after high-intensity exercises. *Journal of Physical Education and Sport, 21*(6).

24 Nardi, M.D., Torre, A.L., Barassi, A., Ricci, C., & Banfi, G. (2011). Effects of cold-water immersion and contrast-water therapy after training in young soccer players. *THE JOURNAL OF SPORTS MEDICINE AND PHYSICAL FITNESS, 51*(4).

25 Stanley, J., Buchheit, M., & Peake, J.M. (2012). The effect of post-exercise hydrotherapy on subsequent exercise performance and heart rate variability. *European Journal of Applied Physiology, 112*(3), 951–961. https://doi.org/10.1007/s00421-011-2052-7.

26 Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness. *European Journal of Applied Physiology, 102*(4), 447–455. https://doi.org/10.1007/s00421-007-0605-6.

27 Vaile, J.M., Gill, N.D., & Blazevich, A.J. (n.d.). *THE EFFECT OF CONTRAST WATER THERAPY ON SYMPTOMS OF DELAYED ONSET MUSCLE SORENESS.*

28 Higgins, T., Cameron, M., & Climstein, M. (2012). Evaluation of passive recovery, cold water immersion, and contrast baths for recovery, as measured by game performances markers, between two simulated games of rugby union. *Journal of Strength and Conditioning Research.* https://doi.org/10.1519/JSC.0b013e31825c32b9.

29 Argus, C.K., Broatch, J.R., Petersen, A.C., Polman, R., Bishop, D.J., & Halson, S. (2017). Cold-Water Immersion and Contrast Water Therapy: No Improvement of Short-Term Recovery After Resistance Training. *International Journal of Sports Physiology and Performance, 12*(7), 886–892. https://doi.org/10.1123/ijspp.2016-0127.

30 Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Medicine, 29*(7), 539–544. https://doi.org/10.1055/s-2007-989267.

31 Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science and Medicine in Sport, 12*(3), 417–421. https://doi.org/10.1016/j.jsams.2007.12.011.

32 Juliff, L.E., Halson, S.L., Bonetti, D.L., Versey, N.G., Driller, M.W., & Peiffer, J.J. (2014). Influence of Contrast Shower and Water Immersion on Recovery in Elite Netballers. *The Journal of Strength & Conditioning Research, 28*(8), 2353. https://doi.org/10.1519/JSC.0000000000000417.

33 Roberts, L.A., Nosaka, K., Coombes, J.S., & Peake, J.M. (2014). Cold water immersion enhances recovery of submaximal muscle function after resistance exercise. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 307*(8), R998–R1008. https://doi.org/10.1152/ajpregu.00180.2014.

34 Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An Evidence-Based Approach for Choosing Post-exercise Recovery Techniques to Reduce Markers of Muscle Damage, Soreness, Fatigue, and Inflammation: A Systematic Review With Meta-Analysis. *Frontiers in Physiology, 9*, 403. https://doi.org/10.3389/fphys.2018.00403.

35 Wilcock, I.M., Cronin, J.B., & Hing, W.A. (2006). Physiological response to water immersion: A method for sport recovery? Sports Medicine (Auckland, N.Z.), 36(9), 747–765. https://doi.org/10.2165/00007256-200636090-00003.

36 Sakakibara, H., Luo, J., Zhu, S. -K., Hirata, M., & Abe, M. (2002). Autonomic Nervous Activity during Hand Immersion in Cold Water in Patients with Vibration-Induced White Finger. *Industrial Health*, *40*(3), 254–259. https://doi.org/10.2486/indhealth.40.254.

37 Greenham, G., Buckley, J.D., Garrett, J., Eston, R., & Norton, K. (2018). Biomarkers of Physiological Responses to Periods of Intensified, Non-Resistance-Based Exercise Training in Well-Trained Male Athletes: A Systematic Review and Meta-Analysis. *Sports Medicine, 48*(11), 2517–2548. https://doi.org/10.1007/s40279-018-0969-2.

38 Callegari, G.A., Novaes, J.S., Neto, G.R., Dias, I., Garrido, N.D., & Dani, C. (2017). Creatine Kinase and Lactate Dehydrogenase Responses after Different Resistance and Aerobic Exercise Protocols. *Journal of Human Kinetics, 58*, 65–72. https://doi.org/10.1515/hukin-2017-0071.

39 Todd, J.J. (2014). Lactate: Valuable for physical performance and maintenance of brain function during exercise. *Bioscience Horizons: The International Journal of Student Research, 7*, hzu001. https://doi.org/10.1093/biohorizons/hzu001.

40 McKenna, M.J., Bangsbo, J., & Renaud, J. -M. (2008). Muscle K+, Na+, and Cl− disturbances and Na+-K+ pump inactivation: Implications for fatigue. *Journal of Applied Physiology.* https://doi.org/10.1152/japplphysiol.01037.2007.

41 Tomlin, D.L., & Wenger, H.A. (2001). The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports Medicine (Auckland, N.Z.), 31*(1), 1–11. https://doi.org/10.2165/00007256-200131010-00001.

42 Hudson, O.D., Loy, S.F., Vincent, W.J., & Yaspelkis, B.B. (1999). Blood lactate concentration and rated perceived exertion following active recovery in water. Sports Medicine, Training and Rehabilitation, 9(1), 41–50. https://doi.org/10.1080/15438629909512543.

43 Smith, L.L. (1991). Acute inflammation: The underlying mechanism in delayed onset muscle soreness? Medicine and Science in Sports and Exercise, 23(5), 542–551.

44 Kovacs, M.S., & Baker, L.B. (2014). Recovery interventions and strategies for improved tennis performance. British Journal of Sports Medicine, 48 Suppl 1(Suppl 1), i18-21. https://doi.org/10.1136/bjsports-2013-093223.

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The study on the relationship between different exercise modalities and physiological effects

This study aimed to systematically review the exercise intensities associated with various physical activities, synthesize the physiological effects induced by different intensity levels, and establish a dose-response reference guide for exercise modalities, thereby providing a foundation for precision-based fitness regimens. Methods: A comprehensive literature search was conducted across PubMed, Cochrane, Embase, Web of Science, EBSCO, CNKI, VIP, and Wanfang databases to identify studies examining the effects of exercise modalities on physiological indicators. The methodological quality of included randomized controlled trials (RCTs) was assessed using the Cochrane 5.1 handbook criteria. Effect sizes were pooled, and subgroup analyses were performed using Review Manager 5.4. Results: A total of 42 RCT studies were included. Low-intensity exercise modalities included ordinary walking, stair climbing, and Pilates. Moderate-intensity exercise modalities included brisk walking, Baduanjin, jogging, square dancing, Tai Chi, swimming, cycling, and dancing. High-intensity exercises included fast walking, fast running, soccer, and yoga. Low-intensity exercises improved HDL-C (d=0.06), resting heart rate (d=-2.98), and diastolic blood pressure (d=-2.93). Moderate-intensity exercises improved TG (d=-0.21), TC (d=-0.32), HDL-C (d=0.09), resting heart rate (d=-4.22), systolic blood pressure (d=-4.92), diastolic blood pressure (d=-3.51), weight (d=-2.46), and vital capacity (d=271.03). High-intensity exercises improved blood glucose (d=-0.18), systolic blood pressure (d=-3.21), and diastolic blood pressure (d=-2.58). Traditional Chinese exercises improved HDL-C (d=0.19), blood glucose (d=-1.49), vital capacity (d=285.09), systolic blood pressure (d=-9.96), and diastolic blood pressure (d=-5.68). Common exercises improved TG (d=-0.18), TC (d=-0.18), HDL-C (d=0.08), vital capacity (d=223.62), resting heart rate (d=-3.51), systolic blood pressure (d=-4.90), diastolic blood pressure (d=-2.96), weight (d=-2.04), and BMI (d=-0.74). Conclusion: Moderate-intensity exercises (e.g., brisk walking, jogging, swimming, Tai Chi) yielded more comprehensive physiological improvements compared to other intensities. Traditional Chinese exercises exhibited superior efficacy in optimizing HDL-C, glucose metabolism, respiratory function, and blood pressure regulation.

Keywords: dose-response relationship, traditional Chinese exercises, exercise modalities, RCT.

Introduction

The health benefits of physical exercise are well-established, with extensive research demonstrating its positive effects on cardiopulmonary function, muscular strength, and metabolic health. Investigating the relationship between exercise modalities and physiological responses holds significant theoretical and practical implications for precision-based fitness interventions.

The latest international Compendium of Physical Activities (CPA) [1] catalogs the metabolic equivalent of task (MET) values for over 1,000 specific activities across 21 categories. Similarly, domestic studies have quantified energy expenditure in physical activities among Chinese populations [2]. However, these efforts primarily focus on energy expenditure calibration and lack exploration of the dose-response relationships between exercise intensity and physiological outcomes.

Furthermore, emerging evidence suggests that different exercise modalities, such as traditional Chinese exercises (e.g., Tai Chi, Baduanjin, Qigong) and conventional exercises (e.g., brisk walking, swimming, Pilates), elicit distinct physiological adaptations and health benefits. Thus, synthesizing the physiological effects of traditional Chinese exercises alongside conventional exercises is critical for optimizing exercise prescriptions.

Methods and materials

2.1 Data Sources and Search Strategy

A systematic literature search was performed across multiple databases, including PubMed, Cochrane, Embase, Web of Science, EBSCO, CNKI, VIP, and Wanfang, to identify relevant studies. In PubMed and Cochrane, Medical Subject Headings (MeSH) terms were employed, while Emtree terms were used for Embase. The specific search strategies are detailed in Table 1.

Table 1

Summary of Search Strategies

	Search Term
P (population)	young people; adolescence; young; Middle Aged [Mesh]; middle age; aged [Mesh]; elderly
I (intervention)	Dancing[Mesh]; Dance; Ballet; Square Dance; Dance, Square; Hip-Hop Dance; Dance, Hip-Hop; Hip Hop Dance; Jazz Dance; Dance, Jazz; Tap Dance; Dance, Tap; Modern Dance; Dance, Modern; Salsa Dancing; Dancing, Salsa; Line Dancing; Dancing, Line; Tai Ji[Mesh]; Tai-ji; Tai Chi; Chi, Tai; Tai Ji Quan; Ji Quan, Tai; Quan, Tai Ji; Taiji; Taijiquan; T'ai Chi; Tai Chi Chuan; Martial Arts[Mesh]; Arts, Martial; Hap Ki Do; Judo; Karate; Jujitsu; Tae Kwon Do; Aikido; Wushu; Kung Fu; Gong Fu; Fu, Gong; Gongfu; Racquet Sports[Mesh]; Racquet Sport; Sport, Racquet; Sports, Racquet; Racket Sports; Racket Sport; Sport, Racket; Sports, Racket; Squash (Sport); Racquetball; Racketball; Racket Ball; Ball, Racket; Badminton; Lacrosse; Bicycling[Mesh]; Jogging[Mesh]; Joggings; Swimming[Mesh]; Basketball[Mesh]; Basketballs; Netbal; Soccer[Mesh]; Soccers; Yoga[Mesh]; Gymnastics[Mesh]; Calisthenics; Mountaineering[Mesh]; vigorously walks; walking; brisk walking; fitness walking; walk
C (comparison)	blank control
O (outcomes)	resting heart rate; hrrest; heart rate at rest; serum total cholesterol; total cholesterol; total serum cholesterol; Lipoproteins, HDL [Mesh]; HDL Lipoproteins; Heavy Lipoproteins; Lipoproteins, Heavy; High-Density Lipoproteins; High Density Lipoproteins; Lipoproteins, High-Density; alpha-Lipoproteins; alpha Lipoproteins; alpha-1 Lipoprotein; Cholesterol, LDL [Mesh]; Low Density Lipoprotein Cholesterol; beta-Lipoprotein Cholesterol; Cholesterol, beta-Lipoprotein; beta Lipoprotein Cholesterol; LDL Cholesterol; Cholesteryl Linoleate, LDL; LDL Cholesteryl Linoleate; Vital Capacity [Mesh]; Capacities, Vital; Capacity, Vital; Vital Capacities; Forced Vital Capacity; Capacities, Forced Vital; Capacity, Forced Vital; Forced Vital Capacities; Vital Capacities, Forced; Vital Capacity, Forced; Blood Pressure [Mesh]; Pressure, Blood; Diastolic Pressure; Pressure, Diastolic; Pulse Pressure; Pressure, Pulse; Systolic Pressure; Pressure, Systolic; Pressures, Systolic; Triglycerides[Mesh]; Triacylglycerol; Triacylglycerols; Metabolic Equivalent; Metabolic Equivalents; RPE;
S (study design)	randomized controlled trial; randomized; placebo

2.2 Inclusion and Exclusion Criteria

Eligible studies met the following criteria: (1) randomized controlled trials (RCTs); (2) participants categorized as adolescents, middle-aged, or older adults; (3) interventions involving common exercise modalities; and (4) outcome measures including at least one of the following: triglyceride (TG), total cholesterol (TC), high-density lipoprotein (HDL), low-density lipoprotein (LDL), resting heart rate, vital capacity (VC), systolic blood pressure (SBP), diastolic blood pressure (DBP), rating of perceived exertion (RPE), body weight, or body mass index (BMI). Studies were excluded if they were duplicate publications, literature reviews, letters to the editor, conference abstracts, or animal model research. Additionally, articles lacking full-text availability or original data were excluded.

2.3 Data Extraction

Two independent researchers extracted all data and compiled the results. Discrepancies were resolved through consultation with a third reviewer. Extracted data included: (1) primary author and publication year; (2) baseline characteristics (age and sample size of experimental and control groups); (3) exercise parameters (type, frequency, duration, and intensity); and (4) reported outcomes. The risk of bias in included studies was assessed using the Cochrane Risk of Bias Tool, which evaluates seven domains: (1) random sequence generation, (2) allocation concealment, (3) blinding of participants and personnel, (4) blinding of outcome assessment, (5) incomplete outcome data, (6) selective reporting, and (7) other potential biases.

2.4 Data Analysis

Quantitative synthesis and subgroup analyses were performed using Review Manager software (version 5.4). Effect sizes were pooled using a random-effects model. Heterogeneity among studies was assessed using the I^2 statistic and Cochran's Q test, with $I^2 > 50\ \%$ or a Q test P-value ≤ 0.10 indicating significant heterogeneity. Publication bias was evaluated via funnel plot inspection. Sensitivity analyses were conducted by excluding trials with a high risk of bias to test the robustness of the pooled results.

Results and Discussion

2 Results

2.1 Search Results

A total of 4,846 potentially eligible articles were initially identified through database searches. After a systematic screening process—including removal of duplicates, title/abstract screening, and full-text assessment—42 studies met the predefined inclusion criteria and were included in the final analysis.

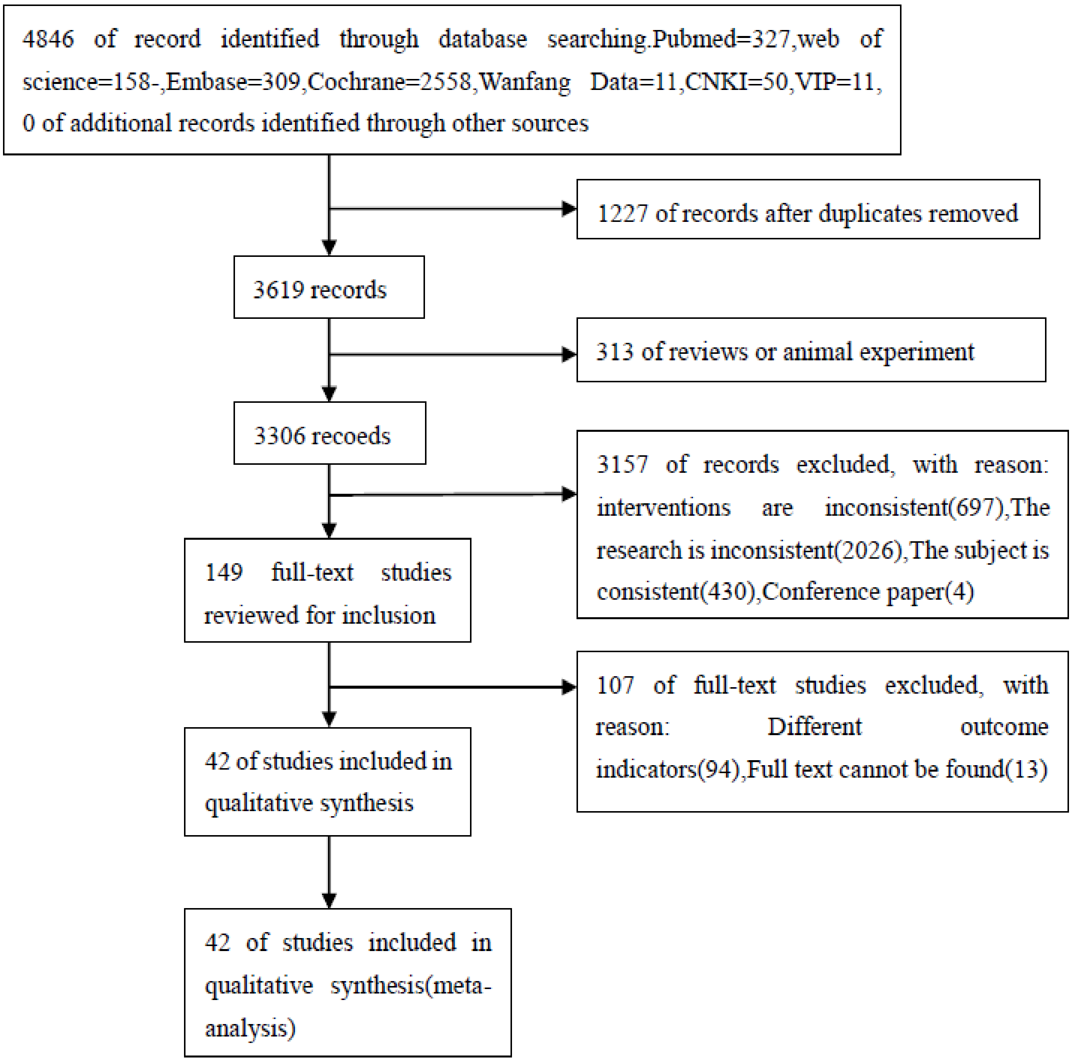

Figure 1. Flowchart of Literature Selection

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2.2 Basic Characteristics of Included Literature

The basic characteristics of the included literature are shown in Table 2. The quality evaluation is presented in Figure 2.

Table 2

Basic Characteristics of Included Literature

Study	Sample Size	Gender	Age	Mode	Intensity	Inflammatory outcome
Guaxia Hu 2014 [3]	230	Male/Female	53~70	Baduanjin	100beats/min	LC, SBP, DBP
A RCOOPER 2000 [4]	176	Male/Female	46-49	walk	4~5mets	SBP, DBP, Body weight
Abdelbasset WK 2020 [5]	31	Male/Female	54.9±4.7	bicycle	50~70 %HRmax	TG, TC, LDL-C, HDL-C
Asikainen, T.M 2003 [6]	385	Female	55（3.7）	walk	45 %VO2max	TC/LDL-C/HDL-C/Glucose/SBP/DBP
Baker, T.T 1986 [7]	34	Male	58.2	running	65 %~85 %HRmax	TC, LDL-C, HDL-C, Body weight
Buttelli 2021 [8]	61	Male	60-75	Pilates	1.5~2met	TG, TC, LDL-C, HDL-C, Glucose
F.M. Finucane 2010 [9]	100	Male/Female	67.4-76.3	Bicycle	50~70 %HRmax	HDL-C, Glucose, SBP, DBP, Body weight
Fulin Lu 2018 [10]	96	Female	57.2 ±10.1.	Dance	Heart rate=170-age（>60age） Heart rate =160-age（<60age）	TG, TC, LDL-C, HDL-C, Glucose, RHR, SBP, DBP, WHR, BMI
Haiping Zhang 2016 [11]	40	Female	62.85 ±1.66	walk	50 %~60 %VO2max	TG, TC, LDL-C, HDL-C, LC, VO2max
Hanxiao Zhu 2009 [12]	135	Male	61-65	walk	30 %~45 %F.C	LC, RHR, SBP, DBP, Body weight, BMI
JE Donnelly 2000 [13]	11	Female	45-60	walk	60~75 %HRmax	TC, HDL-C, Glucose, RHR, SBP, DBP
Koh, Y 2018 [14]	27	Male/Female	18-65	running	70 %HRmax	TG, TC, LDL-C, HDL-C, Body weight
Krustrup P 2013 [15]	66	Male	31~54	Soccer	85 % ± 7 %HRmax	LDL-C, HDL-C, Glucose, RHR
Krustrup, P 2009 [16]	47	Male	20-43	running/Soccer	82 %HRmax	TC, LDL-C, HDL-C, RHR, SBP, DBP, Body weight
Kuo, M. C. 2018 [17]	36	Male/Female	>65	walk	13~15 RPE	WHR
Lee SH 2019 [18]	20	Female	70 ± 4	taekwondo	30~60 %HRR	RHR, SBP, DBP, Body weight
LI He 2018 [19]	88	Male/Female	58±2	walk	45~50 %HRmax	RHR, SBP, DBP, Body weight
Lian, X. Q 2014 [20]	330	Male/Female	40~78	walk	3~6METs	TG, TC, LDL-C, HDL-C
Lorenzo A 2008 [21]	288	Male/Female	63.5±1	Dance/Yoga	70 %HRmax	TG, TC, Glucose
Mao, H. N 2006 [22]	62	Male/Female	45~72	Tai Chi	50~60 %VO2max	SBP, DBP
Marti, B 1990 [23]	61	Male	38.8 + 8.9	running	85 %HRmax	TG, TC, LDL-C, HDL-C, RHR, WHR
Mazurek, Krzystof 2014 [24]	64	Male/Female	19.5±0.6	bicycle	65 %~75 % HRmax	TG, TC, LDL-C, HDL-C, WHR
Miao Sun 2018 [25]	60	Female	55-70	Dance	110~130beats/min	TG, TC, LDL-C, HDL-C, Glucose, LC, RHR, SBP, DBP, Body weight, WHR, BMI
Min Jeong 2018 [26]	18	Male/Female	20.8±1.9	walk/ Climb the stairs	50~60 %HRmax	RHR/SBP/DBP/ Body weight
Miyaki A 2012 [27]	22	Female	52~77	walk/bicycle	60~75 %HRmax	TG, TC, LDL-C, HDL-C, RHR, SBP, DBP, Body weight
Papp 2016 [28]	44	Male/Female	20~37	Yoga	RPE 14~17	RHR, SBP, DBP, Body weight, WHR
Philippe 2018 [29]	115	Female	44±11.5	Walk	4~10 RPE	SBP, DBP, Body weight
Rodrigues-Krause 2018 [30]	30	Female	60~70	Dance	60 % VO2peak	TG, TC, LDL-C, HDL-C, Glucose, Body weight
Shanwei Xue 2013 [31]	40	Male/Female	66.96±13.2	Baduanjin	170-age（>60age); 180-age（<60age)	LC, RHR
Songtao Wang 2005 [32]	99	Male	61-65	Walk	30 %~ 45 %F.C	TG, TC, LDL-C, HDL-C, Body weight, BMI
Tanaka 1997 [33]	18	Male/Female	44~50	Swimming	60 %HRmax	RHR, SBP, DBP
Tsung-Lin 2019 [34]	41	Male/Female	19.72±0.8	Walk	RPE 8	TG, HDL-C, RHR, SBP, DBP, Body weight
Vasconcellos 2016 [35]	30	Male/Female	12.8~15.4	Soccer	80.4 %~88.6 %HRmax	TG, TC, LDL-C, HDL-C, SBP, DBP, Body weight
Vasconcellos 2021 [36]	13	Male/Female	12.3~15.5	Soccer	84.5 %HRmax	TG, HDL-C, Glucose, SBP, DBP, Body weight
Woolf-May 1999 [37]	237	Male/Female	40-66	Walk	68.6 %~78.2 %HRmax	TC, LDL-C, HDL-C
Woolf-May 2000 [38]	97	Male/Female	40-69	Walk	75 %~80 %HRmax	TC, LDL-C, HDL-C
Xiao-Ling 2019 [39]	198	Male/Female	45.5~58.4	Tai Chi	70 %~80 %HRmax	TG, TC, LDL-C, HDL-C, SBP, DBP
Xiaoxia Li 2012 [40]	92	Male/Female	50～65	Walk	40 %~65 %F.C.	TG, TC, LDL-C, HDL-C
Xiaoying Han 2010 [41]	236	Male/Female	45～75	Tai Chi	70%~80%HRmax	SBP, DBP
Xijun Xiao 2005 [42]	120	Male/Female	≥40	Running	40 %~50 %HRR	TG, TC, HDL-C, SBP, DBP, Body weight, WHR, BMI
Yaping Bai 2019 [43]	133	Male/Female	45-75	Dance	60 %~80 %HRmax	TG, TC, LDL-C, HDL-C, SBP, DBP, BMI
zhang 2008 [44]	20	Female	51.2-63.6	Tai Chi	62 %~72.2 %HRmax	TG, TC, LDL-C, HDL-C, Glucose
LC：肺活量，RHR，WHR：waist hip rate						

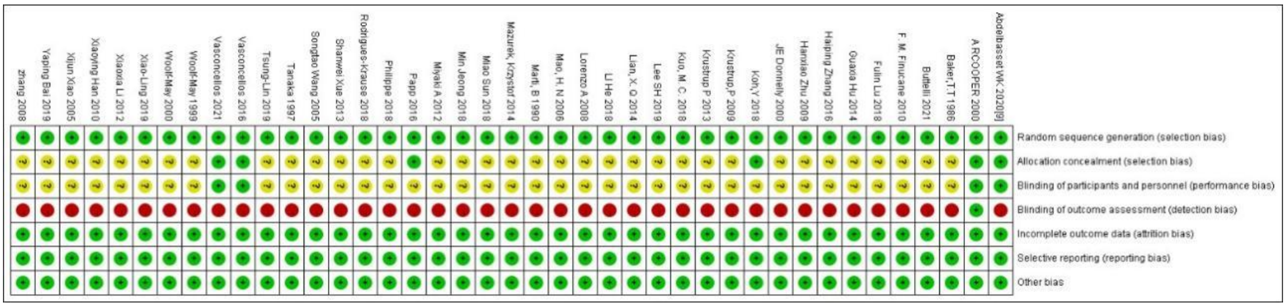

Figure 2. Quality Evaluation Chart

2.3 Dose-Response Relationship of Exercise Intensity

2.3.1 Classification of Exercise Modalities by Intensity

The exercise interventions from the included studies were categorized into three intensity levels based on the American College of Sports Medicine (ACSM) guidelines [45] (Table 3).

Table 3

Classification of Exercise Modalities by Intensity

Intensity	**Exercise Modalities**
Low	Casual walking, Stair climbing, Pilates
Moderate	Walk, Ba duan jin, Jogging, Dance, Tai Chi, Swimming, Bicycle, Dance, Yoga, Taekwondo
High	Power walking, Running, Soccer, Yoga

2.3.2 Physiological Effects of Different Exercise Intensities

The physiological benefits of different exercise intensities are shown in Figure 3. Low-intensity exercise improved HDL-C (d=0.06, 95 %CI: 0.02–0.10; P<0.05), resting heart rate (d=-2.98, 95 %CI: -4.77 to -1.19; P<0.05), and diastolic blood pressure (d=-2.93, 95 %CI: -5.50 to -0.36; P<0.05). Moderate-intensity exercise improved TG (d=-0.21, 95 %CI: -3.5 to -0.07; P<0.05), TC (d=-0.32, 95 %CI: -0.52 to -0.12; P<0.05), HDL-C (d=0.09, 95 %CI: -0.02 to -0.15; P<0.05), resting heart rate (d=-4.22, 95 %CI: -5.56 to -2.88; P<0.05), systolic blood pressure (d=-4.92, 95 %CI: -8.59 to -1.24; P<0.05), diastolic blood pressure (d=-3.51, 95 %CI: -5.33 to -1.68; P<0.05), body weight (d=-2.46, 95 %CI: -3.79 to -1.16; P<0.05), and vital capacity (d=271.03, 95 %CI: 119.35–422.71; P<0.05). High-intensity exercise improved blood glucose (d=-0.18, 95 %CI: -0.27 to -0.08; P<0.05), SBP (d=-3.21, 95 %CI: -6.07 to -0.34; P<0.05), and DBP (d=-2.58, 95 %CI: -4.31 to -0.85; P<0.05).

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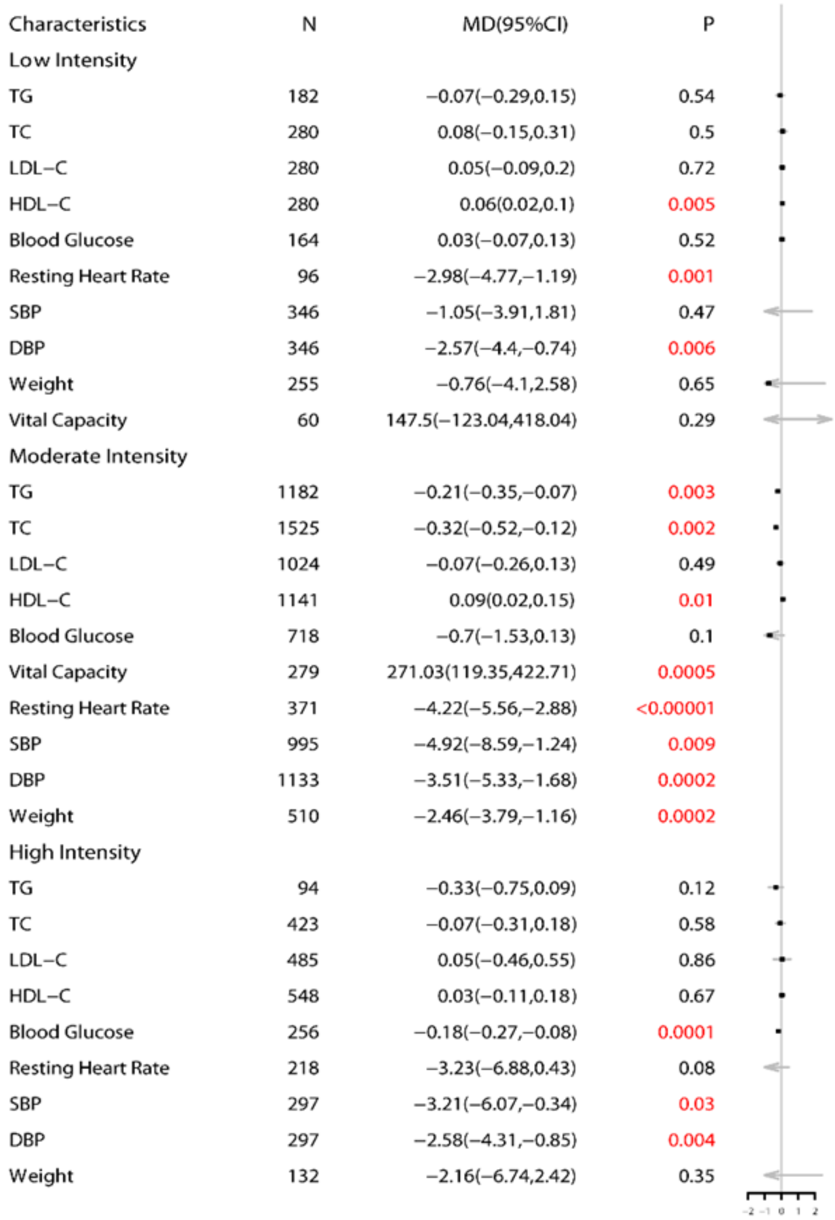

Figure 3. Forest Plot of Physiological Effects by Exercise Intensity

2.4 Dose-Response Relationships of Different Exercise Types

2.4.1 Exercise Modalities Under Different Exercise Types

The specific exercise modalities corresponding to different exercise types are presented in Table 4 below.

Table 4

Exercise Types and Corresponding Modalities

Exercise Type	**Exercise Modalities**
Traditional Chinese Exercises	Tai Chi, Ba Duan Jin
Popular Exercises	Casual walking, Stair climbing, PilatesWalk, Jogging, Dance, Swimming, Bicycle, Dance, Yoga, TaekwondoPower walking, Running, Soccer, Yoga

2.4.2 Dose-Response Relationships of Different Exercise Types

As shown in Figure 4, traditional Chinese exercises significantly improved HDL-C (d=0.19, 95 %CI: 0.10–0.29, P<0.05), blood glucose (d=-1.49, 95 %CI: -2.83 to -0.15, P<0.05), vital capacity (d=285.09, 95 %CI: 84.05–486.13, P<0.05), systolic blood pressure (d=-9.96, 95 %CI: -15.85 to -4.08, P<0.05), and diastolic blood pressure (d=-5.68, 95 %CI: -7.22 to -4.13, P<0.05). Common exercises demonstrated benefits in improving TG (d=-0.18, 95 %CI: -0.27 to -0.09, P<0.05), TC (d=-0.18, 95 %CI: -0.34 to -0.01, P<0.05), HDL-C (d=0.08, 95 %CI: 0.01–0.15, P<0.05), vital capacity (d=223.62, 95 %CI: 40.97–406.28, P<0.05), resting heart rate (d=-3.51, 95 %CI: -4.92 to -2.10, P<0.05), systolic blood pressure (d=-4.90, 95 %CI: -7.05 to -2.75, P<0.05), diastolic blood pressure (d=-2.96, 95 %CI: -4.53 to -1.40, P<0.05), body weight (d=-2.04, 95 %CI: -3.36 to -0.72, P<0.05), and BMI (d=-0.74, 95 %CI: -1.33 to -0.15, P<0.05).

Characteristics	N	MD(95%CI)	
Traditional Chinese Exercises			
TG	217	-0.50 [-1.14, 0.14]	0.130
TC	217	-0.36 [-0.73, 0.01]	0.060
LDL-C	217	-0.38 [-0.98, 0.23]	0.220
HDL-C	217	0.19 [0.10, 0.29]	0.000
Blood Glucose	19	-1.49 [-2.83, -0.15]	0.030
Vital Capacity	149	285.09 [84.05, 486.13]	0.000
Resting Heart Rate	40	-2.09 [-7.67, 3.49]	0.460
SBP	487	-9.96 [-15.85, -4.08]	0.000
DBP	487	-5.68 [-7.22, -4.13]	0.000
Popular Exercises			
TG	1261	-0.18 [-0.27, -0.09]	0.003
TC	1878	-0.18 [-0.34, -0.01]	0.030
LDL-C	1572	0.02 [-0.15, 0.19]	0.800
HDL-C	1726	0.08 [0.01, 0.15]	0.020
Blood Glucose	1099	-0.40 [-0.97, 0.17]	0.170
Vital Capacity	190	223.62 [40.97, 406.28]	0.020
Resting Heart Rate	665	-3.51 [-4.92, -2.10]	0.000
SBP	894	-4.90 [-7.05, -2.75]	0.000
DBP	894	-2.96 [-4.53, -1.40]	0.000
Weight	947	-2.04 [-3.36, -0.72]	0.000
WHR	421	-0.03 [-0.06, 0.01]	0.110
BMI	420	-0.74 [-1.33, -0.15]	0.010

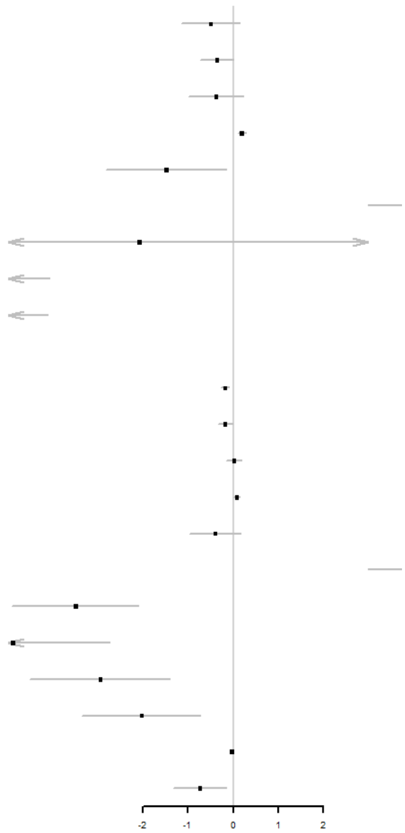

Figure 4. Forest Plot of Physiological Effects by Exercise Type

4 Discussion

4.1 Dose-Response Relationship of Exercise Intensity

The present study demonstrates that body weight improvement was observed only with moderate-intensity exercise, while no significant effects were found for low- or high-intensity interventions. Previous research has established a dose-response relationship between aerobic exercise volume and visceral fat reduction, with a minimum requirement of 10 METs·h/week for significant visceral fat loss [46–48]. The American College of Sports Medicine (ACSM) recommends moderate-intensity physical activity for at least 150 minutes/week for overweight/obese individuals to achieve weight or body fat reduction, supporting moderate intensity as the optimal exercise intensity for body weight management.

Regarding lipid metabolism, our findings show that low-intensity exercise improved HDL-C levels, moderate-intensity exercise benefited TG, TC, and HDL-C, while high-intensity exercise showed no significant lipid-modifying effects. The HDL-C improvement with low-intensity exercise may be mediated through

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enhanced insulin sensitivity and reduced body fat content [49]. Sunami et al. [50] reported significant HDL-C elevation following 5 months of moderate-intensity cycling training. Ye Guohong et al. [51] proposed that prolonged moderate-intensity endurance exercise reduces plasma TG levels by increasing lipoprotein lipase activity, promoting fatty acid utilization in skeletal muscle and hepatic TG export. Moderate-intensity exercise may also improve TC levels by enhancing cholesterol ester transfer protein (CETP) activity, which facilitates cholesterol exchange between HDL-C and LDL-C [52]. Collectively, the lipid-lowering effects of exercise appear to diminish with increasing intensity, with small-to-moderate intensity aerobic exercise demonstrating superior lipid-modulating effects compared to high-intensity exercise [32].

High-intensity exercise significantly reduced blood glucose levels, likely through improved insulin sensitivity in muscle cells and accelerated glycogen synthesis in muscle and liver tissues [53]. Blood pressure improvements were observed across all three intensity levels, consistent with aerobic exercise's established benefits for vascular function, arterial stiffness reduction in hypertensive patients [54, 55], and decreased risk of acute cardiovascular events [56].

Both low- and moderate-intensity exercises reduced resting heart rate, potentially through enhanced parasympathetic nervous system activity [57]. Moderate-intensity exercise uniquely improved vital capacity, attributable to increased tidal volume during exercise and long-term adaptations in respiratory muscle function and lung-thorax elasticity [58].

4.2 Dose-Response Relationship of Different Exercise Modalities

Traditional Chinese exercises (e.g., Tai Chi, Baduanjin) emphasize fluid and continuous movements with mind-body integration, focusing on breath-movement coordination and mental concentration [59]. These exercises typically feature slow tempo and gentle motions but require high neuromuscular control [60]. In contrast, conventional exercises (e.g., running, swimming) prioritize cardiorespiratory endurance and muscular strength through higher-intensity movements with greater physical demands [61].

Regarding antioxidant and anti-inflammatory effects, traditional Chinese exercises reduce oxidative stress and inflammation through slow, rhythmic movements combined with deep breathing, potentially improving HDL-C and blood glucose levels more effectively [62]. Conventional exercises also exhibit antioxidant properties (e.g., running and swimming can increase HDL-C), though high-intensity exercise may transiently elevate oxidative stress [63].

For neuromodulation and cardiovascular health, traditional Chinese exercises improve vascular endothelial function by balancing the autonomic nervous system (reducing sympathetic activity while enhancing parasympathetic tone), thereby lowering blood pressure and improving cardiovascular outcomes [64]. Conventional exercises enhance cardiac function and vascular elasticity to improve blood pressure and cardiovascular health, though acute sympathetic activation may attenuate blood pressure reduction [65].

In terms of energy metabolism and body weight management, traditional Chinese exercises (with lower intensity) show limited direct effects on body weight and BMI [66], whereas conventional exercises effectively manage body weight and BMI through higher energy expenditure [67].

Conclusions

5.1 Low-intensity exercises include regular walking, stair climbing, and Pilates; Moderate-intensity exercises include brisk walking, Baduanjin, jogging, square dancing, Tai Chi, swimming, cycling, and dance; High-intensity exercises include power walking, running, soccer, and yoga.

5.2 Low-intensity exercise can improve HDL-C, resting heart rate, and diastolic blood pressure; moderate-intensity exercise can improve TG, TC, HDL-C, resting heart rate, systolic blood pressure, diastolic blood pressure, body weight, and vital capacity; high-intensity exercise can improve blood glucose, systolic blood pressure, and diastolic blood pressure.

5.3 Traditional Chinese exercises can improve HDL-C, vital capacity, blood glucose, systolic blood pressure, and diastolic blood pressure. Common exercises can improve TG, TC, HDL-C, vital capacity, resting heart rate, systolic blood pressure, diastolic blood pressure, body weight, and BMI.

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References

1 Ainsworth, B.E., Haskell, W.L., Herrmann, S.D., et al. (2011). 2011 Compendium of Physical Activities: a second update of codes and MET values. *Medicine and science in sports and exercise, 43(8),* 1575–1581.

2 Junqiang, Q., Junchao, Y., Mingyue, L., et al. (2022). Compilation of Physical Activities of Healthy Chinese Adults: Reference Values for Energy Expenditure [J]. *Chinese Journal of Sports Medicine, 41(05),* 335–349.

3 Guangxia, H., & Keping, G. (2014). The Impact of Health-Qigong Eight-Section Exercises on the Quality of Life of Elderly People in a Community in Jilin Province. *Medicine and Society, 27(5),* 74–76.

4 Cooper, A.R., Moore, L.A., Mckenna, J., et al. (2000). What is the magnitude of blood pressure response to a programme of moderate intensity exercise? Randomised controlled trial among sedentary adults with unmedicated hypertension. *British journal of general practice, 50(461),* 958–962.

5 Abdelbasset, W.K., Elsayed, S.H., Nambi, G., et al. (2020). Effect of Moderate-Intensity Aerobic Exercise on Hepatic Fat Content and Visceral Lipids in Hepatic Patients with Diabesity: a Single-Blinded Randomised Controlled Trial. *Evidence-based complementary and alternative medicine,* 1923575.

6 Asikainen, T.M., Miilunpalo, S., Kukkonen-harjula, K., et al. (2003). Walking trials in postmenopausal women: effect of low doses of exercise and exercise fractionization on coronary risk factors. *Scandinavian journal of medicine & science in sports, 13(5),* 284–292.

7 Baker, T.T., Allen, D., Lei, K.Y., et al. (1986). Alterations in lipid and protein profiles of plasma lipoproteins in middle-aged men consequent to an aerobic exercise program. *Metabolism: clinical and experimental, 35(11),* 1037–1043.

8 Buttelli, A.C.K., Costa, R.R., Farinha, J.B., et al. (2021). Pilates training improves aerobic capacity, but not lipid or lipoprotein levels in elderly women with dyslipidemia: A controlled trial. *Journal of Bodywork and Movement Therapies, 26,* 227–232.

9 Finucane, F.M., Sharp, S.J., Purslow, L.R., et al. (2010). The effects of aerobic exercise on metabolic risk, insulin sensitivity and intrahepatic lipid in healthy older people from the Hertfordshire Cohort Study: a randomised controlled trial. *Diabetologia, 53(4),* 624–631.

10 Fulin, L., Shuyong, M., & Qi, Y. (2018). Effect of Square Dance Intervention on Type 2 Diabetes Mellitus in Middle-aged and Elderly Women. *International Journal of Geriatrics, 39(3),* 119–122.

11 Haiping, Z., Yixin, W., & Feng, Y. (2016). The impact of brisk walking on the cardio-pulmonary endurance and lipid-related indicators of elderly women. *Chinese Journal of Gerontology, 36(14),* 3514–3516.

12 Hanxiao, Z. (2009). Study on advisable exercise intensity for elder men. *Modern Preventive Medicine, 36(1),* 107–109, 116.

13 Donnelly, J.E., Jacobsen, D.J., Heelan, K.S., et al. (2000). The effects of 18 months of intermittent vs. continuous exercise on aerobic capacity, body weight and composition, and metabolic fitness in previously sedentary, moderately obese females. *International journal of obesity and related metabolic disorders, 24(5),* 566–572.

14 Koh, Y., Park, J., & Carter, R. (2018). Oxidized Low-Density Lipoprotein and Cell Adhesion Molecules Following Exercise Training. *International journal of sports medicine, 39(2),* 83–88.

15 Krustrup, P., Randers, M.B., Andersen, L.J., et al. (2013). Soccer Improves Fitness and Attenuates Cardiovascular Risk Factors in Hypertensive Men. *Medicine and Science in Sports and Exercise, 45(3),* 553–560.

16 Krustrup, P., Nielsen, J.J., Krustrup, B.R., et al. (2009). Recreational soccer is an effective health-promoting activity for untrained men. *British journal of sports medicine, 43(11),* 825–831.

17 Kuo, M.C., Chen, C.M., & Jeng, C. (2018). A Randomized Controlled Trial of the Prescribed Stepper Walking Program in Preventing Frailty Among the Dwelling Elderly: application of Comprehensive Geriatric Assessment. *Topics in geriatric rehabilitation, 34(3),* 223–33.

18 Lee, S.H., Scott, S.D., Pekas, E.J., et al. (2019). Taekwondo training reduces blood catecholamine levels and arterial stiffness in postmenopausal women with stage-2 hypertension: randomized clinical trial. *Clinical and experimental hypertension, 41(7),* 675–681.

19 He, L., Wei, W.R., & Can, Z. (2018). Effects of 12-week brisk walking training on exercise blood pressure in elderly patients with essential hypertension: a pilot study. *Clinical and experimental hypertension, 40(7),* 673–679.

20 Lian, X.Q., Zhao, D., Zhu, M., et al. (2014). The influence of regular walking at different times of day on blood lipids and inflammatory markers in sedentary patients with coronary artery disease. *Preventive medicine, 58,* 64–69.

21 Gordon, L.A., Morrison, E.Y., Mcgrowder, D.A., et al. (2008). Effect of exercise therapy on lipid profile and oxidative stress indicators in patients with type 2 diabetes. *BMC complementary and alternative medicine, 8,* 21.

22 Mao, H.N., & Sha, P. (2006). Effect of Tai Chi exercise on blood pressure, plasma nitrogen monoxidum and endothelin in hypertensive patients. *Chinese journal of clinical rehabilitation, 10(48),* 65–67.

23 Marti, B., Suter, E., Riesen, W.F., et al. (1990). Effects of long-term, self-monitored exercise on the serum lipoprotein and apolipoprotein profile in middle-aged men. *Atherosclerosis, 81(1),* 19–31.

24 Mazurek, K., Krawczyk, K., Zmijewski, P., et al. (2014). Effects of aerobic interval training versus continuous moderate exercise programme on aerobic and anaerobic capacity, somatic features and blood lipid profile in c Ilegate females. *Annals of Agricultural and Environmental Medicine, 21(4),* 844-849.

25 Yan, S., Qingzhi, Z., Dan, Z., et al. (2018). The impact of square dancing exercise on the physical and mental health of middle-aged and elderly women. *Chinese Journal of Applied Physiology, 34(03),* 246–248.

26 Cho, M.J., Park, Y.R., Bunsawat, K., et al. (2018). Comparison of the effects of short-term stair climbing and walking exercise on vascular function in healthy young adults. *IJASS (International Journal of Applied Sports Sciences), 30(2),* 125–33.

27 Miyaki, A., Maeda, S., Choi, Y., et al. (2012). Habitual aerobic exercise increases plasma pentraxin 3 levels in middle-aged and elderly women. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme, 37(5),* 907–911.

28 Papp, M.E., Lindfors, P., Nygren-Bonnier, M., et al. (2016). Effects of High-Intensity Hatha Yoga on Cardiovascular Fitness, Adipocytokines, and Apolipoproteins in Healthy Students: a Randomized Controlled Study. *Journal of alternative and complementary medicine (New York, NY), 22(1),* 81–87.

29 Gradidge, P.J., & Golele, P.N. (2018). Walking as a feasible means of effecting positive changes in BMI, waist, and blood pressure in black South African women. African historical studies, 18(4), 917–21.

30 Rodrigues-Krause, J., Farinha, J.B., Ramis, T.R., et al. (2018). Effects of dancing compared to walking on cardiovascular risk and functional capacity of older women: a randomized controlled trial. *Experimental gerontology, 114,* 67–77.

31 Weishan, X. (2013). The effect of Health Qigong Ba Duan Jin on cardiopulmonary function of aged people. *Journal of Bohai University, 34(4),* 431–434.

32 Songtao, W., Anli, W., Zhengzhen, W., et al. (1997). A comparison of the effects of different-intensity brisk walking exercises on body composition and blood lipids in elderly men. *Chinese Journal of Sports Medicine, 24(5),* 599–601.

33 Tanaka, H., Bassett, D.R., Howley, E.T., et al. (1997). Swimming training lowers the resting blood pressure in individuals with hypertension. *Journal of hypertension, 15(6),* 651–657.

34 Chiang, T.L., Chen, C., Hsu, C.H., et al. (2019). Is the goal of 12,000 steps per day sufficient for improving body composition and metabolic syndrome? The necessity of combining exercise intensity: a randomized controlled trial. *BMC public health, 19(1),* 1215.

35 Vasconcellos, F., Seabra, A., Cunha, F., et al. (2016). Health markers in obese adolescents improved by a 12-week recreational soccer program: a randomised controlled trial. *Journal of Sports Sciences, 34(6),* 564–575.

36 Vasconcellos, F., Cunha, F.A., Gonet, D.T., et al. (2021). Does Recreational Soccer Change Metabolic Syndrome Status in Obese Adolescents? A Pilot Study. *Research Quarterly for Exercise and Sport, 92(1),* 91–99.

37 Woolf-May, K., Kearney, E.M., Owen, A., et al. (1999). The efficacy of accumulated short bouts versus single daily bouts of brisk walking in improving aerobic fitness and blood lipid profiles. *Health education research, 14(6),* 803–815.

38 Woolf-May, K., Jones, W., Kearney, E.M., et al. (2000). Factor XIIa and triacylglycerol rich lipoproteins: responses to exercise intervention. *British journal of sports medicine, 34(4),* 289-292.

39 Shou, X.L., Wang, L., Jin, X.Q., et al. (2019). Effect of T'ai Chi Exercise on Hypertension in Young and Middle-Aged In-Service Staff. *Journal of alternative and complementary medicine (New York, NY), 25(1),* 73–78.

40 Xiaoxia, L., Ming, J., Yong, W., et al. (2012). Effects of walking exercise on lipids of elderly obese people and its correlation with adiponectin gene polymorphis. *Journal of Shandong Institute of Physical Education, 28(06),* 52–58.

41 Qiaoying, H., Xiufeng, H., Lei, L., et al. (2010). The effect of shadow boxing exercise on the long-term quality of life in middle-aged and elderly patients with primary hypertension. *Chinese Journal of Modern Nursing, 16(14),* 1617–1619.

42 Xijun, X. (2005). Effect of different exercise intensities to grade-1 hypertensives. *Chinese Journal of Rehabilitation Medicine, 20(5),* 349–352.

43 Yaping, B., Ying, L., Dongmei, W., et al. (2019). The impact of community square dancing on blood pressure and lipid levels of middle-aged and elderly patients with hypertension. *Chinese Journal of Hypertension, 27(05),* 474–478.

44 Zhang, Y., & Fu, F.H. (2008). Effects of 14-week Tai Ji Quan exercise on metabolic control in women with type 2 diabetes. *The American journal of Chinese medicine, 36(4),* 647–654.

45 Thompson, P.D., Arena, R., Riebe, D., et al. (2013). ACSM's new preparticipation health screening recommendations from ACSM's guidelines for exercise testing and prescription, ninth edition. *Current sports medicine reports, 12(4),* 215–217.

46 Miyatake, N., Nishikawa, H., Morishita, A., et al. (2002). Daily walking reduces visceral adipose tissue areas and improves insulin resistance in Japanese obese subjects. *Diabetes research and clinical practice, 58(2),* 101–107.

47 Halverstadt, A., Phares, D.A., Ferrell, R.E., et al. (2003). High-density lipoprotein-cholesterol, its subfractions, and responses to exercise training are dependent on endothelial lipase genotype. *Metabolism: clinical and experimental, 52(11),* 1505–1511.

48 Wilund, K.R,. Ferrell, R.E., Phares, D.A., et al. (2002). Changes in high-density lipoprotein-cholesterol subfractions with exercise training may be dependent on cholesteryl ester transfer protein (CETP) genotype. *Metabolism: clinical and experimental, 51(6),* 774–778.

49 Kodama, S., Tanaka, S., Saito, K., et al. (2007). Effect of aerobic exercise training on serum levels of high-density lipoprotein cholesterol: a meta-analysis. *Arch Intern Med, 167(10),* 999–1008.

50 Sunami, Y., Motoyama, M., Kinoshita, F., et al. (1999). Effects of low-intensity aerobic training on the high-density lipoprotein cholesterol concentration in healthy elderly subjects. *Metabolism, 48(8),* 984–988.

51 Guohong, Y., Zhengyi, W., Jiansheng, X., et al. (2004). The Development of Exercise and Serum Lipids. *Journal of Beijing Sport University, 27(7),* 933–935.

52 Durstine, J.L., Grandjean, P.W., Davis, P.G., et al. (2001). Blood lipid and lipoprotein adaptations to exercise: a quantitative analysis. *Sports Med, 31(15),* 1033–1062.

53 Holloszy, J.O. (2005). Exercise-induced increase in muscle insulin sensitivity. *Journal of applied physiology (Bethesda, Md: 1985), 99(1),* 338–343.

54 Woolley, B., Stoner, L., Lark, S., et al. (2015). Effect of early exercise engagement on arterial stiffness in patients diagnosed with a transient ischaemic attack. *Journal of human hypertension, 29(2),* 87–91.

55 Collier, S.R., Sandberg, K., Moody, A.M., et al. (2015). Reduction of plasma aldosterone and arterial stiffness in obese pre- and stage1 hypertensive subjects after aerobic exercise. *Journal of human hypertension, 29(1),* 53–57.

56 Goldberg, M.J., Boutcher, S.H., & Boutcher, Y.N. (2012). The effect of 4 weeks of aerobic exercise on vascular and baroreflex function of young men with a family history of hypertension. *Journal of human hypertension, 26(11),* 644–649.

57 Nunan, D., Sandercock, G.R., & Brodie, D.A. (2010). A quantitative systematic review of normal values for short-term heart rate variability in healthy adults. *Pacing Clin Electrophysiol, 33(11),* 1407–1417.

58 Yuhong, X., & Yiming, B. (2017). The impact of moderate-intensity aerobic exercise on the cardio-pulmonary functions of minority college students in Guizhou. *Chinese Journal of School Health, 38(09),* 1424–1426.

59 Lan, C., Chen, S.Y., Lai, J.S., et al. (1999). The effect of Tai Chi on cardiorespiratory function in patients with coronary artery bypass surgery. *Medicine and science in sports and exercise, 31(5),* 634–638.

60 Hong, Y., & Li, J.X. (2007). Biomechanics of Tai Chi: a review. *Sports Biomech, 6(3),* 453–464.

61 Oja, P., & Titze, S. (2011). Physical activity recommendations for public health: development and policy context. *Epma j, 2(3), 253–259.*

62 Wang, C., Bannuru, R., Ramel, J., et al. (2010). Tai Chi on psychological well-being: systematic review and meta-analysis. *BMC Complement Altern Med, 10, 23*.

63 Fatouros, I.G., Jamurtas, A.Z., Villiotou, V., et al. (2004). Oxidative stress responses in older men during endurance training and detraining. *Medicine and science in sports and exercise, 36(12),* 2065–2072.

64 Taylor-Piliae, R.E., & Haskell, W.L. (2007). Tai Chi exercise and stroke rehabilitation. *Top Stroke Rehabil, 14(4), 9–22*.

65 Maron, B.J., Thompson, P.D., Ackerman, M.J., et al. (2007). Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. Circulation, 115(12), 1643–1655.

66 Tsai, J.C., Wang, W.H., Chan, P., et al. (2003). The beneficial effects of Tai Chi Chuan on blood pressure and lipid profile and anxiety status in a randomized controlled trial. *Journal of alternative and complementary medicine (New York, NY), 9(5),* 747–754.

67 Penedo, F.J., & Dahn, J.R. (2005). Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Curr Opin Psychiatry, 18(2),* 189–193.

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