EFFECTS OF CORE STRENGTH TRAINING ON PHYSICAL FITNESS AND SKILLS PERFORMANCE AMONG YOUTH MALE FIELD HOCKEY PLAYERS IN GANSU, CHINA

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By

MA HUCHENG

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

February 2025

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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By

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February 2025

Chairman : Professor Soh Kim Geok, PhD
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This study aimed to evaluate the effects of a 12-week core strength training intervention on physical fitness (strength, power, speed, endurance, agility, and flexibility) and field hockey skills (dribbling, pulling, passing, and shooting accuracy) of Chinese young male field hockey players. The study was conducted meticulously, considering four major areas for the cluster selection process in the Gansu Province region of China. Two districts were randomly selected, and the core strength training group (CSTG) and control training group (CTG) were selected using the fishbowl method. Forty-eight eligible participants were recruited from two training sites in Gansu Province, aged between 15 and 17 years. A cluster-randomised controlled trial study was conducted, and the two groups performed 60 minutes of training thrice a week for 12 weeks. The data collection procedures for CTG were the same as those for CSTG. In addition, these test protocols were used to evaluate the changes in dependent variables at 0, six, and 12 weeks after the intervention.

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Generalised estimating equations (GEE) determined differences between and within groups at baseline, week six, and week 12. The significance level was fixed at $P < 0.05$. Results showed interaction effect (time*group) showed significant differences in most variables ($p<0.05$). Strength ($X^2=176.367$, $p<0.001$), power ($X^2=28.636$, $p<0.001$), speed ($X^2=170.182$, $p<0.001$), endurance ($X^2=32.196$, $p<0.001$), agility ($X^2=205.528$, $p<0.001$), dribbling ($X^2=287.613$, $p<0.001$), pulling ($X^2=16.121$, $p<0.001$), and shooting ($X^2=23.054$, $p=0.001$). All indicators changed significantly over time (12 weeks) between the two groups, indicating the impressive effectiveness of core strength training. Among them, strength (sit-up - effect size = 3.68) and skills (dribbling - effect size = 2.01) showed the largest differences. In contrast, the interaction effects of the remaining variables (flexibility and passing skills) were reported as not significantly different.

In conclusion, a core strength training approach focusing on whole-body stabilising muscle training in a high-load and high-threshold environment aims to adapt to overload training through muscle hypertrophy, enhancing core strength, improving core stability, and sports performance. The specificity of this training approach lies in using multi-joint and multi-muscle group exercises to meet the specific performance demands of the sport. In addition, core strength training significantly enhances the abdominal strength of field hockey players through multiple mechanisms. The training emphasises multi-joint and compound movements, such as planks, bridges, and Russian twists, which can effectively activate the rectus abdominis and oblique abdominal muscles, improving muscle strength and endurance. At the same time, core strength training enhances the athlete's core stability and postural control, which is crucial for overall athletic performance, especially during dribbling. Enhanced pelvic

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and trunk stability improves the athlete's coordination during rapid turns and reduces rotation time, further improving the dribbling skills of youth hockey players. Therefore, systematic core strength training strengthens abdominal strength and significantly enhances dribbling skills. This study underscores the need for future research to be expanded to other sports and athletes of different genders to evaluate its effects on various physical fitness and skill parameters. It highlights the potential for further exploration in this field and the urgency of expanding the study to other areas of sports and athletes.

Keywords: Core strength training, field hockey, physical fitness; skills.

SDG: GOAL 4: Quality Education

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN LATIHAN KEKUATAN TERAS TERHADAP KECERGASAN FIZIKAL DAN PRESTASI KEMAHIRAN DALAM KALANGAN PEMAIN HOKI PADANG LELAKI MUDA DI GANSU, CHINA

Oleh

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Kajian ini bertujuan untuk menilai kesan intervensi latihan kekuatan teras selama 12 minggu terhadap kecergasan fizikal (kekuatan, kuasa, kelajuan, daya tahan, ketangkasan, dan fleksibiliti) dan kemahiran hoki padang (menggelecek, menarik, menghantar, dan ketepatan menembak) dalam kalangan pemain hoki padang lelaki remaja di China. Kajian ini dijalankan dengan teliti, melibatkan proses pemilihan kelompok daripada empat kawasan utama di Wilayah Gansu, China. Dua daerah dipilih secara rawak, dan kumpulan latihan kekuatan teras (CSTG) serta kumpulan kawalan (CTG) dipilih menggunakan kaedah cabutan mangkuk ikan (fishbowl method). Seramai 48 peserta yang layak telah direkrut dari dua pusat latihan, berumur antara 15 hingga 17 tahun. Kajian ini menggunakan reka bentuk ujian terkawal secara rawak berkelompok (cluster-randomised controlled trial), di mana kedua-dua kumpulan menjalani latihan selama 60 minit, tiga kali seminggu selama 12 minggu. Prosedur pengumpulan data bagi kumpulan CTG adalah sama seperti kumpulan CSTG. Protokol ujian digunakan untuk menilai perubahan dalam pembolehubah

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bersandar pada minggu ke-0, minggu ke-6, dan minggu ke-12 selepas intervensi.

Kaedah Generalised Estimating Equations (GEE) digunakan untuk menentukan perbezaan antara dan dalam kumpulan pada garis dasar, minggu keenam, dan minggu kedua belas. Tahap signifikan ditetapkan pada $P < 0.05$. Keputusan menunjukkan kesan interaksi (masa*kumpulan) yang signifikan bagi kebanyakan pembolehubah ($p < 0.05$), termasuk kekuatan ($X^2=176.367$, $p<0.001$), kuasa ($X^2=28.636$, $p<0.001$), kelajuan ($X^2=170.182$, $p<0.001$), daya tahan ($X^2=32.196$, $p<0.001$), ketangkasan ($X^2=205.528$, $p<0.001$), menggelecek ($X^2=287.613$, $p<0.001$), menarik ($X^2=16.121$, $p<0.001$), dan menembak ($X^2=23.054$, $p=0.001$). Semua penunjuk menunjukkan perubahan yang ketara sepanjang tempoh 12 minggu antara dua kumpulan, menandakan keberkesanan intervensi latihan kekuatan teras. Antara semua pembolehubah, kekuatan (sit-up – saiz kesan = 3.68) dan kemahiran (menggelecek – saiz kesan = 2.01) menunjukkan perbezaan paling besar. Sebaliknya, kesan interaksi bagi pembolehubah fleksibiliti dan kemahiran hantaran dilaporkan tidak signifikan.

Kesimpulannya, pendekatan latihan kekuatan teras yang memberi tumpuan kepada otot penstabil seluruh badan dalam persekitaran beban tinggi dan ambang tinggi bertujuan untuk menyesuaikan diri dengan latihan berlebihan melalui hipertrofi otot, sekali gus meningkatkan kekuatan teras, kestabilan teras, dan prestasi sukan. Kekhususan pendekatan ini terletak pada penggunaan latihan pelbagai sendi dan kumpulan otot, yang disesuaikan dengan tuntutan prestasi khusus sukan. Latihan ini turut meningkatkan kekuatan otot abdomen melalui pelbagai mekanisme, terutamanya melalui aktiviti planks, bridges, dan putaran Rusia yang mengaktifkan otot rectus abdominis dan obliques, lalu meningkatkan kekuatan dan daya tahan otot. Latihan ini

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juga memperkukuhkan kestabilan pelvik dan batang tubuh, meningkatkan kawalan postur serta koordinasi pergerakan semasa perubahan arah yang pantas, justeru meningkatkan kemahiran menggelecek pemain hoki remaja. Oleh itu, latihan kekuatan teras secara sistematik bukan sahaja memperkukuhkan otot abdomen tetapi juga meningkatkan prestasi kemahiran menggelecek secara signifikan. Kajian ini mencadangkan agar penyelidikan lanjut dijalankan ke atas sukan lain dan populasi atlet berlainan jantina untuk menilai kesannya terhadap pelbagai parameter kecergasan fizikal dan kemahiran, serta membuka ruang penyelidikan baharu dalam bidang ini.

Kata Kunci: Latihan kekuatan teras, hoki padang, kecergasan fizikal, kemahiran.

SDG: MATLAMAT 4: Pendidikan Berkualiti

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the supervisory committee were as follows:

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LIST OF ABBREVIATIONS

BS	Back Squat
BPT	Backhand Pass Test
CHA	Chinese Hockey Association
CSTG	Core Strength Training
CTG	Control Group
FPT	Forehand Pass Test
GEE	Generalised Estimating Equations
IHF	International Hockey Federation
LGB	Left Gravity Ball
LART	Left Arrow Run Test
OMPT	One meter Pull Test
PU	Push-ups
RART	Right Arrow Runs Test
RGB	Right Gravity Ball
SU	Sit-up
SAR	Sit and Reach
SLJ	Standing Long Jump
SDT	Slalom Dribble Test
SAT	Shooting Accuracy Test

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CHAPTER 1

INTRODUCTION

This chapter mainly elaborates on the overview of field hockey, problem statement, research objective, research hypothesis, study significance, study limitations, delimitations, and conceptual and operational definitions.

1.1 Background

1.1.1 Overview of Field Hockey

Field Hockey, a sport that is now popular worldwide, traces its history back to ancient Egypt around 4000 BC(*International Hockey Federation*, 2024; Nallella & Kumar, 2021). This ancient sport was named after the French word "hocquet," meaning "shepherd's stick," which reflects its deep historical roots (Anders & Myers, 2008; *International Hockey Federation*, 2024). The early form of hockey was found in ancient Egypt and the historical remains of Ethiopia and Iran. This suggests that hockey has a broad cross-cultural historical heritage long before the early Olympic Games (*International Hockey Federation*, 2024; MacKeddie-Haslam, 2022).

By the mid-19th century, modern field hockey began to rise in the United Kingdom and underwent a process of standardisation (*International Hockey Federation*, 2024; Mcclain, 2022). In 1876, the first hockey club was established in the UK, and formal rules for the game were developed, marking the official start of hockey's modernisation (Forsyth et al., 2023; *International Hockey Federation*, 2024). The sport gained official status at the Olympic Games in 1908, further establishing its international influence, and the International Hockey Federation (FIH) was founded

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in Paris in 1924, signifying a new chapter in hockey's globalisation (*International Hockey Federation*, 2024). FIH has members in 137 countries today, with approximately 30 million hockey players worldwide (Batchelor & Coombs, 2012; *International Hockey Federation*, 2024; Proteau, 2011). This reflects hockey's broad impact on modern society and showcases its enduring appeal as an ancient sport (Adnan et al., 2018; Hardy & Holman, 2018).

However, field hockey garners widespread attention primarily because it places exceptionally high demands on athletes' physical fitness and skills. This sport requires athletes to possess excellent speed, strength, power, and endurance and to engage in high-intensity intermittent movements on the field (Alias et al., 2017; Razali et al., 2017). Athletes must demonstrate exceptional agility and flexibility in fast-paced games while mastering various technical skills, including dribbling, ball control, passing, shooting, tackling, and defending (Mitchell-Taverner, 2005; Naicker et al., 2016; Thiel et al., 2012). Each action requires athletes to find the perfect balance between precision and power, making hockey a challenging yet highly entertaining team sport.

1.1.2 Field Hockey in China

Since its first professional team was established in 1976, Chinese men's field hockey has developed rapidly, yet its performance on the international stage could have been better (Da, 2018; Xie & Cao, 2024). From the 1980s to now, the Chinese men's hockey team has achieved notable success in Asian competitions. The team secured a third-place finish at the inaugural Asian Cup in Pakistan in 1982. They won a silver medal at the 2006 Doha Asian Games and achieved their best-ever finish, 11th place, at their

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first appearance in the 2008 Beijing Olympics (Huo et al., 2016; Yan, 2013).

Unfortunately, since the 2008 Beijing Olympics, the team's performance in international competitions has declined. Notably, they must still qualify for the recent Olympic Games (Huo et al., 2016; Wu, 2023). However, they achieved a tenth-place finish at the 2018 World Cup held in India, marking the team's best-ever result in World Cup history - an unprecedented achievement for Chinese men's field hockey (*International Hockey Federation*, 2024). Currently, the team ranks 23rd in the international standings, making it one of the lowest-ranked teams globally (*International Hockey Federation*, 2024). However, compared to leading Asian and world teams such as the Netherlands, Australia, India, and England, Chinese field hockey players still exhibit significant gaps in physical fitness, skills, and tactics (Huo et al., 2016; Wu, 2023).

However, the challenges faced by Chinese men's field hockey extend beyond improving skills and physical fitness to include coping with the pressure of repeated defeats in international competitions (Chen, 2014; Liu & Wang, 2016). Hockey demands rigorous requirements from athletes regarding physical fitness, skills, psychological resilience, and technical actions, encompassing the comprehensive mastery of skills such as dribbling, passing, shooting, and defending (Wang, 2023; Yan, 2013).

Research indicates that strength, skill, agility, speed, endurance, and flexibility influence hockey performance (Jakeman et al., 2016; Singh et al., 2018; Yan, 2013). A longstanding lack of understanding of these factors often leads to poor performance

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by athletes in competitions (Bruin, 2020). To regain competitiveness on the international stage, the Chinese men's field hockey team needs systematic reforms and improvements, including in-depth exploration of effective training methods and strategies to enhance overall performance and achieve better results.

1.1.3 Application of Sports Training in Field Hockey

Sports training methods are the core means to improve athletes' physical fitness and the key elements to optimise skill performance (Guo et al., 2024; Luo et al., 2023; Turner & Comfort, 2022; Wang et al., 2023; Xiao et al., 2021). By rationally designing training load and recovery cycle, scientific training programs can enhance athletes' core physical qualities such as strength, speed, endurance and agility (Bompa & Buzzichelli, 2021; Luo et al., 2023). In addition, training methods tailored to the characteristics of sports events can optimise the acquisition and application of sports skills and ensure the stability and effectiveness of athletes' performance in different situations (Dabuleanu et al., 2024; Luo et al., 2022; Mulugeta, 2022; Sellathurai, 2023). Therefore, combining multiple training methods and making individual adjustments is essential to improving overall athlete performance.

Many studies have shown that different sports training methods can significantly affect the physical performance of field hockey players (Chaudhary et al., 2021; Krishnan & Rajawadha, 2020; Taylor & Jakeman, 2022). Various training techniques affect athletes' physical fitness and skill performance differently. These methods include strength and coordination training (Jothilingam, 2024), high-intensity interval training (Elumalai et al., 2020; Quezada-Muñoz et al., 2021), weight training (Ansari, 2020), resistance training (Koca & Revan, 2023), aerobic and anaerobic training

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(Kumar & Pandey, 2023; Muniraj & Saikumar, 2019), plyometric training (Sener et al., 2021; Singh et al., 2018) , and core training (Ramasamy et al., 2022).

These training methods effectively improve athletes' physical fitness, such as strength, speed, and endurance, and also show excellent effects on improving sports-specific skills. Therefore, the rational use and combination of various training methods can help athletes maximise their overall physical fitness and skill performance and provide a solid theoretical foundation for the scientific nature of sports training.

1.2 Problem Statement

Field Hockey is a popular sport, with over one million athletes participating globally each year, spanning 132 countries (*International Hockey Federation*, 2024). According to the latest data from the official website of the China Hockey Association, 4,000 active hockey players participated in the National Games (*China Field Hockey Federation*, 2024). However, the performance of the Chinese men's field hockey team in international competitions could have been better in recent years (Huo et al., 2016; Wu, 2023). Currently, the level of the Chinese men's professional hockey program is in the middle range within Asia, trailing behind Asian countries such as India, Pakistan, Japan, Malaysia, South Korea, and Indonesia, and even further behind the world's leading nations (Wu, 2023). According to data from the International Hockey Federation, the Chinese men's field hockey team has only participated in one Olympic Games and one World Cup, with their best result being 11th place at the Beijing Olympics, and they are currently ranked 23rd in the world (*International Hockey Federation*, 2024). Compared to the strong teams in Asia and worldwide, the Chinese men's field hockey team has significant gaps in training methods, physical fitness, and

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technical skills (Huo et al., 2016).

Field Hockey imposes extremely stringent physical demands on athletes (Lemmink, 2004; Yan, 2013). During matches, players repeatedly engage in irregular high-intensity intermittent activities, significantly demanding strength, power, speed, endurance, agility, and flexibility (Lythe & Kilding, 2011; Razali et al., 2017; Yan, 2013). Moreover, early studies have highlighted that excellent physical fitness is a prerequisite for high-level competition performance (Farley et al., 2020; Reilly & Borrie, 1992).

One study from China revealed the problems of Chinese athletes in terms of physical fitness by comparing the physical fitness of Chinese field hockey players with that of international elite hockey players (Chen, 2009). Through systematic analysis and comparison, Cheng pointed out that Chinese hockey players must catch up with top athletes from foreign countries regarding crucial physical fitness indicators such as strength and speed (Chen, 2009; Li, 2015; Yu, 2023). For instance, in a strength survey of the Guangdong men's field hockey team, ranked second among professional teams in China, it was found that only seven players (44% of the team) met the required strength standards, and just two players (12.5% of the team) reached the strength level of elite athletes. These results are suboptimal, indicating significant room for improvement in strength training for the Guangdong men's field hockey team (Chen, 2009). In terms of speed, Chinese hockey players also need to meet expectations. Data show that the average power output for Chinese athletes is 546.94 watts, while elite athletes average 748.45 watts (Chen, 2009). When intensity is measured by speed and load, the intensity variables for Chinese athletes are lower than those reported for the

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Australian men's national team athletes by 11% and 30%, respectively (Lombard et al., 2021).

Additionally, youth field hockey players must possess high-level technical skills, such as passing, dribbling, and accurate shooting without losing speed, which are crucial for scoring (Badr, 2018). However, based on an analysis of game footage, Chinese field hockey players frequently make errors during ball passing. They perform poorly in shooting within the 16-yard area and face difficulties when attempting to dribble past opponents (Huo et al., 2016; Wang, 2023; Yan, 2013). A study further revealed that Chinese hockey players exhibited poor passing skills, with 1,373 passing errors recorded across 20 matches by eight teams. For example, the Inner Mongolia team, which made more passing errors, lost 0:2 to the stronger Liaoning team and unfortunately lost the championship (Huo et al., 2016).

Regarding shooting skills, technical statistics show that only 59 out of 184 shots were successful, which is significantly below the level of the world's top teams. For example, the Jiangsu team, whose shooting success rate was only 24.7%, was defeated 4:1 by the stronger Guangdong team, whose shooting success rate was 36.7% (Huo et al., 2016). It's good to highlight that a study combining physical and skills is required to assess hockey players' performance better.

Moreover, research indicates that the training methods of Chinese hockey players need to be updated (De, 2019; Fan, 2021; He, 2022). In many provincial and municipal hockey teams in China, strength training often focuses on conventional muscle-strengthening exercises, such as weighted squats, to develop essential lower-body

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strength. However, these exercises can significantly stress athletes' knees (Huo et al., 2016). Studies have shown that coaches frequently rely on traditional strength training methods, such as bench press exercises, to improve hockey players' shot velocity. Nonetheless, results indicate that these conventional methods have little impact on shot velocity (De, 2019; Qin, 2017; Zhou, 2022). Another study noted that Chinese hockey teams need more training plans, including specific information on training content, duration, frequency, and the number of sets and repetitions (He, 2016). A scientific and well-structured training program is crucial for improving athletic performance. Without it, athletes risk failing to enhance their strength and being more susceptible to injuries, potentially shortening their careers (Fan, 2021).

Core strength training has been widely applied in competitive sports (Bauer & Muehlbauer, 2022; Kumar & Zemková, 2022; Özdal, 2016). Core strength training is a high-load, dynamic approach designed to induce muscle hypertrophy and enhance neural activation within motor units, thereby increasing muscle strength and density. By improving core strength, this method can enhance overall performance, speed, agility, and power (Hibbs et al., 2008).

Previous studies have shown that core strength training can improve athletic performance in basketball, soccer, volleyball, javelin, and tennis (Feng et al., 2024; Mossa, 2022; Yang et al., 2022; Yapıcı, 2019; Yılmaz, 2022). However, research on using core strength training to enhance the performance of hockey players still needs to be improved and needs more investigation. Hence, this study aims to fill this gap by investigating the effects of core strength training on hockey players' physical performance and skills.

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1.3 Research Objective

1.3.1 General Research Objective

The overall objective of this study was to investigate the effects of a 12-week core strength training program on physical fitness and field hockey skill performance among youth Chinese male field hockey players.

1.3.2 Specific Research Objective

As stated in the overall objective above, two specific objectives were identified. The following is a list of the specific objectives is to:

Assess the effects of a 12-week core strength training program on the physical fitness components (strength, power, speed, endurance, agility and flexibility) among young Chinese male field hockey players at baseline, week 6, and week 12.

Investigate the effects of a 12-week core strength training program on the skills performance (dribbling, pulling, passing and shooting) among young Chinese male field hockey players at baseline, week 6, and week 12.

1.4 Research Hypothesis

The main two hypotheses of this study were to assess whether a 12-week core strength training program would significantly affect (i) physical fitness and (ii) skills performance among young Chinese male field hockey players through the following null hypotheses. Ten specific research hypotheses developed based on these two main hypotheses are listed below.

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Specific null hypotheses 1-6 related to the first objective are physical fitness in terms of strength (push-ups, sit-ups, and back squats), power (left gravity ball, right gravity ball, and standing long jump), speed (25-yards sprint and 50-yards sprint), endurance (300-yards switchback run), agility (left arrow run and right arrow run) and flexibility (sit and reach). Physical fitness performances are:

Strength：

H01. There were no significant differences in strength (push-ups, sit-ups and back squats) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players.

Power：

H02. There were no significant differences in power (left gravity ball, right gravity ball and standing long jump) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players.

Speed：

H03.There were no significant differences in speed (25-yards sprint and 50-yards sprint) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players.

Endurance:

H04.There were no significant differences in endurance (300-yard shuttle run) between the core strength training group and the control group at baseline, week 6,

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and week 12 among young Chinese male field hockey players.

Agility:

H05. There were no significant differences in agility (left arrow run and right arrow run) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players.

Flexibility:

H06. There were no significant differences in flexibility (sit and reach) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players.

The 7-10 specific null hypotheses associated with the second objective as dribbling (slalom dribble skills), pulling (one-meter pull skills), passing (forehand pass skills and backhand pass skills), and shooting (shooting accuracy skills). Skills performances are:

Dribbling:

H07.There were no significant differences in dribbling (slalom dribble skills) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players

Pulling:

H08.There were no significant differences in pulling (one-meter pull skills) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players.

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Passing:

H09.There were no significant differences in passing (forehand pass skills and backhand pass skills) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players.

Shooting:

H010. There were no significant differences in shooting (shooting accuracy skills) between the core strength training group and the control group at baseline, week 6, and week 12 among young Chinese male field hockey players.

1.5 Significance of the Study

The study's significance is divided into two main areas: theoretical and practical. Specific explanations are given below.

1.5.1 Theoretical Significance

The theoretical basis for this study is based on a specific framework. The basis of this framework comes from the core training model (Hibbs et al., 2008), which reveals the potential role of core strength and stability in improving sports performance. Scientific research has shown that this model effectively explains the influence of core muscles on overall sports performance. Although this theory is widely used in various sports, its specific application in field hockey has not been thoroughly studied (Hibbs et al., 2008).

According to the core training model of Hibbs and his colleagues, core training can be divided into two categories: core stability training and core strength training, which

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profoundly impact athletes' stability, strength and overall performance through different physiological mechanisms. The model emphasises that core stability training is a low-threshold method designed to reduce the risk of injury and enhance the stability of athletes. In contrast, core strength training is an integral part of the model that directly improves athletic performance by increasing muscle strength and the nervous system's activation level. Core strength training activates deep core muscles through high-threshold forms of exercise, such as weight training or dynamic movements, promoting motor unit synchronisation and strengthening muscle fibres. This process significantly improves muscle strength and enhances vital athletic abilities such as speed, agility and power. Therefore, core strength training enhances athletic performance, providing athletes with more muscular physical fitness and competitive advantages in high-level competitions.

The theoretical contribution of this study is that it applies Hibbs’ core strength training framework to the field of youth male field hockey, expanding the scope of application of the model. This study aims to systematically evaluate the potential effects of core strength training on athletes' physical fitness and skill performance and provide preliminary support for its effectiveness. Exploring the impact of core strength training on critical indicators such as speed, power, and agility deepens the understanding of the possible benefits of this training method. It provides a theoretical reference for optimising the training of hockey players. The theoretical expansion of the study not only enriches the connotation of the core training model but also provides a theoretical basis for future practical applications in the training of youth field hockey players and helps the subsequent research and practice in related fields.

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1.5.2 Practical Significance

This study has two important practical implications and goals. Firstly, it aims to assist coaches, scientists, and administrators. Secondly, it seeks to meaningfully enrich the knowledge on implementing core strength training among different types of athletes. The study helps to identify effective training programs to optimise the impact of skills and physical fitness on the performance of youth field hockey players. Through a 12-week core strength training program conducted three times weekly, the research can provide practical guidance for improving hockey players' skills and physical fitness.

In addition, the results of this study can guide and become a good benchmark for coaches, sports management professionals, and athletes to develop and implement an efficient and targeted 12-week core strength training program based on Jeffery's core training guidelines to improve sports performance. When training young male field hockey players, coaches can refer to and use the clinical trial results registered in this study to optimise the training program further. This study provides practical guidance for current training and lays a valuable foundation for future research on improving sports skills.

This study contributes to the existing literature on applying core strength training as an intervention among different athletes. Research on core strength training has focused on tennis, basketball, badminton, javelin, soccer, and martial arts athletes (Luo et al., 2022). Although previous studies have shown that hockey positively impacts athletes' physical fitness and skill development, there still needs to be more specific scientific knowledge on core strength training in hockey. Therefore, exploring the benefits of core strength training helps to enrich the current scientific knowledge

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and provide more precise training programs for hockey players.

1.6 Delimitations of the Study

The scope of the current investigation is outlined as follows:

This study's subjects were adolescent male field hockey players aged 15 to 17 from Gansu Province Sports School and Linxia Prefecture Sports School in China. These players were from Lanzhou and Linxia, Gansu Province, and participated in standardised training and the U18 National Hockey Championship in the 2023-2024 season. As this study was limited to this specific group, this limitation provides room for future research to expand and verify, especially further investigation and comparison of different groups.

Although many physical fitness and hockey skill variables can be employed and tested, only six physical fitness variables (strength, power, speed, agility, flexibility, and endurance) and four hockey skill variables (dribbling, shooting, pulling, and passing) were selected for this study. Indeed, these variables were more related to general physical fitness and field hockey skill level (Bartolomei et al., 2019; Mohan et al., 2021; Yan, 2013). Therefore, based on previous literature, physical fitness, and pitch assessment test items, the selected variables were most relevant to improving field hockey athletes' physical and skills performance.

Core strength training programmes are essential for improving athlete performance. However, research on the effects of such core strength training programmes on selected physical field hockey skills in youth hockey players is still limited. In this study, the primary training intervention was inspired by Jeffery's Core Training Guide,

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endorsed by the National Strength and Conditioning Association (NSCA) (Willardson, 2007). A notable reference point is a study of elite Youth Ice Hockey players highlighting the positive impact of core strength training on physical fitness and skill performance (Zou, 2023). However, further research is needed to determine the effectiveness of core strength training programs for field hockey players. Additionally, further research could assess whether similar results apply to field hockey players of different genders or other sports (e.g. football, rugby ball).

1.7 Definitions of Terminology

This section outlines the concepts and operational definitions of core strength training, physical fitness, field hockey skills, and youth field hockey players.

1.7.1 Core Strength Training

Conceptual definition: Core strength training high-threshold and overload training of the global stabiliser muscle system leads to hypertrophy as an adaptation to overload training (Cotton, 2005; Luo et al., 2022; S. Ma et al., 2024). This training method adopts a continuous evaluation approach, ensuring a consistent exercise regimen and enhancing athletic performance.

Operational definition: This study's core strength training program includes static holds and dynamic movements under stable and unstable conditions. Core strength training is divided into seven levels of difficulty: static training under stable conditions, non-weighted training, specialised core strength training, static training under unstable conditions, resistance training, free weight training, and core explosive strength training. The training involves using balance boards, air cushions, stability

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balls, suspension straps, and sliders to conduct core strength exercises under unstable conditions.

1.7.2 Physical Fitness

Conceptual definition: Based on the published study, the researchers concluded that physical fitness can be divided into two categories: health-related fitness and motor skill-related fitness. Health-related fitness includes strength, power, endurance, speed, agility, and flexibility, while motor skill-related fitness provides strength, power, endurance, speed, agility, and flexibility (Bedaso, 2023; Caspersen et al., 1985; Luo et al., 2022; Medicine, 2012; Viran et al., 2022).

Operational definition: Physical fitness comprises attributes related to an individual's ability to perform physical activities efficiently and effectively (Thompson et al., 2012). Based on previous research, this study focuses on fitness elements specifically for young male field hockey players, including strength, power, speed, agility, flexibility, and endurance. It is well known that hockey is a fast-paced sport that places high demands on players' strength and endurance. According to relevant literature, these six fitness elements (strength, power, speed, agility, flexibility, and endurance) must be assessed (Bashir et al., 2024; Noblett et al., 2023). Enhancing these elements through appropriate training programs is crucial for improving the performance of hockey players and maximising their potential.

1.7.3 Field Hockey Skills

Conceptual definition: Filed Hockey is a team sport, and precise individual skills are necessary. It consists mainly of passing, pulling, dribbling, shooting, blocking,

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receiving, moving without the ball, and defending (Anders & Myers, 2008; Antara et al., 2023; Manaf et al., 2021).

Operational definition: In this study, hockey includes the four most critical basic skills: passing, pulling, dribbling, and shooting. Passing skills were measured using 7-yard and 15-yard partner push passes (Anders & Myers, 2008), pulling abilities were measured using a one-yard distance timer to estimate the number of pulls, dribbling skills used the Shuttle (SDT) method to test dribbling performance (Keogh et al., 2003) and shooting accuracy test (SAT) is attempting to score points by passing the ball through the hoop (Lemmink, 2004).

1.7.4 Youth Hockey Player

Conceptual definition: Youth field hockey players are young athletes aged between 5 and 17 who receive specialised training at youth training clubs and participate in local, regional, and even national and international field hockey competitions. These athletes typically represent their training clubs in youth championships, demonstrating high levels of skill and competitive ability (*China Field Hockey Federation*, 2024).

Operational definition: This study recruited 60 male field hockey players aged 15 to 17 years born on or after January 1, 2007. These players received at least two years of systematic training in Gansu Province, China, and participated in the National U18 Field Hockey Series.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an in-depth understanding and elaboration of the relevant literature in the following areas: (2.2) Competitive Demands and Player Characteristics in Field Hockey; (2.3) Current Situation of Chinese Hockey Player Training; (2.4) Definition of terms; (2.5) effects of exercise training on physical fitness and skills among field hockey players; (2.6) effect of core strength training on physical fitness among players in sports; (2.7) effect of core training on skill performance among athletes; and (2.8) the theoretical and conceptual framework.

2.2 Competitive Demands and Player Characteristics in Field Hockey

As modern hockey continues to evolve, the sport has developed a complete technical system where successful competitive performance relies on a complex combination of physical, technical, and tactical skills (Lythe, 2008; Timmerman et al., 2017). Therefore, success in hockey requires a comprehensive understanding of the sport's unique demands and the characteristics required of athletes. This includes proficient technical skills, exceptional physical fitness, and strategic thinking skills to adapt and respond to the game's ever-changing challenges.

2.2.1 Competitive Requirements in Field Hockey

Field Hockey, as a high-intensity intermittent sport, places extreme demands on athletes' physiological and technical abilities. During the game, athletes must

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complete frequent high-intensity sprints at an ever-changing tempo, requiring exceptional physical fitness (Cai & Chen, 2016; Sunderland & Edwards, 2017). In 2014, the Federation International de Lacrosse (FIH) changed the traditional time structure of the game from two 35-minute halves to four 15-minute quarter systems to increase the intensity and pace of the game. This rescheduling has resulted in athletes not only needing to maintain high-intensity sprinting and anaerobic metabolic capacity for a shorter period but also having to recover quickly during short breaks to maintain optimal competitive performance throughout each quarter (Ihsan et al., 2021; *International Hockey Federation*, 2024).

In field hockey, high-intensity and low-intensity activities alternate in a ratio typically around 1:3 to 1:4 (Cai & Chen, 2016). Research has shown that in standard international competitions, athletes are required to run an average of 8 to 10 kilometres, which includes 30 to 40 high-intensity sprints of 5 to 20 metres (Cai & Chen, 2016; Lythe & Kilding, 2011). These high-intensity sprints require athletes to mobilise energy reserves to complete high-intensity anaerobic exercise rapidly. Additionally, athletes have an average heart rate of 150 beats per minute and maintain a heart rate between 84%-95% of their maximum heart rate for more than half of the race. This indicates that they are consistently in a high-intensity competitive state (Jennings et al., 2012; Vescovi, 2016). As athletes in different positions exercise to varying intensities during competition, individualised fitness training is required to meet the specific needs of their respective positions.

At the same time, technical ability is a core component of an athlete's success. Athletes must maintain precise ball control and demonstrate exceptional dribbling, passing, and shooting abilities during play. These skills require high hand-eye coordination, decision-making ability, and precision in high-speed, dynamic play (Lythe & Kilding, 2011; Spencer et al., 2006; Timmerman et al., 2017). Research has shown that elite athletes can perform up to 30 dribbling manoeuvres per minute, achieve a pass success rate of 75% or more, and shoot accurately despite high-pressure situations (Timmerman et al., 2017).

In addition, teams that cover greater distances and successfully execute basic technical manoeuvres such as passing, dribbling, shanking, and shooting usually achieve higher levels of success (Lythe, 2008). Therefore, a lack of athletic ability may affect an athlete's performance. During training, hockey players should consider the essential aspects of hockey game requirements (i.e., physical fitness, and hockey skills).

2.2.2 Competitive Requirements in Hockey Players

Field Hockey presents multiple challenges to athletes' physical fitness and technical ability. At a high level of competition, athletes must have a solid aerobic and anaerobic metabolism to cope with the game’s frequent short sprints and long, sustained runs. They must also maintain running at low to moderate intensities for extended periods and quickly switch to high-intensity explosive activities such as sprinting, accelerating, and stopping sharply during the competition (Lythe & Kilding, 2011; Polglaze et al., 2015).

In addition, high-intensity movements such as dribbling, passing, and confrontation during games require athletes to possess excellent strength, stability, and body control. To gain a competitive advantage in intense matches, athletes must quickly adapt to

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changing game situations, demonstrating agility and quick decision-making skills (Chaudhary et al., 2021). These requirements motivate athletes to develop cardiorespiratory endurance, speed, muscular strength, flexibility, and agility fully in their daily training to perform consistently at a high level during competition (Keogh et al., 2003; Reilly & Borrie, 1992).

From a physiological perspective, hockey is a complex mixed-energy sport that places extreme demands on the athlete's ATP-CP, anaerobic glycolytic, and aerobic energy supply systems. Aerobic capacity forms the basis of an athlete's overall endurance, while anaerobic capacity is a crucial determinant of performance (Yan, 2013). High-level hockey players move an average distance between 7,000 and 10,000 metres per game, completing approximately 50 to 60 sprints of five to thirty metres, equivalent to 1,000 to 1,500 metres of high-intensity exercise (Cai & Chen, 2016; Chen, 2009).

During intense competition, athletes have an average heart rate of 172 beats per minute and a maximum oxygen uptake of 64 ml/kg-min, more than 80% of the maximum oxygen consumption (Fernández et al., 2009; Fernandez-Fernandez et al., 2020). After the game, athletes lost an average of 2200 g of body weight, had a positive urine protein blood rate of 91.7%, and blood lactate levels of 40 to 50 mg. These data suggest that important performance indicators in elite-level hockey include athletes possessing a high aerobic capacity and the ability to perform multiple high-intensity sessions (Cai & Chen, 2016; Konarski & Strzelczyk, 2009; White & Wells, 2013). As Yan (2013) highlighted, key hockey tactics such as starts, shots, scrambles, sharp stops, changes of direction, shifts, continuous dribbling, quick tackles, and passing and receiving are typically completed in less than 10 seconds, reflecting the intensity

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of the sport. As a result, hockey players must have excellent skill and fitness levels to be successful.

2.3 Current Situation of Chinese Hockey Player Training

China's men's field hockey performance has declined in recent years, reflecting a decline in status in the international arena and revealing more profound training and development issues. In the 1980s and early 1990s, the Chinese men's hockey team was once regarded as the powerhouse of Asia, having won numerous Asian tournaments. However, the results in recent years could have been better, especially in performance in major global tournaments. Like the decline of Pakistan hockey, Chinese men's hockey has continued to fall in the international rankings and is currently ranked only 23rd globally (*International Hockey Federation*, 2024). This decline in performance is not only a reflection of short-term results but also exposes many problems in the physical training, technical and tactical improvement, and overall development strategy of Chinese hockey.

Ford et al. (2011) emphasise that adolescence is critical for developing athletes' physical fitness and skills. Training during this period lays the foundation for their future competitive performance and determines their athletic potential in adulthood (Ford et al., 2011; Haff, 2013). However, the problems in Chinese hockey are broader than just the adult teams; the roots can also be traced back to the training and development of the youth. Research has shown that Chinese youth hockey players have significant deficits in physical reserves and correct technique application (He, 2022; Li, 2024; Qin, 2021). High-intensity matches severely demand athletes' physical fitness and technical ability, meaning hockey players must receive scientific and

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targeted training arrangements. Through scientific training, athletes can improve their physical fitness and perfect their hockey skills to achieve better results in high-level competitions. However, the existing training system still needs to meet these demands fully, and further optimisation and reform are necessary.

Zhu et al. (2023) comprehensively analysed the problems existing in the sports training of Chinese youth hockey players. The authors pointed out that the guiding ideology of training needs to be scientific and systematic, making it difficult to effectively improve the athletes' competitive level in actual training. In addition, the authors added that the separation of physical and technical training is severe in the current youth hockey training, with insufficient game experience and a lack of effective competitiveness (Zhu et al., 2023). According to Zhangyan (2019), there are significant problems in the physical training of youth hockey players, mainly reflected in the unsystematic training research, low theoretical level of coaches, and a single training method needing more pertinence. Youth athletes' physical development characteristics and individual differences should be addressed during training, resulting in better training effects (Zhang, 2019).

Zhang (2023) found that the athletic training problems of youth hockey athletes include many aspects, such as the coaches themselves, the training program, the facilities, the training ground, and the training methods. All these problems limit the improvement of their physical fitness (Zhang, 2023). Some studies have pointed out that Chinese adult athletes' physical fitness and technique deficiencies are due to a lack of training or incorrect training during adolescence and that scientific training is crucial (Mi, 2016; Niu et al., 2024). However, it can be seen from the existing literature

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that most of the studies neglected the importance of selecting sports training methods and failed to optimise the training of athletes' physical fitness and skills (Deng et al., 2023; Rechenmacher et al., 2022; Wang et al., 2023). Therefore, more attention should be paid to selecting athletic training methods for hockey players.

2.4 Description of Variables

This section focuses on core strength training, physical fitness, field hockey skills, and youth field hockey players. Below are detailed explanations.

2.4.1 Core Strength Training

Traditional resistance training methods tend to be limited to isolated single-joint movements, which often need to encompass the complexity of multi-joint and planar movements that are recognised as crucial factors in enhancing athletic performance (Santos et al., 2022). In contrast, core strength training has been widely recognised as a highly effective exercise protocol for significantly improving athletic performance (Bora & Dağlıoğlu, 2022; Jeong et al., 2021; S. Ma et al., 2024). Conceptually, core strength training is an exercise that targets strength and stability in the body's core region. This involves building strength in the core muscles, improving core stability, and enhancing balance and control during movement, all aligned with the demands of sport-specific performance (Bliven & Anderson, 2013; Hibbs et al., 2008).

Core strength training focuses on athletic training methods that train the overall stabilising musculature at high thresholds and overloads, which results in muscle hypertrophy to accommodate overload training (Cotton, 2005). The National Strength and Conditioning Association (NSCA) provides a similar commentary. According to

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the NSCA, core strength is required for the performance of almost all sports, and for most sports, the level of core strength capacity largely determines how well an athlete performs (Willardson, 2024).

Fundamentally, core strength training trains the human locomotor chain and its associated parts to achieve specific target movements. To enhance multidimensional movement capabilities such as acceleration, deceleration, and stability control to meet the demands of different athletic tasks. The core strength training movement pattern involves acceleration, deceleration and stabilisation movements across multiple joints and planes. Its structure determines the training methodology's broad applicability and a high degree of sport specificity (Luo et al., 2022; S. Ma et al., 2024).

2.4.2 Physical Fitness

Physical fitness is one of the most critical factors in the overall structure of athletes' athletic ability and is the basis for other elements of athletic ability (Yan, 2013). It is widely recognised in research that physical fitness can be divided into two main categories (Jarani et al., 2016; Utesch et al., 2018): health-related physical fitness and motor-skill-related physical fitness. (1) Health-related physical fitness includes characteristics strongly associated with health outcomes, such as body composition, cardiovascular endurance, flexibility, muscular strength, and endurance (Denysschen et al., 2021; Gula, 2024; Milne et al., 2016). (2) Motor skill-related physical fitness includes those components of ability that enhance athletic performance, such as strength, speed, agility, coordination, balance, and reaction time (Asinyo & Smits-Engelsman, 2021; Farhat et al., 2024; Smits-Engelsman et al., 2020; Smits-Engelsman et al., 2021). The requirements for these physical fitness components vary from sport

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to sport. For example, tennis players must demonstrate high levels of agility and speed during competition, while hockey players rely on these qualities for optimal performance. Based on the established literature, the physical fitness components selected for this study that apply to youth hockey players include strength, power, speed, agility, flexibility, and endurance. These concepts are further explained in the following sections.

2.4.2.1 Strength

Strength is the foundation of all athletic performance; for hockey players, strength capacity is a crucial fitness factor (Suchomel et al., 2016; Yan, 2013). Hockey is a sport that requires athletes to hold a stick and score through techniques such as stopping, dribbling, passing, shooting, and defending. Athletes need to possess essential strength to perform various running movements and specialised strength to perform a variety of complex technical movements (Lord et al., 2022; Mitchell-Taverner, 2005; Timmerman et al., 2019). In competition, athletes are often required to perform technical movements in an unstable state, and athletes with high levels of strength can generate incredible speed when passing and shooting and have a tremendous advantage against their opponents (Haff & Triplett, 2015; Suchomel et al., 2016).

The complexity of the field hockey technique requires that the athlete's body parts work together through coordination to complete the movement, as well as a solid foundation of strength (Yan, 2013). For hockey players, strength is vital in the upper body, enabling powerful hits, shots, and long passes (Manna et al., 2010). The core is a crucial conduit for force transmission between the lower and upper limbs, facilitating

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explosive actions such as passing and shooting (Bostancı & Özdal, 2021). A strong core ensures postural stability, minimizes energy dissipation, and enables more efficient force application during upper-body movements. Moreover, core strength training that targets both slow-twitch (Type I) and fast-twitch (Type II) muscle fibers enhances force production, stability, and power transfer. Training muscles like the rectus abdominis and external obliques—which contain both fiber types—supports the explosive rotational movements essential in field hockey. Additionally, strengthening the transverse abdominis and multifidus, which are primarily composed of Type I fibers, improves postural stability and effective force transfer (Vincent & Vincent, 2018). Therefore, a comprehensive core strength training program is indispensable for field hockey players aiming to optimize upper-body explosiveness, precision, and overall game performance (Ma et al., 2024).

In lacrosse, the effective execution of multiple movements often requires athletes to adopt a semi-squat or lunge position, which places a high demand on lower body and core strength (Murtaugh, 2009). Similarly, the overhead squat (OHS) is a demanding compound exercise that significantly enhances core strength and stability, which is crucial for hockey players. The movement requires sustained isometric contractions of the rectus abdominis, transverse abdominis, and obliques to maintain spinal alignment and resist tilting forces throughout the squat (Bautista et al., 2020; Roth et al., 2020). It also strengthens deep stabilizers such as the multifidus and erector spinae, improving trunk control during high-speed actions, sudden stops, and directional changes (Oshikawa et al., 2021; Roth et al., 2020). Furthermore, by placing the barbell far from the body's center of mass, OHS enhances anti-rotational and anti-lateral flexion control, promoting postural balance, stick control accuracy, and fluidity of

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movement in hockey (Jothilingam, 2024). Frequent running, acceleration, and changes in direction are everyday movements in hockey, all of which rely on the athlete's maximum strength (Manna et al., 2011). Therefore, to achieve an elite level of performance in hockey, athletes must possess extremely high levels of strength, particularly in lower body strength (Sharma & Kailashiya, 2017; Sharma & Kailashiya, 2018). The effectiveness of strength gains depends on several factors, including specific muscle movements, training intensity, volume, exercise selection, training sequence, rest periods between sets, and training frequency. Regardless of the muscle group, the one-repetition maximum test remains a reliable measure of strength levels (Grgic et al., 2020; McBurnie et al., 2019; Seo et al., 2015).

2.4.2.2 Power

Power refers to speed power, which is one of the fundamental qualities of many sports and refers to the combination of strength and speed necessary for an athlete to complete a movement at a high speed in each athletic situation (Sandler, 2005; Stone et al., 2022; Trinschek et al., 2020). Power is a crucial determinant of athlete performance in hockey, especially when performing high-speed and high-intensity athletic tasks. Every hockey movement, such as initiating a sprint, making a sharp stop, changing direction, and hitting and passing the ball, depends on an athlete's explosive power (Lythe & Kilding, 2011; Naicker, 2014; Twist, 2007).

During a game, athletes must accelerate quickly or start suddenly from a standstill, which places extreme demands on the explosive power of the lower limbs (Vescovi, 2016). Additionally, sharp stops and direction changes are frequent manoeuvres that athletes need to perform quickly, and the key to success is strong lower body and core

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explosiveness (Haff & Triplett, 2015; Murtaugh, 2009). Explosive strength affects an athlete's ability to perform high-intensity movements quickly and largely determines the stroke's and pass's effectiveness. When striking the ball, athletes need to transfer power from the lower limbs and core to the upper limbs quickly to ensure the stroke's speed and accuracy, making explosive strength the foundation for the efficiency of technical movements (Bloomfield et al., 2007; S. Ma et al., 2024).

Notably, core strength training can significantly enhance explosive power by improving kinetic chain efficiency, neuromuscular coordination, and force transfer between the upper and lower body (Shinkle et al., 2012). A strong and stable core acts as a central conduit for the transmission of force during high-intensity movements such as jumping, throwing, and sprinting (Bora & Dağlıoğlu, 2022). When the core is properly conditioned, it reduces energy leakage during the initiation of explosive actions and allows for greater force output from the limbs (Zemková, 2022). Moreover, core exercises that emphasize rapid contraction and stabilization—such as medicine ball slams, rotational throws, or dynamic planks—activate type II muscle fibers, which are essential for explosive performance (Brittenham & Taylor, 2014). These adaptations improve the rate of force development (RFD) and overall muscular power output, both of which are critical in sports requiring rapid acceleration, jumping, and powerful changes of direction (Maffiuletti et al., 2016).

2.4.2.3 Speed

Research has shown that developing sprinting speed requires not only powerful lower limbs but also a highly efficient and stable core, which plays a critical role in optimizing sprint mechanics (Horníková & Zemková, 2024). Core strength training

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enhances force transmission, postural alignment, and neuromuscular efficiency during high-speed movements (Mossa, 2022). By stabilizing the torso and reducing unwanted trunk motion, a strong core allows more of the force generated by the legs to be directed into forward propulsion. Improved lumbopelvic control also supports optimal hip and knee joint positioning, contributing to longer strides and reduced ground contact time (Aslan & Kahraman, 2023; Sato & Mokha, 2009). Furthermore, enhanced intermuscular coordination leads to quicker and more synchronized muscle activation during both acceleration and maximal sprint phases (Donaldson et al., 2022). These physiological adaptations improve overall running economy and sprint performance, particularly in high-intensity sports such as hockey.

Importantly, speed ability has been widely recognised as a crucial factor in team sports (Asadi et al., 2016; Spiteri et al., 2015). In hockey, speed is one of the critical factors that significantly impacts the game's outcome. Research has shown that elite-level hockey players spend approximately 10-15% of their game time on high-intensity activities, including sprinting and rapid acceleration, with the time spent on these activities varying depending on the player's position (Vescovi, 2016).

Speed in hockey is the ability to run in a straight line. It includes rapid acceleration, changing direction skills, and maintaining high speeds during sprints and transitions. Fast acceleration can give athletes a positional advantage when chasing the ball, blocking opponents, or initiating an attack, often determining the outcome of one-on-one confrontations (Lythe & Kilding, 2011). In addition, speed plays a crucial role in the transition between attack and defence, where quick transitions can catch opponents off guard and create a numerical advantage on the field (White & Wells, 2013).

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Therefore, speed is not just a reflection of running ability but also includes acceleration, agility, and the ability to sustain high-intensity endeavour throughout the game. Hockey players need to improve their overall performance and game efficiency.

2.4.2.4 Endurance

Endurance is an essential element of fitness, and a vital component of a hockey player's physical fitness is a prerequisite for success in the sport (Georgieva & Kotsev, 2016). Endurance involves the athlete's ability to sustain high-intensity exercise over an extended period and maintain precision and speed of movement throughout the game. In hockey, athletes must run 8 to 10 kilometres throughout the game, including multiple high-intensity sprints of 5 to 20 meters (Lythe & Kilding, 2011; Vescovi, 2016). These high-intensity sprint events place extreme demands on the athletes' aerobic and anaerobic endurance. During a race, athletes' average heart rates typically remain above 80% of their maximal heart rates, indicating a constant state of highly competitive load (Lythe & Kilding, 2011; Vescovi, 2016).

In the later stages of the competition, athletes with insufficient endurance may experience movement distortion, decreased speed, and even a decrease in the quality of technical movement completion. In contrast, athletes with good endurance can perform efficiently at critical game moments, thus gaining an advantage over fierce competition. Therefore, the quality of endurance is crucial to the success of hockey players. It not only affects their performance in the game but also determines the outcome of the game to a large extent.

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Notably, core strength training, while traditionally associated with improving stability and movement efficiency, can also contribute significantly to cardiovascular fitness through several physiological mechanisms(Praveen & Mathavan, 2012; Shamsoddini et al., 2018). Dynamic core exercises—particularly those involving compound movements and larger muscle groups, such as medicine ball throws, rotational lifts, or high-repetition plank variations—elevate heart rate and increase energy expenditure, which can stimulate cardiovascular adaptations over time (Praveen & Mathavan, 2012). When integrated into circuit-style formats core strength training enhances oxygen utilization, stroke volume, and circulatory efficiency, ultimately improving aerobic capacity and cardiovascular endurance (Demir & Serin, 2023). These adaptations are particularly relevant for athletes in intermittent high-speed sports like field hockey, where sustained cardiovascular efficiency supports repeated sprint and recovery demands.

2.4.2.5 Agility

Agility refers to an athlete's ability to change the direction and position of the body quickly and efficiently during movement, which is particularly important when dealing with rapidly changing situations in a game (Sheppard & Young, 2006). In hockey, athletes need to be able to start, stop, and change direction quickly, an essential element in achieving a high level of performance (Krause & Hillmann, 2021). According to Yan (2013), excellent agility in hockey players is critical to improving multi-directional movement and is necessary to escape from defences and shoot quickly. Agility also lays the foundation for the innovation of technical movements, and athletes with higher agility tend to promptly adjust their body postures at critical moments, thus increasing the shooting success rate (Young et al., 2022). In addition,

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excellent agility can also reduce the risk of sports injuries during intense competition, enhancing athletes' competitive abilities (Yan, 2013). Therefore, agility is crucial to hockey players' success and is a critical ability for achieving a perfect combination of overall technical and physical performance.

In addition, core strength training improves agility by improving postural stability, neuromuscular coordination, and efficiency of force transfer, all of which are critical for rapid directional changes, acceleration, and deceleration in dynamic sports such as Invasive team sports (Afyon et al., 2017). A well-developed core stabilizes the pelvis and spine, allowing for more controlled and efficient limb movements during multi-directional tasks (Shetty et al., 2023). Enhanced core strength reduces unwanted trunk sway and improves reactive balance, allowing athletes to transition between movements with greater speed and precision (Rodríguez et al., 2023). Additionally, core strength training improves muscular coordination between the trunk and lower extremities, facilitating faster ground reaction times and more efficient energy transfer during cutting, rotation, and lateral movement. Together, these adaptations enhance an athlete’s ability to perform explosive and agile movements under competitive conditions (Luo et al., 2022).

2.4.2.6 Flexibility

Flexibility is vital to enhancing player performance. It is reflected in the effective use of joints and muscles during movement and the ability to remain coordinated and flexible across different ranges of movement (Bogalho et al., 2022). Stretching techniques can be categorised as static, elastic, and assisted. Static and elastic stretches are controlled autonomously by the athlete. In contrast, assisted stretches rely on

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external forces to help accomplish them (Arntz et al., 2023). For hockey players, a lack of flexibility may lead to joint stiffness, which limits the range of motion and affects the coordination of movements and quality of technical performance. In addition, lack of flexibility increases the risk of sports injuries. Therefore, maintaining good flexibility improves the quality of technical movements and prevents injuries (Yan, 2013).

Given the importance of flexibility in performance and injury prevention, it is valuable to explore how specific training interventions, such as core strength training, may contribute to improvements in flexibility through targeted physiological mechanisms (Kumar & Zemková, 2022). Core strength training, while primarily designed to enhance stability and postural control, also plays a significant role in improving flexibility through multiple physiological mechanisms (Yakut & Talu, 2021). Many core exercises, particularly those involving dynamic rotational and multi-directional movements (e.g., torso twists, side bends, controlled leg raises), help to increase the range of motion in the spine, hips, and shoulders (Guo, 2022). A well-conditioned core also promotes optimal postural alignment and muscle balance, which reduces compensatory tension in surrounding areas such as the hip flexors and lower back (Kim & Yim, 2020). Moreover, regular core training enhances neuromuscular efficiency and muscle elasticity, thereby reducing stiffness and improving the body's ability to move fluidly. Functional exercises that combine strength with active stretching—such as those found in Pilates or dynamic planking routines—further contribute to greater flexibility and joint mobility, which are critical for injury prevention and performance efficiency in sport-specific movements (Oliver & Blair, 2010).

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2.4.3 Field Hockey Skills

In field hockey, players' technical performance relies on their ability to make quick and correct decisions in a changing environment. This involves the flexible application of learned skills and the effective organisation and execution of technical movements to ensure efficient operations in the game (Abernethy, 1996; Brocken et al., 2020). Hockey skills encompass a variety of skills, such as dribbling, passing, shooting, pulling, ball control and catching that are critical to the successful execution of the game (Anders & Myers, 2008; Mitchell-Taverner, 2005).

The basic skills of field hockey include superb dribbling, effective passing, skilful pulling and accurate shooting, which athletes master through a combination of static and dynamic movements. These form the basis of an athlete's ability to excel in the game. A brief description of the nature and characteristics of these skills follows.

2.4.3.1 Dribbling

In field hockey, an essential skill is the ability of the player to control the ball while moving, often referred to as dribbling (Timmerman et al., 2019). Dribbling focuses on stick handling while moving, like carrying the ball in football or basketball. Dribbling aims to move away from defenders on the field and into open areas to maintain possession while creating space and scoring opportunities for teammates. Beating defenders by dribbling in the attacking area near the opponent's goal can lead to a numerical advantage, which increases the likelihood of scoring goals (Anders & Myers, 2008; Keogh et al., 2003).

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Building on this, core strength training has been identified as a critical factor in improving dribbling performance in field hockey by enhancing the functional capacity of key muscle groups responsible for trunk stabilization, dynamic balance, and upper–lower body coordination (Zemková & Zapletalová, 2022). Specifically, strengthening the transverse abdominis, multifidus, and internal and external obliques—muscles rich in type I fibers that support sustained postural control—enables athletes to maintain a stable torso while executing rapid hand and stick movements (Clark, 2018). At the same time, the recruitment of type II fibers in the rectus abdominis and erector spinae enhances the player's ability to initiate and regulate swift trunk rotations and directional changes required during complex dribbling maneuvers (Sasaki et al., 2019).

Furthermore, improved neuromuscular coordination between the core and extremities contributes to more synchronized limb and trunk movements, thereby reducing unnecessary body sway and enabling more precise stick handling (Ma et al., 2024). In addition, enhanced core stability promotes more effective proprioceptive feedback, which is essential for responding quickly to external stimuli such as defensive pressure (Borghuis et al., 2008). Taken together, these physiological adaptations foster more stable, agile, and efficient dribbling performance under dynamic, game-like conditions.

2.4.3.2 Pulling

One-meter in-situ pulling is an essential technique commonly used in hockey, which serves to help players quickly adjust the ball's position in a small space and break through the opponent's defence, thus creating favourable conditions for the next pass or shot (*China Field Hockey Federation*, 2024). Hockey is a sport that requires a high degree of skill and teamwork, and the one-meter pull is an essential movement in

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hockey technique and one of the techniques often used in the game. This movement requires athletes to keep the ball under their control through quick and precise movements in a limited space while avoiding being robbed by the opponent. The one-meter pull is not only a test of individual skill but also a test of reaction speed and strategy. In the game, the success or failure of the 1-meter pull directly impacts the team's attacking efficiency and scoring ability. Therefore, the 1-meter pull technique is one of the basic skills that hockey players must master (*China Field Hockey Federation*, 2024). Given its technical and tactical significance, it is essential to explore the physical components—particularly core strength—that support the effective execution of this movement.

Core strength training enhances this technical ability by improving trunk stability, anti-rotational control, and neuromuscular coordination (Zemková & Zapletalová, 2022). During the pulling movement, the player’s trunk must remain stable while the upper limbs perform fast and precise stick maneuvers. This stability is primarily provided by deep core muscles such as the transverse abdominis, multifidus, and internal and external obliques, which counteract excessive torso movement and enable better postural alignment (Borghuis et al., 2008). Additional research shows that core muscle training significantly improves neuromuscular control of the lower limb and trunk, enhancing movement mechanics during sport-specific tasks (Sasaki et al., 2019).

The effectiveness of the one-meter pull depends not only on upper limb dexterity but also on the athlete’s ability to stabilize the torso and maintain equilibrium under high-speed, close-contact conditions. Core strength training enhances the coordination between the trunk and limbs by improving segmental control, which enables players to separate upper-body movement from lower-body balance (Bliven & Anderson, 2013). This is particularly important in confined spaces where players must shift the ball laterally while keeping the body centered and resisting defensive contact. Exercises involving multi-planar core engagement—such as anti-rotation holds, dynamic plank variations, and medicine ball throws—train the body to generate and control rotational forces without compromising stability (Teixeira et al., 2019). These adaptations improve motor control, reaction efficiency, and ball-handling precision, all of which are essential for successful execution of the one-meter pull in high-pressure game scenarios (Jeong et al., 2021).

2.4.3.3 Passing

The good passing technique requires players to purposefully control the ball within a defined range of motion to articulate better the following technical action: the link and bridge to achieve tactics, organisation and coordination. It is also an essential skill in hockey (Anders & Myers, 2008; Huo et al., 2016). Chai & He (2023) emphasise that passing is not only the starting point of the attack but also the critical control point of the whole game tempo. Even if an individual has excellent dribbling skills, implementing the overall tactics will be hindered by a lack of practical passing ability, which may lead to the team losing control of the situation on the court. Successful passes directly impact the game's direction: accurate passes can quickly create scoring opportunities, while mistakes can allow opponents to counterattack (Chai & He, 2023).

Fluctuations in passing success rates at high levels of play are closely related to a team's tactical style and game pressure. Research shows that the passing success rate

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of elite-level hockey teams is usually between 70%-80%, which directly affects the team's possession of the ball, the rhythm of the attack, and the effectiveness of the overall tactical execution. Excellent passing can help the team better organise the attack and break through the opponent's defence, thus gaining an advantage in the game (Lord et al., 2022). Therefore, the importance of passing technique lies in the fact that it is not just an essential skill but a core element that determines the game's direction and the team's success or failure.

Notably, core strength training significantly enhances this process by improving trunk stabilization, force transmission, and kinetic chain coordination. A strong and stable core minimizes energy leakage during the pass, allowing players to generate greater stick speed and directional accuracy. For instance, weight-supported kinetic chain resistance training has been shown to improve proximal core endurance and trunk-to-arm power, which directly enhances movement speed and control in sports like softball (Palmer & McCabe, 2023). Similarly, core training enhances neuromuscular efficiency throughout the kinetic chain, optimizing load transfer and dynamic stabilization during sport-specific actions (Seid, 2022). During passing—especially push and slap passes—muscles such as the transverse abdominis, obliques, and erector spinae actively stabilize the spine and pelvis, enabling more controlled and powerful upper limb actions (Akuthota et al., 2008; Seid, 2022).

Moreover, core training enhances dynamic postural control, allowing athletes to maintain balance while executing passes under pressure or in motion. It also improves proximal-to-distal sequencing, a key motor control strategy in which force is efficiently transferred from the core (proximal segment) to the arm and stick (distal

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segment). This results in more fluid and precise passing technique, especially in fast-paced or rotational scenarios commonly encountered in match play. Evidence from studies on female athletes shows that core-muscle training improves trunk control and reduces energy loss during dynamic movement tasks like landing and passing, suggesting its importance in maintaining stability and accuracy during motion (Sasaki et al., 2019). Additionally, improvements in proprioception and upper limb control following core training further demonstrate the kinetic chain benefits on distal athletic actions (Luo et al., 2022).

2.4.3.4 Shooting Accuracy

Shooting accuracy is one of the primary skills determining success in the sport (Hidayat et al., 2024; Pavlů et al., 2021). Shooting is one of the most important hockey skills. A player's strength, speed and maximum power directly impact the shot's effectiveness (Cavaco et al., 2014). To improve the shooting technique, it is necessary to practice the skill repeatedly and build muscle strength, speed, and endurance (Pojskic et al., 2018). Even though the target position in hockey is fixed, the target is often missed due to the attacker's immense pressure before the shot. The success of the shot is dependent mainly on the player's timing and positional choice.

In their study, Keogh et al. (2003) developed a hockey test designed to assess the speed and accuracy of the shot. The test measured ball speed through a pushing technique and evaluated the accuracy of pushing and hitting shots at five locations in the goal area. Studies have shown that elite university players have significantly better shot accuracy than club players (Manaf et al., 2021).

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Although shooting accuracy in field hockey is influenced by multiple factors such as visual perception, stick mechanics, and decision-making, core strength training provides a specific and measurable contribution by enhancing the physical foundations of shooting performance (Ma et al., 2024). In particular, it improves trunk stability, rotational power, and proximal-to-distal force transmission, all of which are critical for generating shot velocity and maintaining accuracy (Bostancı & Özdal, 2021). During slap shots or drag flicks, athletes must coordinate lower-body force, trunk rotation, and upper-limb control in a single explosive action (Luo et al., 2022). Core muscles such as the obliques, transverse abdominis, rectus abdominis, and erector spinae are central to stabilizing the torso, generating torque, and maintaining postural alignment, especially during dynamic or off-balance positions commonly seen in match play (Hassan et al., 2023).

Moreover, enhanced core strength contributes to greater neuromuscular coordination and movement efficiency, facilitating better synchronization between trunk rotation and stick release mechanics (Bostancı & Özdal, 2021; Xue, 2024). This leads to more fluid motion, reduced energy leakage, and ultimately improved shot consistency and control (Hassan et al., 2023). While shooting accuracy involves various technical and perceptual components, the unique role of core strength lies in its ability to stabilize the body, optimize kinetic transfer, and reduce technical variability (Badr, 2019; Ma et al., 2024)—thus offering a clear and evidence-based pathway through which core training supports shooting performance (Bostancı & Özdal, 2021).

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2.4.4 Field Hockey Players

field hockey player is an athlete who participates in hockey games and practices. Hockey is a team sport, usually played on grass or artificial turf. Players play with a curved stick, which must not exceed 95cm long. During the game, the player can control the ball using only the flat side of the stick, controlling a ball that weighs about 160 grams and has a circumference of about 23.5cm (Chaudhary et al., 2021; *China Field Hockey Federation*, 2024). Hockey players' responsibilities are not limited to a specific role of attacking or defending. Still, they need to switch flexibly during the game depending on the situation on the field and participate in several technical actions such as passing, dribbling, shooting, stealing, and blocking to contribute to the team's overall strategy. For this study, 'junior men's hockey players' refers to individuals who have participated in formal training for at least two years, from 2021 to 2023.

Adolescents are generally defined as those between the ages of 10 and 19, while 'youth' refers to those between the ages of 15 and 24 (Sawyer et al., 2018). The World Health Organization (WHO) provides this generic definition and states that the group of young people includes everyone between the ages of 10 and 24. These definitions are adapted from study to study or organisation to organisation. For example, the U.S. Department of Health and Human Services defines the range of adolescents as 10 to 19 years of age, but in other government statistics, the range of adolescents may extend to 12 to 17 or 15 to 19 years of age (Kinghorn et al., 2018; Patton et al., 2016).

Although there have been previous classifications of adolescent age, many things could still be improved in defining teenage age. However, most early studies on youth

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hockey players typically selected athletes in the 14 to 18-year-old age group (Barboza et al., 2019; Furlong & Rolle, 2018; Mason et al., 2021). In addition, this study determined the age range of youth male hockey players based on the regulations of youth hockey tournaments on the website of the Handicap Baseball and Softball Sports Administration Centre of the General Administration of Sport of China and the China Hockey Association. The study defined the age of young male hockey players as 15-17 years old.

2.5 Effects of Exercise Training on Physical Fitness and Skills among Field Hockey Players

The researcher conducted a comprehensive assessment of the effectiveness of fitness and motor skill training in hockey players, systematically reviewing several studies to examine the effects of different training methods on fitness levels and skills in hockey players. Male and female athletes aged between 13 and 27 years were covered in this assessment. The study's outcomes were evaluated using predefined inclusion and exclusion criteria outlined in the document, which can be found in Appendix O, along with Figures 1, Table 1, and Table 2. A total of 10 studies were included in the selected studies, including randomised controlled trials (RCTs) and non-randomised controlled trials (non-RCTs). The review results revealed the following gaps in investigating multisport training for fitness and skills in hockey players: (1) intervention and (2) outcome measure gaps.

2.5.1 Interventions Gaps

It was found that different athletic training methods significantly affected the physical performance of hockey players. Specifically, various training techniques affected

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athletes' physical performance. These methods include sprint interval training, such as uphill and flat sprints (Taylor & Jakeman, 2022), high-intensity interval training (Chapman et al., 2009; Elumalai et al., 2020; Quezada-Muñoz et al., 2021), plyometric training (Sener et al., 2021; Singh et al., 2018), and uphill sprint training (Jakeman et al., 2016). In addition, hockey-specific training (Spencer et al., 2004) and sprint strength and agility training (Sharma & Kailashiya, 2018) have also positively affected fitness improvement.

Whilst several studies have shown that short-term training can help to improve player performance, evidence on its long-term effects in 12-week interventions remains limited (Boraczyński et al., 2023; Silva et al., 2015). Core strength training has received much attention in sports science but has yet to be sufficiently investigated in field hockey-related literature. However, it has many applications in other sports and has reported a significant improvement (Bora & Dağlıoğlu, 2022; Jeong et al., 2021; Thompson, 2017; Yang et al., 2022). Therefore, it is imperative to examine further the profound effects of core strength training on hockey players' physical and technical abilities. This can provide a more solid basis for the overall development of athletes and help to optimise the training program to enhance competitive performance.

2.5.2 Outcome Gaps

Physical fitness test results have centred around speed, agility, and body composition, which are among the most common characteristics of the performance of hockey players in athletic training interventions (Jothilingam & Murugan, 2024; Sharma & Kailashiya, 2018). However, research on technical skills such as shooting, dribbling, and passing remains limited (see Appendix O). Only three articles on skills mentioned

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these skills (Jakeman et al., 2016; Quezada-Muñoz et al., 2021; Subijana et al., 2012), of which only one specifically reported on shooting accuracy (Quezada-Muñoz et al., 2021), while the other two dealt with dribbling (Jakeman et al., 2016; Quezada-Muñoz et al., 2021). Nonetheless, critical aspects of hockey performance, such as endurance, flexibility and strength, must be explored in depth. Strength and explosiveness play a crucial role in the game, especially in sprinting and effective execution of ball control skills (Manna et al., 2011; Oja, 2014).

Through the summary and induction of existing literature, few studies on field hockey players have combined physical fitness and skills to evaluate overall sports performance. More importantly, physical fitness and skills must be excellent to cultivate excellent hockey players. Therefore, when assessing the physical fitness of hockey players, the six factors of speed, strength, explosive power, agility, endurance, and flexibility are essential, fully reflecting athletes' physical quality (Naicker, 2014; Twist, 2007). However, there is still a lack of systematic and comprehensive evaluation of these physical fitness elements and specific skills (such as dribbling, passing, shooting, and pulling the ball) (Kumari, 2023; Mitchell-Taverner, 2005). Therefore, research should further explore the interaction of these factors to optimise training plans and more effectively cultivate well-rounded hockey players.

2.6 Effect of Core Strength Training on Physical Fitness among Players in Sports

To evaluate the effects of core strength training on athletes' physical fitness, the researcher conducted a systematic review to examine the specific effects of such training on physical performance. The validity of the results was ensured by setting

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inclusion and exclusion criteria. The systematic review analysed 12 relevant literature, including randomised controlled trials (RCTs) and non-RCT studies, to explore the effects of core strength training on athletes' physical performance. This review was submitted to Plos One Journal in August 2024 and is currently under review (see Appendix O, Figure 2, Table 1, and Table 3 for details). The systematic review results identified research gaps in core strength training for athletes' physical fitness, population, and outcome measure gaps. The gaps are listed below:

2.6.1 Population Gaps

The review revealed that the population characteristics of the 12 included studies were based on the following (refer to Appendix O, Table 2): (1) Classification of athletes. Of the included literature, two studies did not report athlete categorisation (Kumar & Zemková, 2022; Lu et al., 2022). However, only beginners were reported in them, whereas 10 articles covered athlete types, including basketball players (Feng et al., 2024; Li, 2022; Yılmaz, 2022), football players (Mossa, 2022), handball players (Bauer & Muehlbauer, 2022), sport dancers (Yue, 2022), javelin throwers (Yang et al., 2022), martial arts players (Li & Du, 2022), badminton players (Ozmen & Aydogmus, 2016) and karate players (Kabadayı et al., 2022). However, out of twelve studies, six reported athletes as adolescents (Bauer & Muehlbauer, 2022; Feng et al., 2024; Kabadayı et al., 2022; Kumar & Zemková, 2022; Mossa, 2022; Yılmaz, 2022).

Based on the systematic review results, the researchers found a need for research on core strength training for elite field hockey players in the current literature. This research gap suggests that despite the widespread positive effects of core strength on sports performance, research on field hockey continues. This sport requires extremely

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high overall physical fitness but needs improvement. Elite Chinese field hockey players are often at a performance disadvantage when competing with international competitors (such as Asian powerhouses). Due to field hockey's high physical fitness requirements, such as speed, strength, agility, and endurance, the lack of research on core strength training for elite athletes may hinder the further optimisation of training methods. However, core strength training has been shown to improve the physical fitness of athletes in other sports significantly, so introducing it into the training of elite field hockey players may fill the gap in the current training system and enhance the competitiveness of athletes in competitions.

2.6.2 Outcome Gaps

In the included studies, physical fitness assessments for core strength training focused on speed, endurance, power, explosiveness, agility, and flexibility (see Appendix O). It should be emphasised that different athletes have different physical fitness needs, so selecting appropriate measures when assessing their fitness is essential. These six critical components can measure the physical fitness of hockey players as they adequately reflect the overall fitness level of the athlete (Bashir et al., 2024; Chiarlitti et al., 2018; Motte et al., 2019). In the included studies, the focus of the physical fitness outcome measures of core strength training was speed, endurance, strength, agility, and flexibility (see Appendix O). It should be emphasised that different athletes have different physical fitness needs, so it is crucial to choose appropriate measurement methods when evaluating their physical fitness. However, when assessing the physical fitness level of field hockey players, strength, power, speed, endurance, agility, and flexibility can be measured because these six physical fitness fully reflect the overall physical fitness level (Bashir et al., 2024; Naicker, 2014; Razali et al., 2017).

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It should be noted that only one article reported on college athletes among the included studies. This article only focused on measuring speed, endurance, strength, and flexibility and lacked the measurement of other physical qualities. Therefore, studying young male hockey players' six essential physical fitness elements is imperative.

2.7 Effect of Core Training on Skill Performance among Athletes

Based on a previous systematic literature review by Luo et al. (2022), it was found that in a systematic review of the literature related to core training and motor skill performance, researchers systematically assessed the effects of core training on athlete performance through specific inclusion and exclusion criteria. The review included 16 papers covering randomised controlled trials (RCTs) and non-randomised controlled studies. This systematic review was published in the June 2022 issue of (Frontiers in Physiology) (see Appendix O). Based on previous studies, the researchers conducted a systematic keyword search in five major databases (EBSCOhost, Scopus, PubMed, Web of Science, and Google Scholar), focusing on relevant literature published between June 2022 and 2024. After rigorous screening, five new articles closely related to the research topic were finally identified. To better present these studies, the researchers used the PICO framework (problem, intervention, control, outcome) to summarise the literature. The main contents of these five articles will be discussed in detail in the following paragraphs, and a theoretical basis and new research directions for subsequent research will be provided. The systematic review results identified (i) population and (ii) outcome measure gaps in research on the effect of core training on athlete skill performance.

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2.7.1 Population Gaps

The review found that the demographic characteristics of the 21 included studies were reported according to the following aspects (see Appendix O): (1) Categorisation of athletes. All the 21 included studies reported the classification of athletes, including football players (Ahmed et al., 2022; Bavli & Koç, 2018; Mahmoud, 2018; Mahmoud, 2021; Mossa, 2022), handball players (Akçinar & Macit, 2020; Mahmoud, 2021; Manchado et al., 2017), basketball players (Doğan & Savaş, 2021; Feng et al., 2024; Gong et al., 2024; Şahiner & Koca, 2021; Suveren et al., 2024), swimmers (Patil et al., 2014), dancers (Watson et al., 2017), karate players (Kamal, 2015), Muay Thai boxers (Lee & McGill, 2017), gymnasts (Abuwarda, 2014), volleyball players (Yapıcı, 2019), badminton players (Hassan, 2017), tennis players (Huang et al., 2023) and golfers (Weston et al., 2013). Although core training significantly affects athlete skill performance, none of the 22 existing studies involved hockey players, indicating a research gap in this area. Hockey is a sport that requires highly high skills. Athletes must have excellent ball control skills during the game and continuous dribbling, passing, shooting, and defence in high-intensity confrontations. Core training has effectively improved athlete skill performance in other sports. Introducing it into hockey training may compensate for the existing system's shortcomings and enhance athletes' combat competitiveness.

2.7.2 Outcome Gaps

A systematic review of the effects of core training on athletes' skills (see Appendix O) led to the following conclusions: four of the 21 published papers were on passing skills (Akçinar & Macit, 2020; Bavli & Koç, 2018; Doğan & Savaş, 2021; Mahmoud, 2018), five on dribbling skills (Akçinar & Macit, 2020; Bavli & Koç, 2018; Doğan & Savaş, 2021; Feng et al., 2024; Mahmoud, 2018), and five articles on shooting techniques (Akçinar & Macit, 2020; Bavli & Koç, 2018; Doğan & Savaş, 2021; Mahmoud, 2018; Yapıcı, 2019). None of the studies reported on hockey players. However, the importance of hockey as one of the top six sports in the world cannot be overstated (Mohan & Rajeswaran, 2019).

In the included studies, the skill assessment of core training mainly focused on passing, dribbling, and shooting. However, according to the literature review, the researchers found that no research specifically focuses on core training for field hockey players. As one of the six major sports in the world, the importance of field hockey cannot be ignored (Mohan & Rajeswaran, 2019). In a high-intensity competition, field hockey players must have various superb skills, including passing, dribbling, shooting, hitting, pulling, trapping, and catching (Mitchell-Taverner, 2005). These skills have a direct impact on the outcome of the game. Therefore, it is necessary to explore the effect of core training on the skill performance of hockey players. Such research will not only help optimise the training program but also enhance the competitiveness of athletes in high-level competitions.

2.8 Theoretical and Conceptual Framework

This part introduces the theoretical framework and conceptual framework.

2.8.1 Theoretical Framework

A dichotomous model in athletic performance and physical fitness distinguishes between core stability and strength (Hibbs et al., 2008). Core stability, achieved

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through non-weight-bearing and static slow-motion exercises, is associated with increased muscular endurance and overall stability. There is no conclusive evidence that it directly improves athletic performance; however, it significantly reduces the risk of injury.

On the other hand, core strength training characterised by high-load, dynamic patterns promotes muscle hypertrophy, enhances neural activation of motor units and significantly improves muscular strength, core strength and sport performance indices, particularly speed, agility, and power (Hibbs et al., 2008). The theoretical framework emphasises the inherent benefits of core strength training. Still, it acknowledges the limitations of its applicability, focusing primarily on speed, agility, and power, which still need to be applied to technical performance. Nonetheless, the model elucidates the profound impact of core stability and core strength in the domain of skill performance (Reed et al., 2012).

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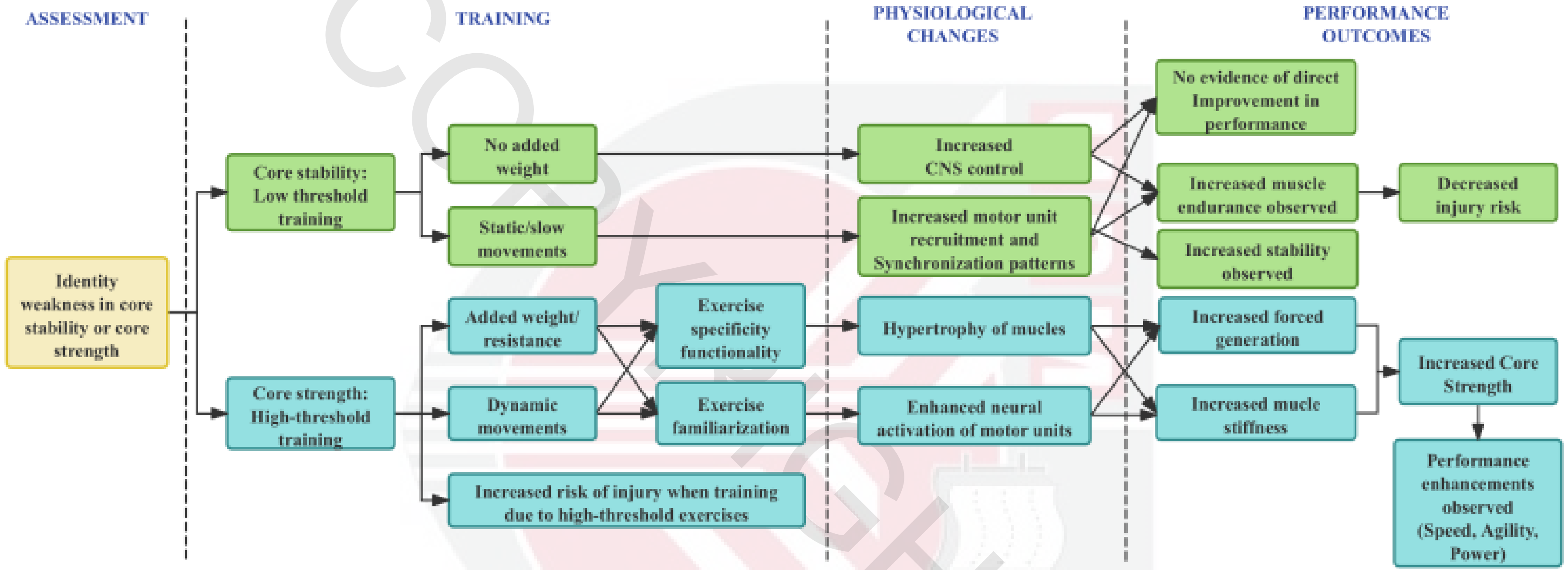

Figure 2.1 : Theoretical Framework
(Hibbs et al., 2008)

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2.8.2 Conceptual Framework

Numerous studies have confirmed the widespread use and effectiveness of the core training model introduced by Hibbs 2008 in various sports, improving athletes' fitness and skill performance. The model has been applied in golf, karate, basketball, handball, and football (Doğan & Savaş, 2021; Kamal, 2015; Mahmoud, 2021; Weston et al., 2013). However, its application in hockey is still limited. To address this gap, the theoretical contribution of this study lies in the novel affirmation of core training theory by introducing core strength training into a Chinese youth hockey program. In this way, this study aims to emphasise the effectiveness and importance of core strength training.

This study's independent variables were core strength training and standard exercise routines. In contrast, the dependent variables were the selected physical fitness variables (strength, power, speed, agility, endurance, and flexibility) and hockey skill (dribbling, shooting accuracy, passing, and pulling), which are essential for hockey players. The conceptual framework of the variables in this experimental study is shown in Figure 2.2, which briefly describes the intervention treatment of core strength training. At the same time, the control group received standard training without additional intervention. They all underwent 36 sessions of 60 minutes each for 12 weeks, three times a week.

In addition, although early studies have shown that core strength training is efficacious in improving the physical performance of athletes in basketball and football (Prieske et al., 2016; Sannicandro et al., 2020; Yılmaz, 2022), research on hockey still needs

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to be done. For this reason, the present study focused on analysing the effects of core strength training on adolescent male field hockey players' physical fitness and skill performance to provide more targeted guidance for future training.

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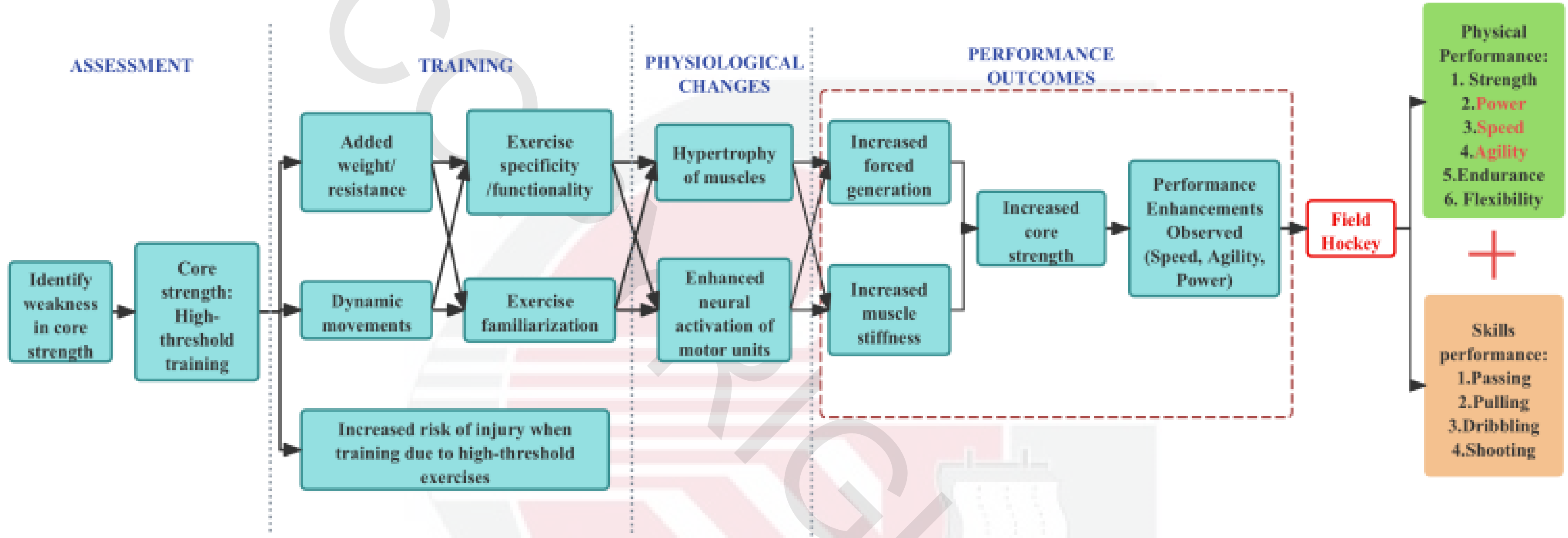

Figure 2.2 : Conceptual Framework
Indicate in the figure above is the Hibbs Model (Hibbs et al., 2008)

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CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This study aimed to determine the effects of a 12-week core strength training programme on the performance of Chinese youth male field hockey players. This chapter describes the research design, the study site, the selection of variables and tests, the experimental design, the pilot study, the control of extraneous variables, the implementation of the training programmes, the collection of data, and the statistical techniques used in the analysis of the data.

3.2 Research Design

This study adopted a true experimental pre-test–post-test design utilizing a Cluster-Randomized Controlled Trial (CRCT) framework, in which entire groups (clusters) rather than individual participants were randomly assigned to either the intervention or control condition (Brown et al., 2015). Cluster randomization was employed to ensure baseline equivalence between groups and to minimize selection bias. To control for extraneous variables, standardized protocols for training, testing, and data collection were implemented, with the core strength training intervention administered exclusively to the experimental group. A three-phase measurement schedule—comprising pre-test, mid-test (week six), and post-test (week twelve)—was used to monitor performance changes over time. Collectively, these design features supported the establishment of a causal relationship between core strength training and observed improvements in physical fitness and sport-specific skill performance, thereby strengthening the internal validity and methodological rigor of the study (Brown et al., 2015).

This study used different regions in Gansu Province, China, as randomized units. Initially, four regions with sports schools specializing in field hockey were selected: Lanzhou, Jiayuguan, Linxia, and Baiyin. Subsequently, a randomization process was applied to select two regions for the study. As a result, Lanzhou was designated as the experimental group (CSTG), while Linxia was assigned as the control group (CTG). The two regions were separated by 150 kilometres, effectively reducing communication between participants and preventing intervention “contamination” (Cuzick et al., 1997) . Cluster randomisation is the only reasonable design approach to assess the effects of core strength training on physical fitness and skill performance in youth field hockey players. In this study, athletes were randomly assigned to different training sites, and the experiment was conducted for three months, three times per week for one hour per session (total of 3 hours), which consisted of 1.5 hours of skill training and 1.5 hours of strength training. The skill training content was the same in both groups, with the difference being that the strength training in the experimental group included a core strength intervention.

In contrast, the CTG conducted standard training. The primary dependent variables were physical fitness (strength, power, speed, endurance, agility, flexibility) and skill performance (dribbling, shooting, passing and pulling). During the intervention period, the variables were measured at pre-test, post-test 1 after six weeks, and post-test 2 after 12 weeks to observe the differences between the experimental and control groups. In addition, this study was registered and approved at ClinicalTrials.gov (ID: NCT06297889, Appendix E), and the associated experimental design and framework

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are shown in Figure 3.1.

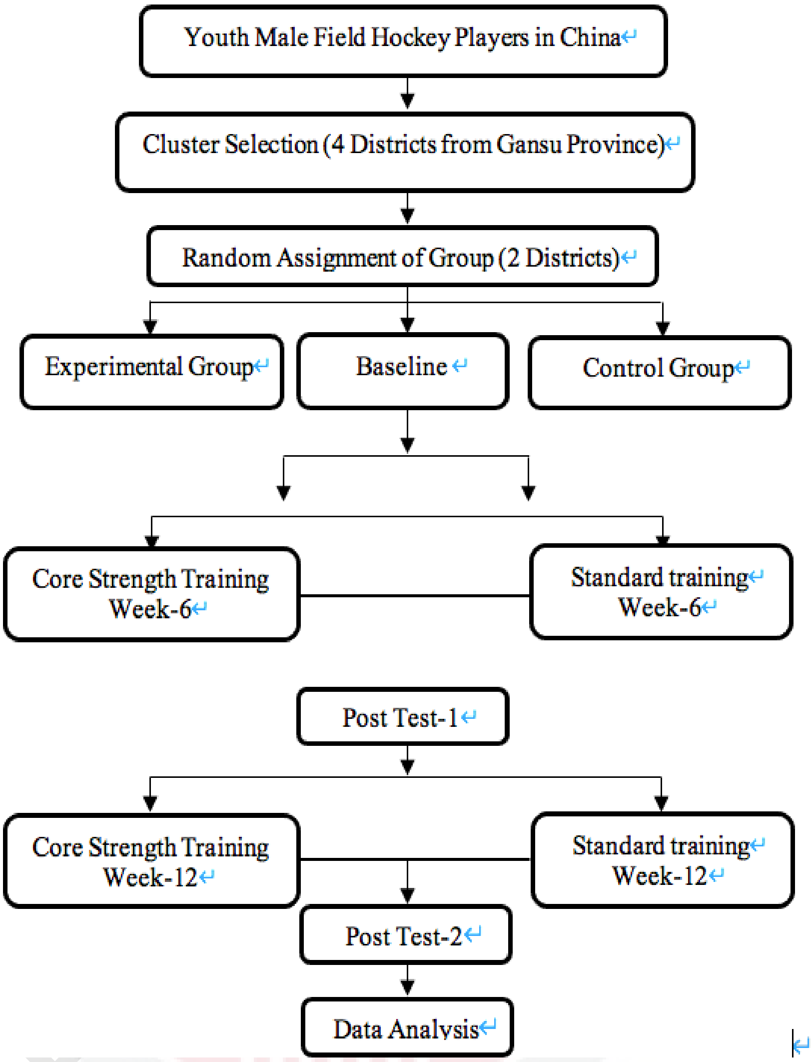

Figure 3.1 : Research Framework

3.3 Location of the Study

This study was conducted in Lanzhou and Linxia, Gansu Province, China. The region was chosen because Gansu Province is the reserve training base for Chinese national hockey. Many eligible adolescent male hockey players received full-time training in the area. Using the fishbowl method, the researchers randomly selected two sites in the region as the experimental group and the control group. The coaches in the chosen areas are all coaches of provincial and municipal sports school professional teams with rich coaching experience. They have been selected for the national team, proving their high performance in the competitive field. After their professional athlete career ended, the two coaches have long focused on coaching youth field hockey teams and accumulated profound teaching experience and practical skills. The experimental group (EG) and the control group (CG) coaches have more than ten years of experience as professional team athletes. After finishing their professional athletic career, they obtained senior coach qualification certificates, ensuring their professionalism and consistency in training design and technical guidance. This provides a reliable and fair experimental environment for this study, which helps to ensure the scientificity and credibility of the research results.

Figure 3.2 : Experimental Location
(Sources : https://en.wikipedia.org/wiki/Gansu)

3.4 Population and Sampling Method

This section mainly includes population and sampling, sample size, criteria for the participants, and sampling process.

3.4.1 Population and Sampling

This study's target population was adolescent male field hockey players aged 15-17 in Gansu Province, China. The experimental and control groups comprised healthy adolescent male field hockey players. Participants with a history of sports injury or a history of receiving treatment were excluded because their experimental data might contaminate the comprehensive empirical data. Therefore, only healthy adolescent male field hockey players were selected for this study.

3.4.2 Sample Size

GPower 3.1 software was used to calculate the sample size for this study. Before calculating the sample size, the effect sizes for the interventions in this study were based on previous research (Appendix B). The researcher chose the smallest effect size (0.23) for speed performance (Fernández-Fernández et al., 2015). This study involved two groups with three repeated tests. An F-test ANOVA involving repeated measures within interactions was chosen to calculate the sample size. In addition, type error I (αerr prob) was 0.05, and efficacy (1-βerr prob) was 0.8 and was calculated using three measurements for both groups (Tomczak & Tomczak, 2014). Based on the selection process, the sample size was estimated to be 32 participants, with 16 in each group. The sample size calculation is shown in Figure 3.3.

Equation 1:

$$DE= 1+p\ (M-1)$$

$$DE=1+0.01= (16-1) =1.15$$

Equation 2:

$$ESS= DE*MK$$

In this equation, ‘m’ represents the number of individuals in each cluster and ‘k’ represents the total number of participants in the entire cluster study. Effective sample size (ESS) was calculated by considering the design effect (DE), which is the effect of cluster design on sample size estimation, and p, which represents the intracultural correlation coefficient (ICC), which is used to measure the degree of similarity within a cluster (Killip et al., 2004). Based on these components, the study's final effective sample size is calculated accordingly:

$$ESS= 1.15*32=36.8$$

Figure 3.3 : The Equation for Calculating Sample Size

A dropout rate of 30% of the total sample size was adhered to based on differences in groups, training modalities, and training volume and intensity (Hecksteden et al., 2018). Therefore, an additional 11 participants were added to the initial participants to ensure the completeness of the sample size. To further improve the sample’s representativeness, it was decided to add 12 participants for a final sample total of 48 participants. An experimental group (EG, n=24) and a control group (CTG, n=24) were used to ensure that the groups were balanced in training and assessment.

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3.4.3 Criteria for Participants

All 48 participants were full-time youth hockey players from sports schools in two different regions. The researchers recruited volunteers from the two schools' youth men's hockey teams based on pre-set criteria. To ensure the breadth and representativeness of the study, the researchers invited all youth hockey players from the two schools to participate in the experiment. After screening, 24 volunteers from the Gansu Sports School were assigned to the experimental group (EG). In comparison, 24 volunteers from the Linxia Sports School were assigned to the control group (CG), thus ensuring the balance of the two groups in terms of number distribution and providing a scientific basis for the comparability of the experimental design.

3.4.3.1 Inclusion Criteria

The participants were healthy youth field hockey players with at least two years of standardised training experience but had yet to receive core strength training in the past two years. They lived in Gansu Province and had medical insurance. One week before the start of the study, participants were centrally placed at the National Hockey Training Base in Gansu Province, China, for pre-study assessment. This study established strict inclusion and exclusion criteria for participants to ensure the consistency of study participant characteristics and limit recruitment to the target group.

The Inclusion criteria for potential participants were as follows:

1. Youth male field hockey players aged from 15 to 17.

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2. Reside in Lanzhou and Linxia City, Gansu Province
3. Healthy
4. Participation in this study was predicated on the participant's apparent willingness to participate and ability to complete all required tests.
5. Two years of training experience
6. Participants were physically active but had no experience with core strength training.

3.4.3.2 Exclusion Criteria

The exclusion criteria for potential participants were as follows:

1. The participation of those on medication may affect body composition and muscle activity, like Diabetes Mellitus.
2. The participant is currently participating in regular resistance training.
3. Players with recent (less than one year) sports injuries, such as ankle or various arthritis and back injuries, are excluded.
4. Players at risk of discontinuing hockey training due to unpredictable circumstances were excluded from the study.

3.4.4 Sampling Process

This study was a CRCT with clusters rather than individuals in Gansu Province, China, as the randomisation unit. Four important regions in Gansu Province were considered for inclusion in the cluster selection process. Among them, two areas (Lanzhou and Linxia) were randomly selected, and the functional training group (CSTG) and control group (CTG) were selected using the fishbowl method. Sixty young male field hockey players from the two regions were screened for this study. Twelve participants who

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did not meet the criteria were excluded from the screening process; five were unable to participate due to injuries, and another seven refused to participate due to conflicts with the national team training schedule. Finally, 48 eligible participants were assigned to the CSTG group (n=24) or the CTG group (n=24). All participants signed an informed consent form (IFC), agreeing to participate in the study voluntarily and deciding to strictly adhere to the training intervention protocol throughout the 12 weeks. Finally, 48 complete data sets were ultimately collected for analysis (Figure 3.4).

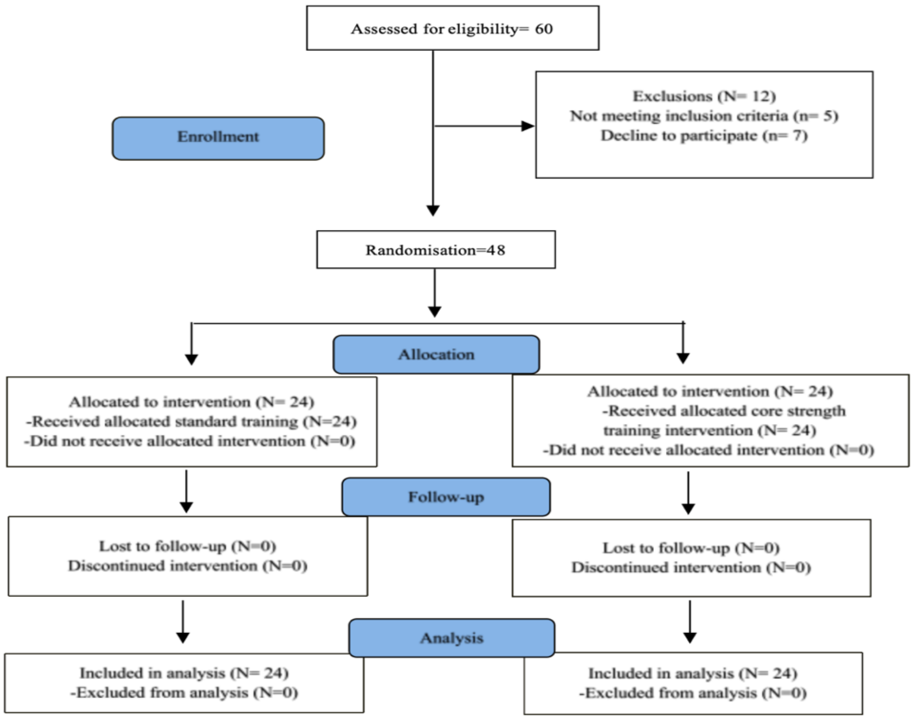

Figure 3.4 : Consort Table
(Source : Moher et al., 2012)

3.5 Study Instruments

The primary instrument used in this study was a field experiment, which was chosen because it is more environmentally friendly. The tools used in the experiment consisted of three categories: the first was a training tool used in a core strength training program, the second was a tool used to measure the demographic characteristics of the participants, and the third was a tool used to measure the dependent variable of this study. These tools were carefully designed and selected to ensure the accuracy of data collection and reproducibility of the study.

3.5.1 Instruments Used in Core Strength Training Program

Core strength training usually involves a variety of equipment, and the correct selection of equipment is critical to ensuring the success of the intervention. According to Willardson (2024), the equipment used in core strength training includes (1) dumbbells, (2) barbell plates, (3) AB wheels, (4) fitness balls, (5) stability balls, and (6) yoga mats. Willardson pointed out in the book "Developing the Core (NSCA Sports Performance)" that this equipment can help enhance the core muscles' strength and stability, especially for improving sports performance (Willardson, 2024). Based on this theory, this study designed a core strength training intervention program and used equipment configuration consistent with expert recommendations. For detailed information on the specific intervention equipment and procedures, please refer to Appendix D.

3.5.2 Instruments Used to Measure Demographic Characteristics

Before and after the intervention plan, researchers conducted detailed measurements of the participants' height and weight. During the measurements, participants were required to empty their bladders and avoid eating within four hours before the test. Height was recorded using a portable stadiometer, ensuring the head was aligned with the Frankfurt plane while the tester gently extended the chin to ensure spinal

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elongation before recording the height (Louer et al., 2017). Weight was measured using an electronic scale, and participants were instructed to be barefoot during the process (Casadei & Kiel, 2019).

3.5.3 Instruments Used to Measuring Dependent Variables

The dependent variable instruments for this study included physical fitness and skills.

3.5.3.1 Instruments Used to Measuring Physical Fitness Variables

This study used a field test instrument specialising in evaluating physical fitness and testing parameters. All physical fitness test items were designed according to the standards of the Chinese Hockey Association Hockey Players' Physical Fitness and Skills Test Evaluation Manual (Chinese Hockey Association). Subsequent items from related literature were introduced in this study to enhance the comprehensiveness of the test. The specific tests covered strength (PU: push-up; SU: sit-up; BS: back squat), power (GB: gravity ball; SLJ: standing long jump), speed (25 yards; 50 yards), endurance (300-yard shuttle run), agility (AR: arrowhead run), and flexibility (SAR: sit and reach). Specific test methods and instrumentation are shown in Table 3.1. For the specific operation process, see Appendix I Table.

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Table 3.1 : Instruments Used to Measure Physical Fitness Variables

Variables	Measurement method	Instruments	Reference
Strength	PU	Yoga mat, stopwatch	(China Hockey Association, 2013; Yan, 2013)
	SU	Yoga mat, stopwatch	(China Hockey Association, 2013; Yan, 2013)
	BS	A barbell, weight plates, and a power rack	(China Hockey Association, 2013; Yan, 2013)
Power	GB	2kg medicine ball, tape measure, marking bucket	(China Hockey Association, 2013; Yan, 2013)
	SLJ	Tape measure, marking line	(China Hockey Association, 2013; Yan, 2013)
Speed	25 yards	Electronic timer, bunting	(China Hockey Association, 2013; Yan, 2013)
	50 yards	Electronic timer, bunting	(China Hockey Association, 2013; Yan, 2013)
Endurance	300 yards	Electronic timer, bunting	(China Hockey Association, 2013; Yan, 2013)
Agility	ART	Stopwatches, signposts, sign barrels, arrow signs	(China Hockey Association, 2013; Yan, 2013)
Flexibility	SART	Sit and reach test box	(Rajan & Ahamed Faiz, 2018)

3.5.3.2 Instruments Used to Measuring Field Hockey Skills Variables

The field hockey skills assessment consists of the following tasks: The Slalom Dribble Test (SDT) and the Shooting Accuracy Test (SA), the Passing Test (PT), and the One-Meter Pull Test (OMPT) to assess field hockey skills(Anders & Myers, 2008; Keogh et al., 2003; Lemmink et al., 2004). The specific test methods and instruments are shown in Table 3.2. The procedure is shown in Appendix I Table.

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Table 3.2 : Instruments Used to Measure Field Hockey Skills Variables

Variables	Measurement method	Instruments	Reference
Dribbling	SDT	Hockey; sticks; hockey rinks; cones; stopwatches; laptops and video cameras	Keogh et al., 2003
Shooting accuracy	SAT	Hockey sticks; hockey rinks; goals; measures; score sheets; laptops and video cameras	Lemmink et al., 2004
Passing test	PT	Hockey; Sticks; Score sheets and Logo buckets	Anders & Myers, 2008
Pulling Tests	OMPT	Hockey; sticks; marking buckets; stopwatches and score sheets	China Hockey Association, 2013

3.6 Validation of Methods

During the study, it was crucial to ensure the validity of the data collection procedures (Mokkink et al., 2010). To this end, the expert team scrutinised and assessed the methodology's surface and content validity.

3.6.1 Face Validity

Surface validity is an approach to validity assessment that seeks to confirm that a measurement instrument conforms to the apparent logic of the intended concept (Kemper, 2022). Although it provides an initial judgment of validity, there are better ways to assess validity than this. Therefore, content validity is more critical to determine whether the research instrument comprehensively covers all aspects of the concepts and variables under study. In this study, face validity was assessed by a committee of experts after the research instrument was identified. The members of the expert committee, who were senior experts in the field of study, reviewed the tools in detail and provided specific feedback. In addition, all of the instruments used in the study have demonstrated good validity in previous studies, especially the physical

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fitness testing protocol, based on the recommendations of the Chinese Hockey Association and the Hockey Skills Assessment Program combined with those selected by several researchers (Anders & Myers, 2008; Keogh et al., 2003; Lemmink, 2004).

3.6.2 Content Validity

Content validity is usually verified for applicability through assessment by a panel of experts or scholars (Beckstead, 2009). Although the size of an expert panel is not strictly defined, between three and ten experts are usually involved (Lynn, 1986). In this study, six experts in the field assessed the content validity of the intervention and research instrument. The assessment utilised a five-point Likert scale (1=Strongly Disagree, 2=Disagree, 3=Unsure, 4=Agree, and 5=Strongly Agree), and a questionnaire was designed to collect their opinions (see Appendix F and G). In addition, the questionnaire contained open-ended questions for experts to make suggestions for further improvement of the intervention and research tools.

The effectiveness of the developed tool's content was analysed using the Item Content Validity Index (I-CVI). For each program, the I-CVI was calculated by dividing the number of experts rated the item as 3 or 4 by the total number of experts. To assess the correlation, the Kappa Modified Coefficient was employed(Polit et al., 2007). Furthermore, Lynn's (1986) I-CVI criteria were applied (I-CVI=1 for 3-5 experts and ≥0.78 for 6-10 experts). Fleiss' (1981) Kappa was also used, where values above 0.75 indicated excellent agreement, 0.40 to 0.75 signified fair to good, and below 0.40 was poor(Fleiss et al., 1981; Lynn, 1986). Elements with I-CVI values below 0.78 were either modified or excluded based on the input of seven experts. The test program's content validity was determined qualitatively and quantitatively by six experts, whose

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information is provided in Appendix H, Table 1. Clarity agreements for the intervention items are displayed in Appendix N, Table 1 and Table 2, showing acceptable content validity (physical fitness: I-CVI=0.833-1.000, Kappa=0.816-1.000; field hockey skills: I-CVI=0.833-1.000, Kappa=0.816-1.000). This suggests that the test program exhibited strong content validity.

3.7 Intervention

The intervention program was developed based on research on Developing the Core (Willardson, 2024). A panel of experts examined the effectiveness of the intervention program protocol. The following discussion expands on the design of the core strength training intervention and program and its effectiveness.

3.7.1 Design of the Core Strength Training Intervention

To develop a core strength training program for adolescent male field hockey players, this study is based on Frequency, Intensity, Time, and Type (FITT) principles to ensure that the training process effectively improves the athletes' fitness and skill levels. Applying the FITT principles aims to scientifically optimise the training parameters to adapt to the specific needs of adolescent athletes to achieve the best training results in a limited period. FITT Through systematic design and individualised adjustments, this training program seeks to enhance the athlete's core strength, thereby improving overall performance in competition.

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3.7.1.1 Frequency, Length and Time

Based on a systematic review of the effects of core training on athletes' physical fitness and skills (Luo et al., 2022), this study determined the training frequency and duration and decided to adopt a training program of three times a week, 60 minutes each time, for 12 weeks. Several studies have shown that this training frequency and duration can significantly improve athletes' strength, speed, agility, and explosive power (Feng et al., 2024; Kumar & Zemková, 2022; Li, 2022; Lu et al., 2022; Yang et al., 2022). Therefore, combined with the existing literature, this study rationally selected a 12-week training cycle to ensure the effectiveness of training on physical fitness and skill development.

Research has shown that regular core strength training enhances athletes' core muscle groups, thereby improving their performance in competition (Abuwarda, 2014; Liu et al., 2022). In addition, a training frequency of three times per week can ensure adequate strength while avoiding the physical burden of overtraining. This scientific training schedule is consistent with the FITT principle and maximises the enhancement effect of core strength training on youth field hockey players.

3.7.1.2 Loads and Intensities

This study's training load and intensity design was based on four training phases.

1. **Basic Training Phase**

   During the initial training phase, the focus is on establishing a basic core strength foundation for the athlete and improving trunk stability. The core goal of this phase is to help athletes progressively adapt to the core muscles through low-intensity core stabilisation exercises to ensure that they can

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perform basic locomotor movements with proper posture (Martuscello et al., 2013; Prieske et al., 2016). Willardson (2007) suggests that this training phase could use bodyweight exercises and isometric contraction training to enhance trunk stability, typically using Three to five sets of 15 to 20 repetitions, each with 60-second recovery intervals. This training design is effective in helping athletes establish initial control and stability over fundamental movements, ensuring a solid foundation for subsequent higher-intensity training (Willardson, 2007).

2. **Intermediate Training Phase**

As training progresses, the focus gradually shifts to muscular endurance improvement, explicitly working on core strength in more complex and challenging environments (Kumar & Zemková, 2022; Li, 2022). According to Willardson's (2024) recommendations, more dynamic exercises should be incorporated to develop muscular endurance further. Athletes can gain significant endurance through body weight and low-intensity weight training (Willardson, 2024). The training intensity can be set at around 20 repetitions per set, divided into three to five sets, with a recovery time of 60 to 90 seconds between each set. Research has shown that a light-load, high-repetition training pattern (more than 15 repetitions per set with loads of less than 60-65% of 1RM) can effectively improve localised muscular endurance (Haff & Triplett, 2015).

3. **Advanced Training Phase**

This training phase introduces higher-intensity core strength exercises and complicates movement patterns to optimise core strength use and delivery (Liu et al., 2022). At this point, muscle growth and strength gains are maximised. Some early research suggests that moderate repetitions (8-12 reps per set) with moderate loads (60%-80% of 1RM) optimally promote muscle hypertrophic growth, whereas low repetitions with high loads (1-5 reps per set, 80%-100% of 1RM) contribute more to strength gains (Haff & Triplett, 2015). However, additional research has shown that muscle growth is significantly increased when using eight repetitions per set with a load of

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80% of 1RM (Hirono et al., 2022).

4. Strengthening and Consolidation Phase

During this training phase, the focus is on utilising the muscular strength developed in the previous phases to further build the athlete's explosive power. Willardson (2024) mentions that during high intensity loading workouts (loads of 80-100% of 1RM), up to five sets of one to five repetitions should be maintained with a rest period of 120 to 180 seconds between sets. Additionally, lower-intensity explosive strength training, such as medicine ball throwing, can be increased in repetitions by performing three sets of ten repetitions each, with a rest period between sets of approximately 90 seconds to 150 seconds (Willardson, 2024).

3.7.2 Core Strength Training Programme

This study's core strength training program draws on the ice hockey training protocol presented by Jeffrey M. Willardson in Developing the Core (NSCA Sports Performance) (Willardson, 2024). As team sports, ice hockey and field hockey have much in common regarding primary goals and tactics to defeat opponents, primarily through offence, such as putting the puck in the opposing team's goal. Both sports contain similar vital elements such as player positional distribution (forwards, midfielders, defenders, and goalkeepers) and core skills (passing, shooting, and dribbling) (McMorris & Hale, 2012; Williams et al., 2003; Yard & Comstock, 2006). Based on these commonalities, the present study designed a field hockey training program inspired by existing hockey training models, a core strength training program consisting of systematic, progressive exercises to improve fitness and performance.

During the intervention period, the control group (CTG) performed a conventional training regime (i.e., standard training) three times per week throughout the

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experimental period; after the study, they were provided with the same training program and equipment as the experimental group (CSTG). For the CTG, the training program focused on single-joint strength training and weighted resistance training. The main phase lasted 60 minutes and 12 weeks (Appendix D; Table 2). The core strength training program for the experimental group (CSTG) consisted of four distinct phases: the first phase is the primary training phase (3 weeks), the second phase is the intermediate training phase (3 weeks), and the third phase is the advanced training phase (3 weeks). The last phase is the consolidation and strengthening phase (3 weeks). The training frequency for each phase was 60 minutes three times per week. This training volume setting meets the criteria of most core strength training studies and allows for reasonable fitness and performance gains to be observed over 12 weeks. The exercise volume was gradually increased throughout the training program to ensure the athlete's core strength progress was reflected at each stage. The training program is listed in (Appendix D, Table 1)

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Table 3.3 : Information on Training Intervention for Two Groups

Training Section	Exercise		Length/ Frequency/ Time	Intensity	Rest (Reps/ Sets)	Sets/ Reps
	CSTG	CTG				
Warm Up (10 min)	Running and stretching exercises					
	*Swiss Ball Side Crunches *Swiss Ball Rotational Crunches *Supine Leg Swings *Plank *Hanging Knee Raise *Overhead Squat *Barbell Hip Lift	Standard training	12 weeks 3 times/week 60-min	Moderate to high (65-80 Hmax)	60s & 2 min	3 sets 10-20 reps
Cool Down (10 min)	Stretching exercises					

Not: CSTG, Core Strength Training Group; CTG, Control Training Group; Reps, Reptations; Min, Minute; S, Second

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3.7.3 Validity of Intervention

Six experts from the same culture as the target group confirmed intervention content validity through qualitative and quantitative assessments (see Table 3.4) for details of the experts. The results of the clarity consistency assessment of the intervention items are shown in Appendix N, Table 1, with all items achieving an acceptable range of content validity, reflecting a high level of clarity characterisation (I-CVI = 0.833-1.000, Kappa = 0.816-1.000).

Table 3.4 : Information of Experts for Content Validity Intervention and Instruments

Number	Name	Title	Area for research
1	Luo Shengyao	Associate. Professor	Sports training core training
2	Li Long	Associate. Professor	Core strength training
3	Wei Wei	Senior Coach	Exercise Training
4	Qin Chengxiu	Senior Coach	Exercise Training
5	He Changning	Intermediate Coach	Exercise Training
6	Yang peichun	Intermediate Coach	Exercise Training

3.8 Pilot Study

The researcher conducted a pilot study before the formal study to assess the study variables' reliability and the feasibility of the intervention program. The researcher confirmed that 20% of the primary sample size was selected as the appropriate sample size for the pilot study (Hertzog et al., 2008). The length of the pilot study was two weeks, and 16 youth field hockey players aged 15 to 17 years were recruited and randomly assigned to the CSTG (N=8) and the CTG (N=8). It is important to note that the intervention and testing procedures of the pilot study were identical to those of the formal trial, and the pilot study was designed to determine the applicability of the intervention program and testing protocol to adolescent male field hockey players. In

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addition, instruments were carefully evaluated and calibrated during the pilot study.

3.8.1 Reliability of the Methods

Reliability refers to the ability of a measurement tool to obtain consistent results in repeated operations (Bolarinwa, 2015). In social science research, there are usually three ways to assess reliability: test-retest reliability, alternative form reliability, and internal consistency reliability (Bolarinwa, 2015). In this study, the researchers used the test-retest method to assess the reliability of dependent variables such as physical fitness and field hockey skills. This is a simple and effective way to ensure consistency of results. According to Fleiss's classification criteria, the intraclass correlation coefficient (ICC) assesses reliability. ICC values exceeding 0.75 indicate "excellent" reliability, between 0.40 and 0.75 are "moderate to good" reliability, and below 0.40 is considered "poor" reliability (Rodrigues et al., 2019). The reliability of all measurement tools (n=16) in this study reached an acceptable level. The specific data are shown in Tables 1 to 2 in Appendix M.

3.8.1.1 Physical Fitness Variables

The selected physical fitness factors included strength (ICC=0.914-0.943), power (ICC=0.918-0.959), speed (ICC=0.898-0.903), endurance (ICC=0.900), agility (ICC=0.914-0.932), and flexibility (ICC=0.992). The test-retest reliability of physical fitness ranged from 0.898 to 0.992, thus confirming that the test protocol had high reliability and could accurately reflect the physical fitness level of the youth male field hockey players (see Appendix M Table 1 for details).

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Table 3.5 : Test-retest Reliability of Physical Fitness Instruments (n=16)

Variable	Measurement Method	Intra-class Correlation Coefficient	95% Confidence Interval	
			Lower Bound	Upper Bound
	Push-up	0.914	0.695	0.978
Strength	Sit-up	0.943	0.790	0.986
	Back squat	0.926	0.731	0.981
	Left gravity ball	0.918	0.706	0.979
power	Right gravity ball	0.921	0.714	0.980
	Standing long jump	0.959	0.845	0.990
Speed	25 yards	0.898	0.645	0.974
	50 yards	0.903	0.659	0.975
Endurance	300 yards	0.900	0.650	0.974
Agility	Left arrow run test	0.914	0.695	0.978
	Right arrow runs test	0.932	0.751	0.983
Flexibility	Sit and reach test	0.992	0.967	0.998

3.8.1.2 Field Hockey Skills Variables

The selected field hockey skills were dribbling speed (ICC = 0.860), shooting accuracy (ICC = 0.917), pulling the ball (ICC = 0.896), and passing (ICC = 0.960-0.975). Based on these values, the field hockey skills test procedure for on-pitch evaluation has moderate to high validity for assessing players' field hockey skills, and the tool can provide an objective diagnosis of the skill level of field hockey players (see Appendix M, Table 2 for details).

Table 3.6 : Test-retest Reliability of Hockey Skills Instruments (n=16)

Variable	Measurement Method	Intra-class Correlation Coefficient	95% Confidence Interval	
			Lower Bound	Upper Bound
Dribbling	Slalom dribble test	0.860	0.543	0.963
Pulling	One meter pull test	0.896	0.639	0.973
Passing	Forehand pass test	0.960	0.848	0.990
	Backhand pass test	0.975	0.902	0.994
Shooting	Shooting accuracy test	0.917	0.703	0.979

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3.9 Control of Extraneous Variables

Data collection for this study was accomplished primarily through field tests rather than laboratory tests. These tests were conducted in actual sports settings, such as stadiums or athletic fields, enhancing the sports program relevance of the test results. Since the tests were conducted in real-world scenarios, close planning and effective management were required to control extraneous variables, such as environmental factors, participants, preparation before applying the intervention, test protocols, scheduling, field conditions, and athlete fatigue, to ensure the validity of the test results. In addition, the test group should have a balanced distribution of participants regarding age, gender, performance level, physical activity level, weight, height, and sports experience. To avoid the influence of confounding factors, the study ensured that these potentially influential factors were reasonably controlled for among the participants through a more sophisticated approach to random allocation (Bhide et al., 2018).

3.9.1 Control of Environment Factor

This study involved training physical fitness and field hockey skills; all tests were field tests. It is important to note that environmental factors such as weather changes may impact test results, mainly when tests are conducted outdoors. Weather conditions such as rain, slippery or muddy roads, and temperature extremes may interfere with test accuracy and participants' training progress. To combat this, the research team set up similar practices and testing environments indoors, ensuring that the temperature was fixed and that the indoor conditions were controlled by air conditioning, a method approved by both groups of coaches. Barber-Westin et al. (2010) stated that tests

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should be conducted under similar conditions as much as possible to facilitate comparison of results. Therefore, this study paid particular attention to the effect of environmental conditions on test results and adjusted the rest periods in the external environment accordingly to ensure that environmental factors were reasonably controlled.

3.9.2 Control the Participants

During the experimental study, to minimise the impact on the participants due to their own growth or external interventions, participants in the experimental and control groups were explicitly told to refrain from other forms of exercise. They were also asked to refrain from obtaining help from outside professionals or referring to materials related to self-improvement of core strength. The purpose of this measure was to minimise the potential impact of non-experimental interventions on the results of the study, thus ensuring that the internal validity of the research and the validity of the experimental interventions were assured.

3.9.3 Control the Preparation of Participants before Tests

In the preparatory stage before the intervention, it is crucial to ensure that the coaches of the experimental group fully understand the training methods and test content. However, due to the experiment's long duration, the experimental group's coaches must become more familiar with core strength training. They may need help to continuously and effectively monitor the training progress or correct the participants' mistakes during the intervention. To this end, the researchers specially arranged four assistant coaches, two in the experimental and two in the control group. Assist in monitoring the implementation of the intervention program.

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Two weeks before the formal experiment, the researchers communicated in-depth with the coaching team and explained the core strength training, physical fitness test and hockey skill test in detail. The head coaches of the experimental and control groups have more than ten years of coaching experience, and the assistant coaches are retired professional field hockey players to ensure that they can fully understand and accurately implement the intervention content. In addition, the researchers asked the control group coaches to strictly follow the Standard training plan and not conduct systematic core strength training. This preparatory work ensured the smooth implementation of the experimental intervention and guaranteed the experimental results' effectiveness.

3.9.4 Control the Test Protocol

Standardisation of test protocols is one of the most critical factors in ensuring data accuracy during the testing process. Strict adherence to standardised procedures can lead to more reliable and valid results (Thompson et al., 2002). For example, during each testing session, the coaching team and participants must adhere to a prescribed number of attempts and recovery times to ensure consistency. In addition, the coaching team checks and calibrates all testing instruments to ensure the accuracy of the results. This standardised process provides reliable data support for the study.

3.10 Data Collection Procedures

The data collection process was divided into three main phases: (1) permit application, (2) pilot study, and (3) test implementation of the formal study. The relevant elements of the pilot study are described in detail in Section 3.8, and this section will focus on the permit application phase and the specific implementation steps of the formal data

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collection process.

3.10.1 Request for Permission

Before data collection, the Ethics Committee of Sichuan Nursing Vocational College (approval number: 2023006) reviewed and approved this study. The committee also approved the researchers' experimentation with the study participants at the National Field Hockey Training Base (Lanzhou and Linxia) in Gansu Province, China (see Appendix A).

3.10.2 Procedures of Testing

The testing procedure of this study was divided into three stages. The first stage was the pre-intervention preparation stage, during which the researchers explained in detail to the coaches and participants the 12-week core strength training, physical fitness tests, and hockey skills assessment process. This process ensured the coaches and participants fully understood the test requirements to reduce experimental bias caused by unclear communication. In addition, the researchers conducted basic measurements before the intervention and collected relevant data at this stage.

The second stage was the intervention implementation stage. The coach supervised the training process throughout the process. The researchers conducted post-test 1 and collected relevant data in the sixth week. The third stage was the data collection stage after the completion of the intervention. The researchers completed the data collection of post-test 2 after the 12-week intervention to evaluate the intervention effect.

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3.11 Data Analysis

This study used SPSS 26 to perform statistical processing on the experimental data, with a significance level of $p<0.05$. Descriptive analysis and conclusive analysis were mainly used for data analysis. Before data analysis, data cleaning and hypothesis testing were first performed. The researchers entered the data and performed quality control using descriptive techniques to identify potential data problems, including outliers, coding errors, and other inconsistencies. Quality control provides a basis for subsequent analysis and ensures the accuracy and reliability of the analysis results.

For inferential analysis, this study employed the Generalized Estimating Equations (GEE) model to evaluate the effeciveness of the intervention program on the dependent variables across three time points: baseline, week six, and week 12. GEE was chosen because it accounts for repeated measures, does not require normality assumptions, and models time, group, and interaction effects, making it suitable for longitudinal data analysis. It also handles data clustering by extending the logistic regression model, a common approach in cluster-randomized controlled trials (cRCTs). Within the GEE framework, Wald Chi-Square tests were used to assess statistical significance (Wang et al., 2022).

The analysis process was divided into two parts: (1) descriptive statistics were used to analyse the essential demographic characteristics of the participants, and (2) inferential statistics were used to test the hypotheses. This study used the generalised estimating equation (GEE) model to evaluate the effectiveness of the intervention program on the dependent variable. GEE handles the clustering problem of data by extending the logistic regression model, which is commonly used in the analysis of

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cRCT (Barker et al., 2016; Huang et al., 2016; Liu et al., 2019; Ma et al., 2013; McCaffrey & Bell, 2006). In addition, the effect size (d) was automatically calculated by SPSS and evaluated according to the criteria of Cohen (2013), specifically: d = 0.2 represents a small effect, d = 0.5 represents a medium effect, and d = 0.8 represents a large effect.

Table 3.7 : Research Hypotheses and Statistical Analysis

Hypothesis	Physical Fitness Variables	Analysis
H01.1a	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on push-ups of Chinese youth male field hockey players.	GEE
H01.1b	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on sit-ups of Chinese youth male field hockey players.	GEE
H01.1c	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on back squat of Chinese youth male field hockey players.	GEE
H01.2a	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on left gravity ball of Chinese youth male field hockey players.	GEE
H01.2b	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on right gravity ball of Chinese youth male field hockey players.	GEE
H01.2c	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on standing long jump of Chinese youth male field hockey players.	GEE
H01.3a	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on 25 yards of Chinese youth male field hockey players.	GEE
H01.3b	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on 50 yards of Chinese youth male field hockey players.	GEE
H01.4	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on 300-yards switchback run of Chinese youth male field hockey players.	GEE
H01.5a	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on left arrow run of Chinese youth male field hockey players.	GEE

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Table 3.7 : Continued

Hypothesis	Field Hockey Skills Variables	Analysis
H01.5b	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on right arrow run of Chinese youth male field hockey players.	GEE
H01.6	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on sit and reach of Chinese youth male field hockey players.	GEE
H02.1	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on dribble skills of Chinese youth male field hockey players.	GEE
H02.2	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on one meter pull skills of Chinese youth male field hockey players.	GEE
H02.3a	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on forehand pass skills of Chinese youth male field hockey players.	GEE
H02.3b	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on backhand pass skills of Chinese youth male field hockey players.	GEE
H02.4	There are no significant differences effect of 12 weeks core strength training across pretest, post-test 1, and post-test 2 on shooting accuracy skills of Chinese youth male field hockey players.	GEE

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CHAPTER 4

RESULTS

4.1 Introduction

This chapter introduces the effects of core strength training on Chinese youth male hockey players' physical fitness and hockey skills. The experimental process and results were tested according to the methods in Chapter Three. The main results were presented and organised to test the ten null hypotheses proposed in Chapter One.

4.2 Statistical Assumptions

This section evaluated the arithmetic expectation analysis of the data using various statistical tests. Different types of tests were used for quantitative and categorical data analysis. Parametric tests were used preferentially when the assumptions of normal distribution and homogeneity of variance were met. However, if the data did not meet these assumptions, nonparametric tests, especially the Mann-Whitney U test, were used to ensure the analysis's accuracy and the results' reliability.

This study employed the Generalized Estimating Equations (GEE) statistical method to analyze repeated measures data collected at baseline, week six, and week 12. While the dataset primarily consists of parametric data (ratio data with means), the Chi-Square test was used as part of the Wald Chi-Square statistic within the GEE framework to assess the significance of group, time, and interaction effects on dependent variables such as speed, strength, endurance, and field hockey skills performance. The use of Wald Chi-Square statistics in GEE is appropriate because GEE does not assume normality and instead uses robust standard errors, making it

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well-suited for analyzing repeated-measures data with potentially correlated responses (Ballinger, 2004). Although Chi-Square is typically applied to categorical data, its application in GEE allows for valid hypothesis testing without relying on normal distribution assumptions (Zeger & Liang, 1986). Additionally, while parametric tests such as t-tests and ANOVA were used where appropriate, Chi-Square tests were applied when analyzing categorical comparisons. The justification for using Chi-Square in this context ensures that the study maintains statistical rigor while appropriately handling repeated measures data (Hanley et al., 2003).

4.2.1 Normality Test

Before conducting inferential statistics, it is critical to investigate the normality of all variables. As Stevens (2002)described, normality tests can help determine whether parametric or nonparametric statistical methods should be used. If the data conforms to a normal distribution, parametric tests can be used; otherwise, nonparametric tests are a more appropriate choice. For this purpose, there are various methods for testing normality, such as the Shapiro-Wilk and Kolmogorov-Smirnov tests. In this study, the Shapiro-Wilk test was used to assess the normality of the data. The analysis indicated that demographic characteristics (e.g., height and weight), strength, speed, power, flexibility, and hockey skills (dribbling and pulling) followed a normal distribution ($p > 0.05$). However, age, training experience, endurance, agility, as well as passing and shooting skills, did not conform to a normal distribution ($p < 0.05$). For further details, refer to Appendix K, Tables 1-3.

Since some key performance variables did not meet the assumptions of normality, making non-parametric tests the more appropriate choice for these variables.Non-

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parametric methods were selected for several reasons: they effectively handle non-normally distributed data, ensuring statistical validity and accuracy; they are robust to outliers and small sample sizes, making them ideal for analyses where data variability is high; and they allow for flexible analysis of repeated measures. Specifically, this study used the Mann-Whitney U test for group comparisons where normality assumptions were violated, and the Generalized Estimating Equations (GEE) model with robust standard errors to handle longitudinal data without assuming normality (Ito & Sugasawa, 2023; Smeeton et al., 2025). This approach ensured statistically sound inferences while accommodating the distributional characteristics of the dataset.

4.2.2 Homogeneity Test of Variance

The assumption of homogeneity of variance is used to verify whether the variances between different groups are equal, which is an essential assumption for comparing differences between groups. Various methods can be used to assess this homogeneity, including Bartlett, Hartley, and Cochran tests. However, in statistical analysis software (such as SPSS), Levene's test is often used to assess the validity of this assumption (Gastwirth et al., 2009; Ujian et al., 2022). The Levene test results showed that each group's error variances were equal in the baseline phase, which met the assumption of homogeneity of variance. This verification step ensures that further inferential statistical analysis of differences between groups is statistically significant. For more information, see Appendix L, Tables 1-3.

4.3 Demographic Characteristics

Before data analysis, an independent sample T-test was used to assess whether the two groups' demographic characteristics of age, height, weight, and training experience

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were homogeneous. The test results for these variables showed that the core strength training group (CSTG) and the control group (CTG) did not show significant differences in age (t=-0.225, p=0.823), height (t=0.719, p=0.475), weight (t=0.306, p=0.761), and training experience (t=0.337, p=0.738). In other words, all groups showed consistency and homogeneity in demographic characteristics, ensuring the fairness and validity of the comparison between the groups. For more information, see Table 4.1.

Table 4.1 : Comparison between Groups for Demographic Variables

Variables	CSTG	CTG	t-value	P-value
	Mean (SD)	Mean (SD)		
Age (yr.)	15.958 (0.625)	16.000 (0.659)	-0.225	0.823
Height (cm)	173.125 (3.780)	173.875 (3.430)	-0.719	0.475
Weight (kg)	63.208 (5.217)	62.791 (4.170)	0.306	0.761
Experience	33.500 (4.978)	33.000 (5.308)	0.337	0.738

Noted: *p<0.05 level of significance; SD: standard deviation; CSTG: core strength training group; CTG: control group.

4.4 Comparing between CSTG and CTG for Dependent Variables at Baseline

Before conducting data analysis, it is usually necessary to evaluate the homogeneity assumption of each group on critical variables. To this end, this study used independent sample T-test to test the homogeneity of physical fitness (such as strength, PU: push-ups; SU: sit-ups; BS: barbell squat, power, GB: gravity ball; SLJ: standing long jump, speed, 25 yards; 50 yards, endurance, 300 yard shuttle run, agility, AR: arrow run; flexibility, SAR: sit-ups) and field hockey skills (dribbling, SDT: slalom dribbling test, pull, OMPT: one-meter pull, pass, PT: forehand pass; backhand pass, SAT: shooting accuracy test) variables. The analysis showed no significant difference in physical fitness and ice hockey skills variables between the two groups

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at baseline (p>0.05), indicating that the groups were homogeneous. This homogeneity ensures the scientificity and accuracy of the subsequent intervention effect analysis. For more information, please see Table 4.2.

Table 4.2 : Compare the Mean of Groups for Dependent Variables during Baseline

Variables		CSTG	CTG	t-value	P-value
		Mean (SD)	Mean (SD)		
	PU	47.875(1.895)	47.333(1.857)	1.000	0.323
Strength	SU	48.166(1.880)	48.250(1.594)	-0.166	0.869
	BS	76.458(7.868)	75.833 (6.197)	0.306	0.761
	LGB	10.623(1.004)	10.903(0.933)	-0.999	0.323
Power	RGB	11.112(0.816)	11.039(0.811)	0.314	0.755
	SLJ	248.250(4.928)	250.250(4.336)	-1.493	0.142
Speed	25 yards	3.859(0.066)	3.863(0.074)	-0.205	0.839
	50 yards	6.863(0.106)	6.822(0.120)	1.251	0.217
Endurance	300 yards	1.105(0.022)	1.102(0.015)	0.538	0.593
	LART	16.279(0.570)	15.971(0.553)	1.903	0.063
Agility	RART	13.163(0.960)	13.065(0.842)	0.379	0.707
Flexibility	SART	12.063(1.187)	12.217(1.040)	-0.478	0.635
Dribbling	SDT	25.354(0.867)	25.185(0.812)	0.697	0.489
Pulling	OMPT	130.583(10.479)	133.500(8.792)	-1.045	0.302
Passing	FPT	10.458(1.413)	11.041(1.301)	-1.487	0.144
	BPT	9.125(1.075)	8.708(1.732)	1.001	0.323
Shooting accuracy	SAT	2.625(1.172)	2.875(0.947)	-0.813	0.421

Noted: *p<0.05 level of significance; SD: standard deviation; PU: push-ups; SU: sit-ups; BS: barbell squat; LGB: Left gravity ball; RSGB: Right gravity ball; SLJ: standing long jump; LART: left arrow run test; RART: right arrow runs test; SART: sit and reach test; SDT: slalom dribble test; OMPT: one-meter pull test; FPT: forehand pass test; BPT: backhand pass test; SAT: shooting accuracy test.

4.5 Effects of Core Strength Training on Physical Fitness Variables

This section mainly analyses the six hypotheses (H01-H06) proposed for the first research objective. By using the generalised estimating equation (GEE) method, the effect of core strength training intervention on physical fitness changes of young male field hockey players were evaluated to determine whether each hypothesis should be accepted or rejected. This analysis aims to gain a deeper understanding of the actual

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effect of the intervention on physical fitness variables and provide data support for further research.

4.5.1 Strength

In the strength domain, the effects of the core strength training intervention were observed through three strength tests, namely push-ups (PU), sit-ups (SU), and squats (BS). Table 4.3 provides descriptive statistics for these variables, including each test's mean and standard deviation (SD). This will help evaluate the changes in strength before and after the intervention, thereby analysing the effects of core strength training.

Table 4.3 : Descriptive Statistics (Mean and SD) of Strength for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
PUT	CSTG	47.875(1.895)	49.041(2.136)	51.500(2.340)
	CG	47.333(1.857)	48.333(1.606)	48.750(1.750)
SUT	CSTG	48.166(1.880)	51.125(1.918)	54.125(1.361)
	CG	48.250(1.594)	48.541(1.587)	48.875(1.483)
BST	CSTG	76.458(7.868)	79.166(8.030)	87.083(8.189)
	CG	75.833 (6.19)	76.458(5.800)	80.833(6.702)

Noted: PUT: push ups test; SUT: sit ups test; BST: back squat test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *$p<0.05$ level of significance

Table 4.3 shows the descriptive statistics of the push-up (PU) variable at different time points for the core strength training group (CSTG) and the control group (CTG), covering three time periods: baseline, six weeks, and 12 weeks. Specifically, the baseline mean PU of the CSTG group was M=47.875 (SD = 1.895), which slightly increased to M=49.041 (SD = 2.136) at week six, and further increased to M=51.500 (SD = 2.340) at week 12. In contrast, the mean PU of the CTG group was M=47.333

(SD = 1.857) at baseline, which increased to M=48.333 (SD = 1.606) at week six and remained almost unchanged at M=48.750 (SD = 1.750) at week 12. The table provides details of the mean PU changes for both groups at these three-time points and their standard deviations, showing how the performance of the different groups has changed over time.

Table 4.3 shows the descriptive statistics of the sit-up (SU) variable for the core strength training group (CSTG) and the control group (CTG) at different time points, covering the changes in the data at baseline, six weeks, and 12 weeks. Specifically, the mean SU of the CSTG group at baseline was M = 48.166 (SD = 1.880), which increased to M = 51.125 (SD = 1.918) at week six and further increased to M = 54.125 (SD = 1.361) at week 12. In contrast, the mean SU of the CTG group at baseline was M = 48.250 (SD =1.594), which remained stable at M = 48.541 (SD=1.587) at week six and increased slightly to M = 48.875 (SD=1.483) at week 12. This table summarises the trends and standard deviations of the SU changes in the two groups at different time points, clearly reflecting the performance differences between the experimental and control groups in each period.

Table 4.3 shows the mean and standard deviation of the squat (BS) variable for the core strength training group (CSTG) and the control group (CTG) at baseline, week six, and week 12. The results show that the baseline mean of the CSTG was M=76.458 (SD=7.868), which increased to M=79.166 (SD=8.030) at week six and further increased to M=87.083 (SD=8.189) at week 12. In contrast, the baseline mean of the CTG was M=75.833 (SD=6.19), which increased to M=76.458 (SD=5.800) at week six and increased to M=80.833 (SD=6.702) at week 12. This table provides a

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comprehensive overview of the BS means and their corresponding standard deviations for the two groups at different time points.

The PU results in this study showed that time significantly affected PU (X^2=493.448, p<0.001), and the difference between the groups also reached statistical significance (X^2=6.145, p=0.013). In addition, the interaction between time and group was significant (X^2=176.367, p<0.001), indicating that there were significant differences in PU performance between the two groups at different time points (baseline, week six, and week 12). Detailed data are shown in Table 4.4.

Table 4.4 : Results of GEE on Strength Score

Variables	Source	Wald-Chi Square	df	p-value
PUT	Time	493.448*	2	<0.001
	Groups	6.145*	1	0.013
	Time * Groups	176.367*	2	<0.001
SUT	Time	869.314*	2	<0.001
	Groups	32.663*	1	<0.001
	Time * Groups	573.585*	2	<0.001
BST	Time	412.895*	2	<0.001
	Groups	2.582	1	0.108
	Time * Groups	45.888*	2	<0.001

Noted: df: degree of freedom; PUT: push-ups test; SUT: sit-ups test; BST: back squat test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 level of significance.

For SU, the time factor also showed a significant effect (X^2=869.314, p<0.001), and the difference between the groups reached a considerable level (X^2=32.663, p<0.001). The interaction between time and group was also statistically significant (X^2=573.585, p<0.001), indicating that there were substantial differences in SU scores at each time point (baseline, week 6, week 12). See Table 4.4 for details.

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Regarding BS, time also significantly affected the BS variable ($X^2=412.895$, $p<0.001$). However, the difference between the groups was insignificant ($X^2=2.582$, $p=0.108$). The interaction between time and group was statistically significant ($X^2=45.888$, $p<0.001$), indicating that there were differences in BS performance between the two groups over time (baseline, week six, week 12). Detailed data can be found in Table 4.4.

To evaluate the differences in PU between the two groups of youth field hockey players at three-time points, Bonferroni's Post Hoc test was used, and the results are shown in Table 4.5. The analysis results showed that the differences in PU between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) in the CSTG group were statistically significant. Similarly, in the CTG group, the differences between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 were also significant ($p<0.001$). At week 12, the effect size in the CSTG group was large ($d = 1.70$), indicating that time had a significant effect on PU, while the effect size in the CTG group was moderate ($d = 0.66$).

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Table 4.5 : Pairwise Comparison of within Group on Strength Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference LB	95%CIFor Difference UB	d
Push-Up	CSTG	Baseline	Week-6	-1.166*	0.096	1	<0.001	-1.355	-0.978	1.70(L)
		Baseline	Week-12	-3.625*	0.165	1	<0.001	-3.947	-3.302	
		Week-6	Week-12	-2.458*	0.118	1	<0.001	-2.688	-2.227	
	CTG	Baseline	Week-6	-1.000*	0.167	1	<0.001	-1.326	-0.673	0.66(M)
		Baseline	Week-12	-1.416*	0.176	1	<0.001	-1.761	-1.071	
		Week-6	Week-12	-0.416*	0.101	1	<0.001	-0.613	-0.219	
Sit-Ups	CSTG	Baseline	Week-6	-2.96*	0.125	1	<0.001	-3.202	-2.713	3.63(L)
		Baseline	Week-12	-5.958*	0.181	1	<0.001	-6.313	-5.602	
		Week-6	Week-12	-3.000*	0.177	1	<0.001	-3.346	-2.653	
	CTG	Baseline	Week-6	-0.291*	0.093	1	0.002	-0.473	-0.109	0.40(M)
		Baseline	Week-12	-0.625*	0.142	1	<0.001	-0.903	-0.346	
		Week-6	Week-12	-0.333*	0.096	1	0.001	-0.521	-0.144	
Back Squat	CSTG	Baseline	Week-6	-2.708*	0.509	1	<0.001	-3.705	-1.711	1.32(L)
		Baseline	Week-12	-10.625*	0.679	1	<0.001	-11.955	-9.294	
		Week-6	Week-12	-7.916*	0.503	1	<0.001	-8.902	-6.930	
	CTG	Baseline	Week-6	-0.625	0.448	1	0.163	-1.503	0.253	0.80(L)
		Baseline	Week-12	-5.000*	0.510	1	<0.001	-6.000	-3.999	
		Week-6	Week-12	-4.375*	0.448	1	<0.001	-5.253	-3.496	

Noted: PU: push-ups; SU: sit-ups; BS: back squat; CSTG: core strength training group; CTG: control training group; *p<0.05 level of significance

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To evaluate the differences in SU between the two groups of youth field hockey players at three time points, Bonferroni's Post Hoc test was used, and the results are detailed in Table 4.5. The analysis results showed that the CSTG group had significant differences in SU between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$). Similarly, the CTG group had significant differences in SU between baseline and week six ($p=0.002$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p=0.001$). After week 12, the effect size of the CSTG group was large ($d = 3.63$), indicating that time had a substantial effect on SU, while the effect size of the CTG group was relatively small ($d = 0.40$).

To evaluate the differences in back squat (BS) among adolescent hockey players at three different time points, the researchers used Bonferroni's Post Hoc test, and the results are shown in Table 4.5. The analysis results showed that in the CSTG group, the differences in BS between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) were statistically significant. Similarly, for the CTG group, the difference between baseline and week six was not significant ($p=0.163$). Still, the differences between baseline and week 12 ($p<0.001$) and week six and week 12 ($p<0.001$) were statistically significant. After week 12, the effect size for the CSTG group was large ($d = 1.32$), indicating that time had a significant effect on BS, while the effect size for the CTG group was medium ($d = 0.80$).

To compare the push-up performance of the two groups at different periods (baseline, week six, and week 12), this study used the Bonferroni post hoc test, as shown in Table 4.6. The results showed no significant difference in push-up performance between

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CSTG and CTG at baseline (p=0.307) and week six (p=0.184). However, at week 12, the two groups had a significant statistical difference in push-up performance (p<0.001). Further analysis of the effect size at different time points showed that the effect size was small at baseline (d=0.29), moderate at week six (d=0.38), and significant at week 12 (d=1.33).

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Table 4.6 : Pairwise Comparison of between Group on Strength Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95% CI		d
								LB	UB	
Push-Up	Baseline	CSTG	CTG	0.541	0.530	1	0.307	-0.497	1.580	0.29(S)
	Week-6	CSTG	CTG	0.708	0.534	1	0.184	-0.338	1.755	0.38(M)
	Week-12	CSTG	CTG	2.750*	0.584	1	<0.001	1.605	3.894	1.33(L)
Sit-Ups	Baseline	CSTG	CTG	-0.083*	0.493	1	0.866	-1.049	0.882	0.05(S)
	Week-6	CSTG	CTG	2.583*	0.498	1	<0.001	1.608	3.558	1.46(L)
	Week-12	CSTG	CTG	5.250*	0.402	1	<0.001	4.461	6.038	3.68(L)
Back Squat	Baseline	CSTG	CTG	0.625	2.001	1	0.755	-3.297	4.547	0.12(S)
	Week-6	CSTG	CTG	2.708	1.908	1	0.171	-1.171	6.588	0.38(M)
	Week-12	CSTG	CTG	6.250*	2.116	1	0.003	2.102	10.397	0.84(L)

Noted: PU: push-ups; SU: sit-ups; BS: back squat; CSTG: core strength training group; CTG: control training group; *$p<0.05$ level of significance.

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To compare the sit-up performance of the two groups at different time points (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test, and the results are shown in Table 4.6. The analysis showed that at baseline, there was no significant difference in sit-up performance between CSTG and CTG ($p=0.866$). However, at week six ($p<0.001$) and week 12 ($p<0.001$), the performance difference between the two groups reached statistical significance. The effect size was further calculated, and the effect size was small at baseline ($d=0.05$), but the effect size was larger at week six ($d=1.46$), and the effect size was further expanded at week 12 ($d=3.68$).

To compare the back-squat performance of the two groups at different periods (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test, and the results are shown in Table 4.6. The analysis showed no significant difference in back squat performance between CSTG and CTG at baseline ($p=0.755$) and week six ($p=0.171$). However, at week 12 ($p=0.003$), a statistically significant difference in back squat performance between the two groups was found. The effect size calculation showed that the effect size was small at baseline ($d=0.12$) and week six ($d=0.38$), while the effect size was large at week 12 ($d=0.84$).

Figure 4.1 shows the mean PU scores over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the number of PUs increased in both groups and after core strength training, the mean total PU increased more in the CSTG than in the CTG in week 12.

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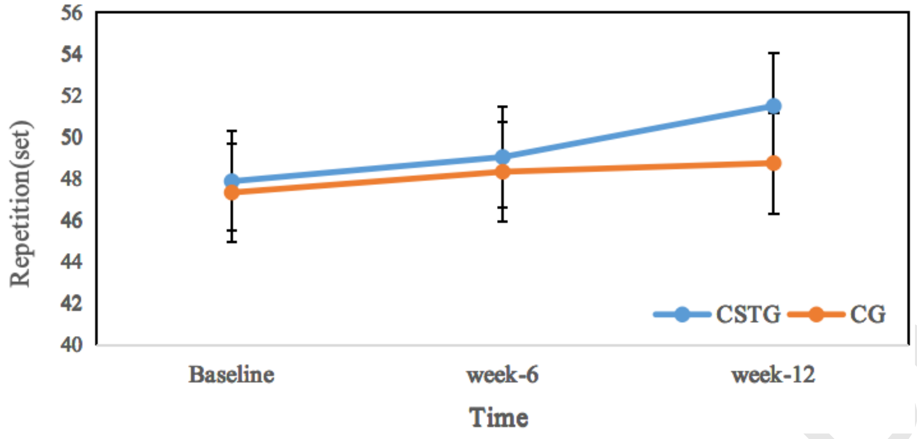

Figure 4.1 : The Mean Scores Changes of Push Up across the Times for Both Groups

Figure 4.2 shows the mean SU scores over time. At baseline, there was no statistically significant difference between the two groups. However, the amount of SUs of CSTG increased compared with CTG in week six, and after core strength training, the mean total SU of CSTG increased more than that of CTG in week 12.

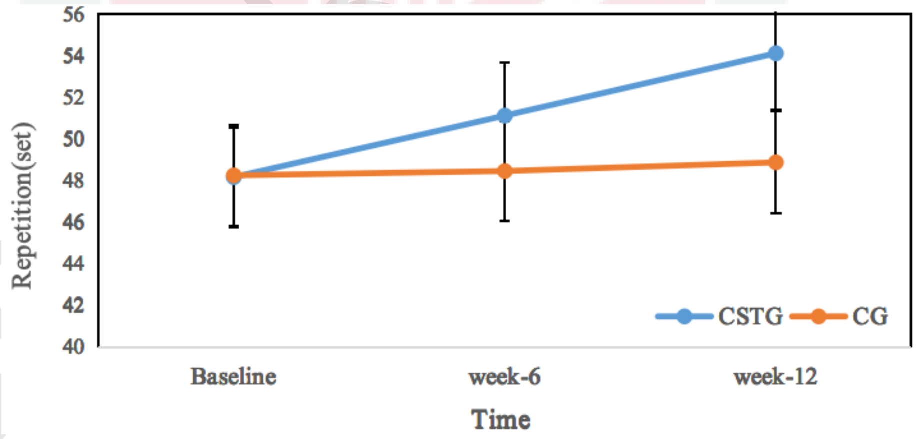

Figure 4.2 : The Mean Scores Changes of Sit-Ups across the Times for Both Groups

Figure 4.3 shows the mean BS scores over time. At baseline, no statistically significant difference was observed between the groups. However, in week six, the BS weights increased in both groups and after core strength training, the CSTG's mean total BS increased more than that of the CTG in week 12.

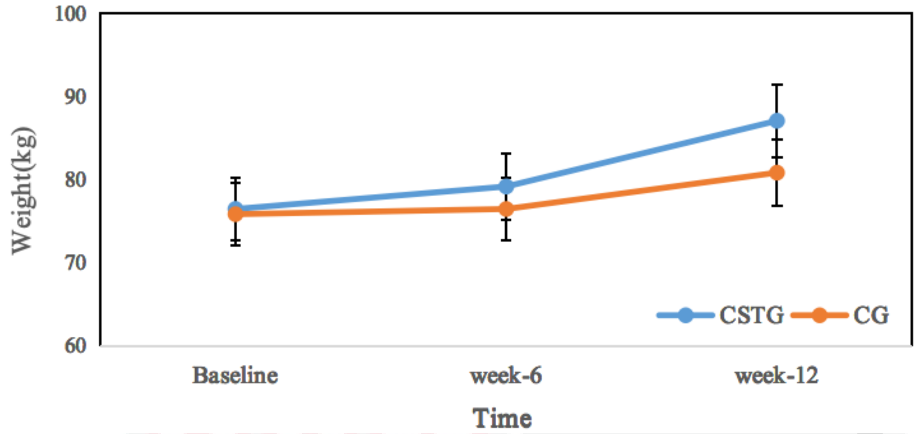

Figure 4.3 : The Mean Scores Changes of Back Squat across the Times for Both Groups

4.5.2 Power

The second physical fitness domain assessed in this study was power, and the effects of a core strength training intervention on power were evaluated using the gravity ball test (GBT) and the standing long jump test (SLJT).

Table 4.7 shows the descriptive statistics of the LGB variables at different time points for the core strength training group (CSTG) and the control group (CTG), covering three time periods: baseline, six weeks, and 12 weeks. Specifically, the baseline mean LGBT of the CSTG group was M = 10.623 (SD = 1.004), which increased to M = 11.508 (SD = 1.062) at week six and further increased to M = 11.833 (SD = 1.054) at week 12. In contrast, the mean LGBT of the CTG group was M = 10.903 (SD = 0.933) at baseline, which increased to M = 10.980 (SD = 0.931) at week six and increased to M = 11.110 (SD = 1.008) at week 12. This table provides details of the mean LGBT changes and their standard deviations for the two groups at these three time points,

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showing how the performance of the different groups has changed over time.

Table 4.7 : Descriptive Statistics (Mean and SD) of Power for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
LGBT	CSTG	10.623(1.004)	11.058(1.062)	11.833(1.054)
	CG	10.903(0.933)	10.980(0.931)	11.110(1.008)
RGBT	CSTG	11.112(0.816)	11.388(0.913)	11.939(1.030)
	CG	11.039(0.811)	11.104(0.827)	11.208(0.851)
SLJT	CSTG	248.250(4.927)	252.125(4.702)	258.416(4.853)
	CG	250.250(4.336)	251.208(4.043)	253.041(5.691)

Noted: LGB: Left gravity ball; RGB: Right gravity ball; SLJ: standing long jump; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 level of significance.

Table 4.7 shows the descriptive statistics of the RGB variables at different time points for the core strength training group (CSTG) and the control group (CTG), covering the data changes at baseline, six weeks, and 12 weeks. Specifically, the average RGB value of the CSTG group at baseline was M=11.112 (SD=0.816), which increased to M=11.388 (SD=0.913) at week six and further increased to M=11.939 (SD=1.030) at week 12. In contrast, the baseline RGBT average value of the CTG group was M=11.039 (SD=0.811), which increased slightly to M=11.104 (SD=0.827) at week six and increased somewhat to M=11.208 (SD=0.851) at week 12. This table summarises the two groups' RGB change trends and standard deviations at different time points, clearly reflecting the performance differences between the experimental and control groups in each period.

Table 4.7 shows the means and standard deviations of the SLJ variables for the core strength training group (CSTG) and the control group (CTG) at baseline, week six, and week 12. The results show that the baseline mean of the CSTG was M=248.250 (SD=4.927), which increased to M=252.125 (SD=4.702) at week six and further

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increased to M=258.416 (SD=4.853) at week 12. In contrast, the baseline mean of the CTG was M=250.250 (SD=4.336), which increased slightly to M=251.208 (SD=4.043) at week six and to M=253.041 (SD=5.691) at week 12. This table comprehensively overviews the SLJ means and their corresponding standard deviations for the two groups at different time points.

In this study, the LGB results showed that time significantly affected LGB ($X^2=326.997$, $p<0.001$). However, the difference between the groups was insignificant ($X^2=0.386$, $p=0.534$). However, the interaction between time and group was significant ($X^2=163.340$, $p<0.001$), which showed that the LGB performance of the two groups was significantly different at different time points (baseline, week six, week 12). Detailed data are shown in Table 4.8.

Table 4.8 : Results of GEE on Power Score

Variables	Source	Wald-Chi Square	df	p-value
LGBT	Time	326.997*	2	<0.001
	Groups	0.386	1	0.534
	Time * Groups	163.340*	2	<0.001
RGBT	Time	69.431*	2	<0.001
	Groups	2.322	1	0.128
	Time * Groups	28.636*	2	<0.001
SLJT	Time	485.271*	2	<0.001
	Groups	1.225	1	0.268
	Time * Groups	166.978*	2	<0.001

Noted: df: degree of freedom; LGB: Left gravity ball; RGB: Right gravity ball; SLJ: standing long jump; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 level of significance.

For RGB, the time factor also showed a significant effect ($X^2=69.431$, $p<0.001$). However, the difference between the groups was insignificant ($X^2=2.322$, $p=0.128$). However, the interaction between time and group was statistically significant ($X^2=28.636$, $p<0.001$), indicating that the RGB performance of the two groups was

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significantly different at different time points (baseline, week six, week 12). Detailed data are shown in Table 4.8.

Regarding SLJ, time also significantly affected the SLJ variable ($X^2=485.271$, $p<0.001$). However, the difference between the groups was insignificant ($X^2=1.225$, $p=0.268$). The interaction between time and group was statistically significant ($X^2=166.978$, $p<0.001$), indicating that there were differences in SLJ performance between the two groups over time (baseline, week six, week 12). Detailed data can be found in Table 4.8.

To evaluate the differences in LGB between the two groups of youth field hockey players at three different time points, this study used the Bonferroni post hoc test, and the results are shown in Table 4.9. The analysis showed that the differences in LGB between baseline and week 6 ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) in the CSTG group were statistically significant. Similarly, the differences between baseline and week 6 ($p=0.004$) and baseline and week 12 ($p=0.001$) in the CTG group also reached significance, while the difference between week six and week 12 was not significant ($p=0.066$). At week 12, the effect size of the CSTG group was larger ($d=1.17$), while the effect size of the CTG group was smaller ($d=0.21$).

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Table 4.9 : Pairwise Comparison of within Group on Power Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference LB	95%CIFor Difference UB	d
LGBT	CSTG	Baseline	Week-6	-0.434*	0.044	1	<0.001	-0.522	-0.346	1.17(L)
		Baseline	Week-12	-1.209*	0.049	1	<0.001	-1.306	-1.112	
		Week-6	Week-12	-0.775*	0.032	1	<0.001	-0.839	-0.710	
	CTG	Baseline	Week-6	-0.076*	0.026	1	0.004	-0.128	-0.024	0.21(S)
		Baseline	Week-12	-0.207*	0.062	1	0.001	-0.330	-0.084	
		Week-6	Week-12	-0.130*	0.071	1	0.066	-0.269	-0.009	
RGBT	CSTG	Baseline	Week-6	-0.276*	0.051	1	<0.001	-0.377	-0.175	0.90(L)
		Baseline	Week-12	-0.827*	0.135	1	<0.001	-1.093	-0.561	
		Week-6	Week-12	-0.550*	0.139	1	<0.001	-0.825	-0.276	
	CTG	Baseline	Week-6	-0.065*	0.027	1	0.016	-0.119	-0.012	0.20(S)
		Baseline	Week-12	-0.170*	0.045	1	<0.001	-0.259	-0.080	
		Week-6	Week-12	-0.104*	0.031	1	0.001	-0.166	-0.042	
SLJT	CSTG	Baseline	Week-6	-3.875*	0.207	1	<0.001	-4.280	-3.469	2.07(L)
		Baseline	Week-12	-10.166*	0.352	1	<0.001	-10.856	-9.476	
		Week-6	Week-12	-6.291*	0.253	1	<0.001	-6.788	-5.795	
	CTG	Baseline	Week-6	-0.958*	0.216	1	<0.001	-1.382	-0.534	0.55(M)
		Baseline	Week-12	-2.791*	0.722	1	<0.001	-4.206	-1.377	
		Week-6	Week-12	-1.833*	0.796	1	0.021	-3.394	-0.272	

Noted: LGBT: left gravity ball test; RGBT: right gravity ball test; SLJT: standing long jump test; CSTG: core strength training group; CTG: control training group; *p<0.05 level of significance.

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To evaluate the differences in RGB between the two groups of youth field hockey players at three time points, the Bonferroni post hoc test was used, and the results are detailed in Table 4.9. The analysis results showed that the differences in RGB between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week 6 and week 12 ($p<0.001$) in the CSTG group were significant. Similarly, the differences between baseline and week six ($p=0.016$), baseline and week 12 ($p<0.001$), and week six and week 12 in the CTG group were significant ($p=0.001$). After week 12, the effect size in the CSTG group was larger ($d=0.90$), indicating that time significantly affected RGB, while the effect size in the CTG group was smaller ($d=0.20$).

To evaluate the differences in SLJ performance among youth field hockey players at three time points, the researchers conducted a Bonferroni post hoc test, and the results are shown in Table 4.9. The analysis results showed that the SLJ differences between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) were significant in the CSTG group. For the CTG group, the difference between baseline and week six was significant ($p<0.001$), but the differences between baseline and week 12 ($p<0.001$) and week six and week 12 ($p=0.021$) were also statistically significant. After 12 weeks, the effect size of the CSTG group was large ($d = 2.07$), indicating that time had a significant effect on SLJ, while the effect size of the CTG group was relatively medium ($d = 0.55$).

To compare the left gravity ball (LGB) performance of the two groups (core strength training group and control group) at three time periods (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test and the specific results are shown in Table 4.10. The analysis showed no significant difference in LGB performance

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between CSTG and CTG at baseline (p=0.307) and week six (p=0.781). Still, the performance difference between the two groups reached a statistically significant level at week 12 (p=0.013). The effect size analysis showed that the effect size was small at baseline (d=0.29), small at week six (d=0.08), but large at week 12 (d=0.70).

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Table 4.10 : Pairwise Comparison of between Group on Power Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
LGBT	Baseline	CSTG	CTG	-0.279	0.273	1	0.307	-0.816	0.257	0.29(S)
	Week-6	CSTG	CTG	0.078	0.282	1	0.781	-0.475	0.631	0.08(S)
	Week-12	CSTG	CTG	0.722*	0.291	1	0.013	0.151	1.294	0.70(L)
RGBT	Baseline	CSTG	CTG	0.073	0.229	1	0.748	-0.377	0.524	0.10(S)
	Week-6	CSTG	CTG	0.284	0.246	1	0.249	-0.198	0.767	0.32(M)
	Week-12	CSTG	CTG	0.730*	0.267	1	0.006	0.207	1.254	0.77(M)
SLJT	Baseline	CSTG	CTG	-2.000	1.312	1	0.127	-4.570	0.570	0.43(M)
	Week-6	CSTG	CTG	0.916	1.240	1	0.459	-1.512	3.345	0.20(S)
	Week-12	CSTG	CTG	5.375*	1.495	1	<0.001	2.445	8.304	1.01(L)

Noted: LGBT: left gravity ball test; RGBT: right gravity ball test; SLJT: standing long jump test; CSTG: core strength training group; CTG: control training group; *$p<0.05$ level of significance.

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To compare the right gravity ball (RGB) performance between the two groups at baseline, week six, and week 12, the researchers used the Bonferroni post hoc test, and the results are shown in Table 4.10. The analysis showed no significant difference in RGB performance between CSTG and CTG at baseline ($p=0.748$). Similarly, there was no significant effect at week six ($p=0.249$). However, the performance difference between the two groups reached statistical significance at week 12 ($p=0.006$). The calculation of the effect size showed that the effect size was small at baseline ($d=0.10$), but it was moderate at week six ($d=0.32$) and moderate at week 12 ($d=0.77$).

To compare the standing long jump performance (SLJT) between the two groups at different periods (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test, and the results are shown in Table 4.10. The analysis showed no significant difference in SLJ performance between CSTG and CTG at baseline ($p=0.127$) and week six ($p=0.459$). However, at week 12 ($p<0.001$), a statistically significant difference in SLJ performance between the two groups was found. The effect size calculation showed that the effect size was small at baseline ($d=0.43$) and week six ($d=0.20$), but the effect size was large at week 12 ($d=1.01$).

Figure 4.4 shows the changes in mean LGB scores over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the LGB distance increased in both groups and after core strength training, the mean total LGB of the CSTG increased more than that of the CTG in week 12.

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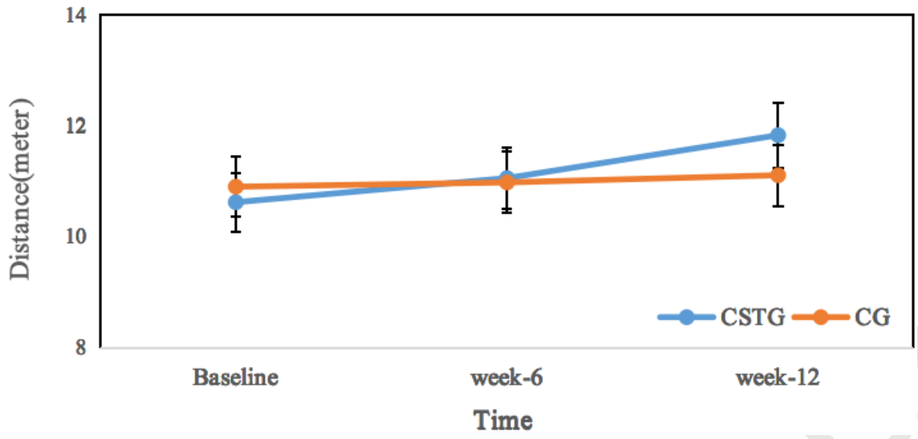

Figure 4.4 : The Mean Scores Changes of Left Gravity Ball across the Times for Both Groups

Figure 4.5 shows the mean RGB scores over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the RGB distance increased in both groups and after core strength training, the mean total RGB of the CSTG increased more than that of the CTG in week 12.

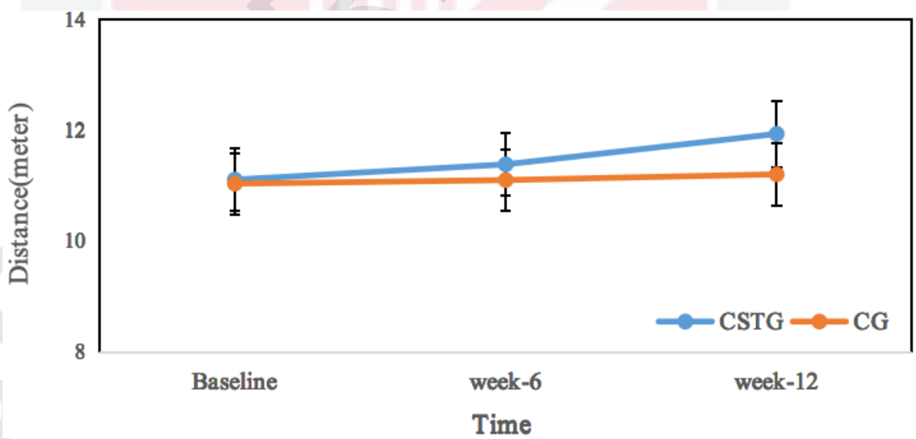

Figure 4.5 : The Mean Scores Changes of Right Gravity Ball across the Times for Both Groups

Figure 4.6 shows the mean SLJ scores over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the SLJ distance increased in both groups and after core strength training, the mean total

SLJ increased more in the CSTG than in the CTG in week 12.

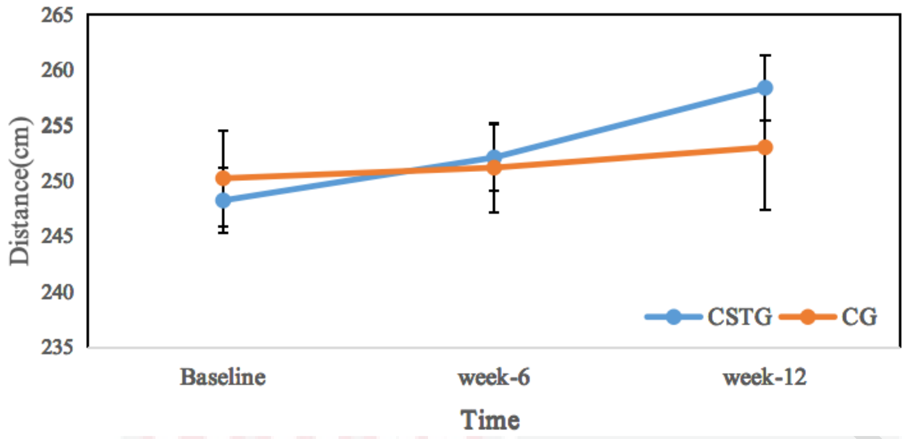

Figure 4.6 : The Mean Scores Changes of Standing Long Jump across the Times for Both Group

4.5.3 Speed

Table 4.11 shows the descriptive statistics of the velocity variable (25YT) at different time points for the core strength training group (CSTG) and the control group (CTG), including the mean and standard deviation (SD), covering the baseline, 6-week, and 12-week measurement periods. The baseline data showed that the average velocity of the CSTG group was M=3.859 (SD=0.066), and after six weeks of intervention, the velocity slightly decreased to M=3.827 (SD=0.060) and further decreased to M=3.816 (SD=0.065) after 12 weeks. In contrast, the average velocity of the CTG group at baseline was M=3.863 (SD=0.074), which remained stable at six weeks with little change, M=3.861 (SD=0.074), and slightly decreased to M=3.851 (SD=0.073) after 12 weeks.

Table 4.11 : Descriptive Statistics (Mean and SD) of Speed for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
25YT	CSTG	3.859(0.066)	3.827(0.060)	3.816(0.065)
	CTG	3.863(0.074)	3.861(0.074)	3.851(0.073)
50YT	CSTG	6.863(0.106)	6.778(0.084)	6.694(0.081)
	CTG	6.822(0.120)	6.819(0.122)	6.797(0.124)

Noted: 25YT: 25-yards sprint test; 50YT: 50-yard test; CSTG: core strength training group; CTG: control training group; $*p<0.05$ level of significance

Table 4.11 shows the descriptive statistics of the 50-yard speed test (50YT) at different time points for the core strength training group (CSTG) and the control group (CTG), covering three measurements at baseline, six weeks, and 12 weeks. The results show that the average speed of the CSTG group was M=6.863 (SD=0.106) at baseline, and after six weeks of training, the speed decreased to M=6.778 (SD=0.084) and further decreased to M=6.694 (SD=0.081) after 12 weeks. In contrast, the average speed of the CTG group was M=6.822 (SD=0.120) at baseline, and the speed change remained relatively stable at six weeks, M=6.819 (SD=0.122), and decreased to M=6.797 (SD=0.124) after 12 weeks.

In the 25-yards sprint dash test, the results showed that time significantly affected the change in speed ($X^2=86.093$, $p<0.001$), indicating that the participants' speed performance improved considerably over time. However, the two groups (core strength training group and control group) did not show a significant difference ($X^2=1.574$, $p=0.210$), indicating no significant statistical difference in the average speed between the two groups. Nevertheless, the interaction between time and group was statistically significant ($X^2=40.674$, $p<0.001$), which means that the 25YT speed of the two groups had significantly different trends at different time points (baseline, week six, and week 12). For more information, see Table 4.12.

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Table 4.12 : Results of GEE on Speed Score

Variables	Source	Wald-Chi Square	df	p-value
25YT	Time	86.093*	2	<0.001
	Groups	1.574	1	0.210
	Time * Groups	40.674*	2	<0.001
50YT	Time	291.704*	2	<0.001
	Groups	1.333	1	0.248
	Time * Groups	170.182*	2	<0.001

Noted: df: degree of freedom; 25YT: 25-yards sprint test; 50YT: 50-yard test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 level of significance.

In the 50-yards sprint test, the results showed that time had a significant effect on speed change (X^2=291.704, p<0.001), indicating that the participants' speed performance improved significantly as the training time continued. However, the inter-group difference between the core strength training group (CSTG) and the control group (CTG) was not significant (X^2=1.333, p=0.248), indicating that there was no significant statistical difference in the average speed of the two groups. Nevertheless, the interaction between time and group showed significance (X^2=170.182, p<0.001), which means that the 50YT sprint speed of the two groups showed different trends at different time points at baseline, week six, and week 12. For more information, see Table 4.12.

To evaluate the speed differences (25YT) of youth male field hockey players at different time points, this study used the Bonferroni post hoc test, and the results are shown in Table 4.13. The analysis results showed that in the core strength training group (CSTG), the differences in 25YT sprint between baseline and week six (p<0.001), baseline and week 12 (p<0.001), and week six and week 12 (p=0.001) were statistically significant. For the control group (CTG), there was no significant difference between baseline and week six (p=0.076). Still, the differences between

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baseline and week 12 ($p<0.001$) and week six and week 12 ($p<0.001$) were significant. At week 12, the effect size for the CSTG group was medium ($d = 0.66$), indicating that time substantially affected speed performance improvement. In contrast, the effect size for the CTG group was small ($d = 0.16$), suggesting that its impact on speed improvement was relatively limited.

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Table 4.13 : Pairwise Comparison of within Group on Speed Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
25YT	CSTG	Baseline	Week-6	0.031*	0.004	1	<0.001	0.022	0.040	0.66(M)
		Baseline	Week-12	0.042*	0.005	1	<0.001	0.032	0.053	
		Week-6	Week-12	0.011*	0.003	1	0.001	0.004	0.018	
	CTG	Baseline	Week-6	0.002	0.001	1	0.076	-0.003	0.004	0.16(S)
		Baseline	Week-12	0.011*	0.002	1	<0.001	0.006	0.017	
		Week-6	Week-12	0.009*	0.002	1	<0.001	0.004	0.014	
50YT	CSTG	Baseline	Week-6	0.085*	0.008	1	<0.001	0.068	0.101	1.75(L)
		Baseline	Week-12	0.168*	0.009	1	<0.001	0.150	0.186	
		Week-6	Week-12	0.083*	0.006	1	<0.001	0.071	0.095	
	CTG	Baseline	Week-6	0.002	0.002	1	0.064	-0.001	0.005	0.20(S)
		Baseline	Week-12	0.024*	0.006	1	<0.001	0.011	0.037	
		Week-6	Week-12	0.022*	0.007	1	0.002	0.008	0.035	

Noted: 25YT: 25-yards sprint test; 50YT: 50-yard test; CSTG: core strength training group; CTG: control training group; *p<0.05 level of significance.

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To evaluate the differences in velocity (50YT) at different time points in young male field hockey players, this study used the Bonferroni post hoc test, and the results are shown in Table 4.13. The results showed that in the core strength training group (CSTG), the differences in 50YT velocity between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) were statistically significant. In the control group (CTG), there was no significant difference between baseline and week six ($p=0.064$), but there were significant differences between baseline and week 12 ($p<0.001$) and week six and week 12 ($p=0.002$). At week 12, the effect size of the CSTG group was larger ($d=1.75$), indicating that core strength training significantly improved speed; in contrast, the effect size of the CTG group was smaller ($d=0.20$), suggesting that its speed improvement effect was limited.

To compare the speed changes (25YT) between the two groups at different periods (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test. According to the results in Table 4.14, the speed difference between CSTG and CTG did not reach a statistically significant level at baseline ($p=0.835$), week six ($p=0.082$), and week 12 ($p=0.072$). The calculation results of the effect size showed that the effect size was small at baseline ($d=0.06$), while the effect size was medium at week six and week 12 ($d=0.50$).

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Table 4.14 : Pairwise Comparison of between Group on Speed Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
25YT	Baseline	CSTG	CTG	-0.004	0.020	1	0.835	-0.043	0.035	0.06(S)
	Week-6	CSTG	CTG	-0.033	0.019	1	0.082	-0.071	0.004	0.50(M)
	Week-12	CSTG	CTG	-0.035	0.019	1	0.072	-0.074	0.003	0.50(M)
50YT	Baseline	CSTG	CTG	0.041	0.032	1	0.201	-0.021	0.103	0.36(M)
	Week-6	CSTG	CTG	-0.041	0.029	1	0.160	-0.099	0.016	0.39(M)
	Week-12	CSTG	CTG	-0.102*	0.029	1	0.001	-0.161	-0.044	0.96(L)

Noted: 25YT: 25-yards sprint test; 50YT: 50-yard test; CSTG: core strength training group; CTG: control training group; *p<0.05 level of significance

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To compare the speed performance (50YT) of the two groups at different periods (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test, and the specific analysis results are shown in Table 4.14. The results showed that the difference in 50YT speed between the core strength training group (CSTG) and the control group (CTG) at baseline (p=0.201) and week six (p=0.160) had yet to reach statistical significance. However, in week 12, the difference in 50YT speed between CSTG and CTG reached a significant level (p=0.001). In addition, the effect size analysis showed that the effect size of the 50YT sprint was small at baseline (d=0.36) and week six (d=0.39), but at week 12, the effect size was large (d=0.96).

Figure 4.7 shows the mean speed scores for the entire time (25 YT). At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, at week six, the 25YT sprint times of both groups decreased, and after core strength training, the mean total 25YT sprint time of the CSTG decreased compared to the CTG at week 12.

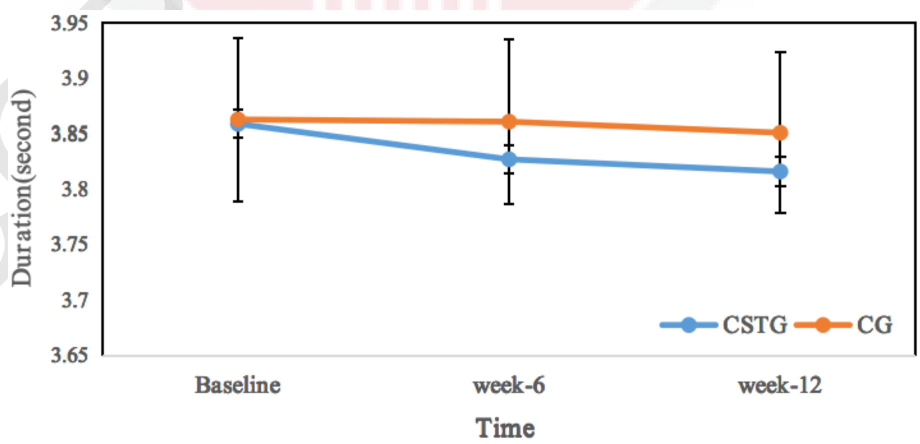

Figure 4.7 : The Mean Scores Changes of 25-Yards Sprint across the Times for Both Groups

Figure 4.8 shows the mean speed scores for the total time (50 YT). At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the 50 YT sprint times decreased in both groups and after core strength training, the mean total 50 YT sprint times of the CSTG decreased compared to the CTG in week 12.

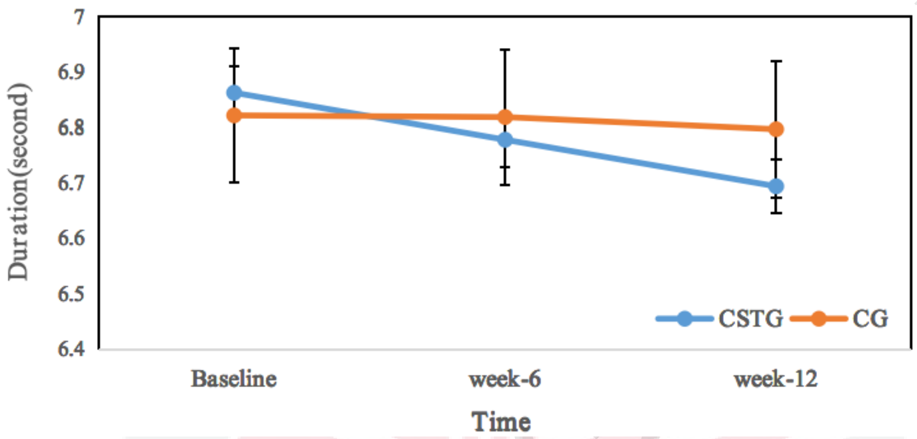

Figure 4.8 : The Mean Scores Changes of 50-yard sprint across the Times for Both Groups

4.5.4 Endurance

The fourth physical fitness domain was endurance, and the 300-yard endurance test (300YT) was used to observe the effects of the core strength training intervention on the 300YT variables. Table 4.15 provides descriptive statistics, including means and standard deviations (SD).

Table 4.15 : Descriptive Statistics (Mean and SD) of Endurance for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
300YT	CSTG	1.105(0.022)	1.094(0.019)	1.077(0.020)
	CG	1.102(0.015)	1.101(0.016)	1.097(0.018)

Noted: 300YT: 300-yard test; CSTG: core strength training group; CTG: control training group; *p<0.05 level of significance.

Table 4.15 shows the descriptive statistics of the 300YT variable at different time points for the core strength training group (CSTG) and the control group (CTG), including the mean and standard deviation (SD). The table covers three periods: baseline, six weeks, and 12 weeks. The data showed that the baseline mean 300YT of the CSTG group was M=1.105 (SD=0.022), which decreased slightly to M=1.094 (SD=0.019) at week six and further decreased to M=1.077 (SD=0.020) at week 12, showing a trend of gradual improvement. In contrast, the mean 300YT in the CTG group was M = 1.102 (SD = 0.015) at baseline, remained almost unchanged at M = 1.101 (SD = 0.016) at week six, and slightly decreased to M = 1.097 (SD = 0.018) at week 12, showing a relatively stable change.

In the 300-yard endurance test, the results showed that time significantly affected the change in endurance (X^2=72.680, p<0.001), indicating that the participants' endurance performance improved considerably over time. However, the two groups (core strength training group and control group) did not show a significant difference between the groups (X^2=2.846, p=0.091), indicating no significant statistical difference in the average endurance of the two groups. Nevertheless, the interaction between time and group was statistically significant (X^2=32.196, p<0.001), which means that the 300YT endurance of the two groups had significantly different trends at different time points (baseline, week six, and week 12). For more information, see Table 4.16.

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Table 4.16 : Results of GEE on Endurance Score

Variables	Source	Wald-Chi Square	df	p-value
300YT	Time	72.680*	2	<0.001
	Groups	2.864	1	0.091
	Time * Groups	32.196*	2	<0.001

Noted: df: degree of freedom; 300YT: 300-yard test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 significance level.

To evaluate the endurance differences (300YT) at different time points in young male field hockey players, this study used the Bonferroni post hoc test, and the results are shown in Table 4.17. The analysis results showed that the differences between baseline and week six (p<0.001), baseline and week 12 (p<0.001), and week six and week 12 (p<0.001) in the core strength training group (CSTG) were statistically significant. The difference between baseline and week six in the control group (CTG) was not substantial (p=0.763), but the differences between baseline and week 12 (p=0.019) and week six and week 12 (p=0.001) were statistically significant. At week 12, the effect size of the CSTG group was larger (d=1.33), indicating that time had a substantial effect on the improvement of endurance performance. In contrast, the effect size of the CTG group was medium (d=0.30), indicating that its effect on endurance improvement was relatively small.

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Table 4.17 : Pairwise Comparison of within Group on Endurance Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
300YT	CSTG	Baseline	Week-6	0.011*	0.001	1	<0.001	0.007	0.014	1.33(L)
		Baseline	Week-12	0.028*	0.003	1	<0.001	0.021	0.034	
		Week-6	Week-12	0.017*	0.002	1	<0.001	0.012	0.021	
	CTG	Baseline	Week-6	0.004	0.001	1	0.763	-0.002	0.003	0.30(M)
		Baseline	Week-12	0.005*	0.002	1	0.019	0.008	0.010	
		Week-6	Week-12	0.004*	0.001	1	0.001	0.002	0.007	

Noted: 300YT: 300-yard test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

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To compare the changes in endurance performance between the core strength training group (CSTG) and the control group (CTG) at different time points (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test. According to the results in Table 4.18, the endurance difference between the two groups did not reach a statistically significant level at baseline (p=0.582) and week six (p=0.124). However, at week 12, the endurance difference between CSTG and CTG was quite substantial (p<0.001). The results of the effect size analysis further confirmed this trend: the effect size was small at baseline (d=0.16), medium at week 6 (d=0.40), and large at week 12 (d=1.05).

Table 4.18 : Pairwise Comparison of between Group on Endurance Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference LB	95%CIFor Difference UB	d
300YT	Baseline	CSTG	CTG	0.003	0.005	1	0.582	-0.007	0.013	0.16(S)
	Week-6	CSTG	CTG	-0.007	0.004	1	0.124	-0.017	0.002	0.40(M)
	Week-12	CSTG	CTG	-0.020*	0.005	1	<0.001	-0.030	-0.009	1.05(L)

Noted: 300YT: 300-yard test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

Figure 4.9 shows the mean endurance scores (300YT) over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, at week six, the 300YT endurance running time of both groups decreased, and after core strength training, the mean total 300YT endurance running time of the CSTG decreased compared to the CTG at week 12.

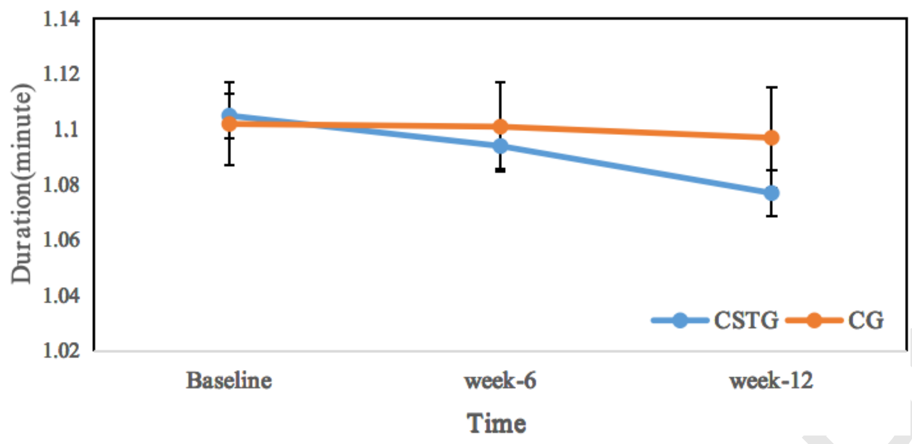

Figure 4.9 : The Mean Scores Changes of 300-Yard across the Times for Both Groups

4.5.5 Agility

Table 4.19 shows the descriptive statistics of the agility variable (LART) at different time points for the core strength training group (CSTG) and the control group (CTG), including the mean and standard deviation (SD), covering the measurement periods of baseline, six weeks, and 12 weeks. For the CSTG group, the mean LART value at baseline was M=16.279 (SD=0.570), which decreased to M=15.967 (SD=0.513) after six weeks of training, and further decreased to M=15.414 (SD=0.501) after 12 weeks. In contrast, the baseline LART value of the CTG group was M=15.971 (SD=0.553), which decreased slightly to M=15.942 (SD=0.558) at six weeks and further decreased to M=15.821 (SD=0.560) after 12 weeks.

Table 4.19 : Descriptive Statistics (Mean and SD) of Agility for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
LART	CSTG	16.279(0.570)	15.967(0.513)	15.414(0.501)
	CG	15.971(0.553)	15.942(0.558)	15.821(0.560)
RART	CSTG	13.163(0.960)	12.377(0.853)	11.661(0.891)
	CG	13.065(0.842)	12.778(0.818)	12.540(0.803)

Noted: LART: left arrow run test; RART: right arrow run test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

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Table 4.19 shows the descriptive statistics of the agility test (RART) at different time points for the core strength training group (CSTG) and the control group (CTG), covering three measurements at baseline, six weeks, and 12 weeks. The results showed that the baseline mean RART value of the CSTG group was M=13.163 (SD=0.960), which decreased to M=12.377 (SD=0.853) after six weeks of training and further decreased to M=11.661 (SD=0.891) at 12 weeks. The baseline RART value of the CTG group was M=13.065 (SD=0.842), which decreased to M=12.778 (SD=0.818) at six weeks and decreased to M=12.540 (SD=0.803) after 12 weeks.

In the agility (LART) test, the results showed that time had a significant effect on the change of LART (X^2=417.184, $p<0.001$), indicating that the participants' LAR performance improved significantly over time. However, the two groups (core strength training group and control group) did not show a significant difference (X^2=0.027, $p=0.870$), indicating no significant statistical difference in the average LART between the two groups. Nevertheless, the interaction between time and group was statistically significant (X^2=205.528, $p<0.001$), which means that the LART of the two groups had significantly different change trends at various time points (baseline, week six, and week 12). For more information, see Table 4.20.

Table 4.20 : Results of GEE on Agility Score

Variables	Source	Wald-Chi Square	df	p-value
LART	Time	417.184*	2	<0.001
	Groups	0.027	1	0.870
	Time * Groups	205.528*	2	<0.001
RART	Time	613.562*	2	<0.001
	Groups	2.682	1	0.101
	Time * Groups	139.851*	2	<0.001

Noted: df: degree of freedom; LART: left arrow run test; RART: right arrow run test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 significance level.

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In the agility (RART) test, the results showed that time had a significant effect on the change of RART (X^2=613.562, p<0.001), indicating that the participants' RAR performance improved significantly with the extension of training time. However, the inter-group difference between the core strength training group (CSTG) and the control group (CTG) was not significant (X^2=2.682, p=0.101), indicating that there was no significant statistical difference in the average RAR between the two groups. Nevertheless, the interaction between time and group showed significance (X^2=139.851, p<0.001), which means that the RART of the two groups showed different change trends at various time points at baseline, week six, and week 12. For more information, see Table 4.20.

To evaluate the differences in agility (LART) among youth hockey players at different time points, this study used the Bonferroni post hoc test, and the results are shown in Table 4.21. The analysis results showed that in the core strength training group (CSTG), the differences in LART between baseline and week six (p<0.001), baseline and week 12 (p<0.001), and week six and week 12 (p<0.001) were statistically significant. For the control group (CTG), the differences in LART between baseline and week six (p=0.001), baseline and week 12 (p<0.001), and week six and week 12 (p<0.001) were statistically significant. At week 12, the effect size of the CSTG group was larger (d=1.61), indicating that time had a substantial impact on the improvement of LART performance. In comparison, the effect size of the CTG group was smaller (d=0.27), indicating that its impact on LART improvement was relatively limited.

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Table 4.21 : Pairwise Comparison of within Group on Agility Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference LB	95%CIFor Difference UB	d
LART	CSTG	Baseline	Week-6	0.312*	0.026	1	<0.001	0.259	0.364	1.61(L)
		Baseline	Week-12	0.865*	0.040	1	<0.001	0.784	0.945	
		Week-6	Week-12	0.553*	0.029	1	<0.001	0.494	0.610	
	CTG	Baseline	Week-6	0.028*	0.008	1	<0.001	0.010	0.045	0.27(S)
		Baseline	Week-12	0.150*	0.029	1	<0.001	0.093	0.205	
		Week-6	Week-12	0.121*	0.022	1	<0.001	0.076	0.165	
RART	CSTG	Baseline	Week-6	0.787*	0.047	1	<0.001	0.695	0.878	1.62(L)
		Baseline	Week-12	1.504*	0.081	1	<0.001	1.344	1.663	
		Week-6	Week-12	0.717*	0.061	1	<0.001	0.598	0.836	
	CTG	Baseline	Week-6	0.287*	0.019	1	<0.001	0.249	0.324	0.64(M)
		Baseline	Week-12	0.525*	0.026	1	<0.001	0.474	0.574	
		Week-6	Week-12	0.238*	0.016	1	<0.001	0.205	0.269	

Noted: LART: left arrow run test; RART: right arrow run test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level

To evaluate the differences in agility (RART) at different time points in youth hockey players, this study used the Bonferroni post hoc test, and the results are shown in Table 4.21. The results showed that in the core strength training group (CSTG), the differences in RART between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) were all statistically significant. For the control group (CTG), the differences in RART between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) were all statistically significant. At week 12, the effect size of the CSTG group was large ($d=1.62$), indicating that core strength training significantly improved RART; in contrast, the effect size of the CTG group was moderate ($d=0.64$), suggesting that its RART improvement effect was relatively limited.

To compare the agility performance (LART) of the two groups in different periods (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test, and the specific analysis results are shown in Table 4.22. The results showed that the difference in LART between the core strength training group (CSTG) and the control group (CTG) at baseline ($p=0.052$) and week six ($p=0.871$) had yet to reach statistical significance. However, at week 12, the difference in RART between CSTG and CTG reached a significant level ($p=0.006$). In addition, the effect size analysis showed that the effect size was medium at baseline ($d=0.55$), the effect size of LART was small at week six ($d=0.05$), and at week 12, the effect size increased to ($d=0.76$).

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Table 4.22 : Pairwise Comparison of between Group on Agility Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
LART	Baseline	CSTG	CTG	0.308	0.158	1	0.052	-0.002	0.619	0.55(M)
	Week-6	CSTG	CTG	0.024	0.151	1	0.871	-0.272	0.321	0.05(S)
	Week-12	CSTG	CTG	-0.407*	0.149	1	0.006	-0.700	-0.115	0.76(M)
RART	Baseline	CSTG	CTG	0.099	0.255	1	0.699	-0.401	0.599	0.11(S)
	Week-6	CSTG	CTG	-0.400	0.236	1	0.090	-0.863	0.062	0.48(M)
	Week-12	CSTG	CTG	-0.880*	0.240	1	<0.001	-1.350	-0.410	1.04(L)

Noted: LART: left arrow run test; RART: right arrow run test; CSTG: core strength training group; CTG: control training group; *$p<0.05$ significance level

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To compare the changes in agility (RART) between the two groups at different periods (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test. According to the results in Table 4.22, the differences in LART between the core strength training group (CSTG) and the control group (CTG) at baseline ($p=0.699$) and week six ($p=0.090$) have yet to reach statistical significance. However, at week 12 ($p<0.001$), the differences in RART between CSTG and CTG reached statistical significance. The calculation results of the effect size showed that the effect size was small at baseline ($d=0.11$), the effect size of LART was medium at week six ($d=0.48$), and at week 12, the effect size increased to ($d=1.04$).

Figure 4.10 shows the mean agility scores (LART) over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, at week six, the LART time decreased in both groups and after core strength training, the mean total LART time decreased in the CSTG compared to the CTG at week 12.

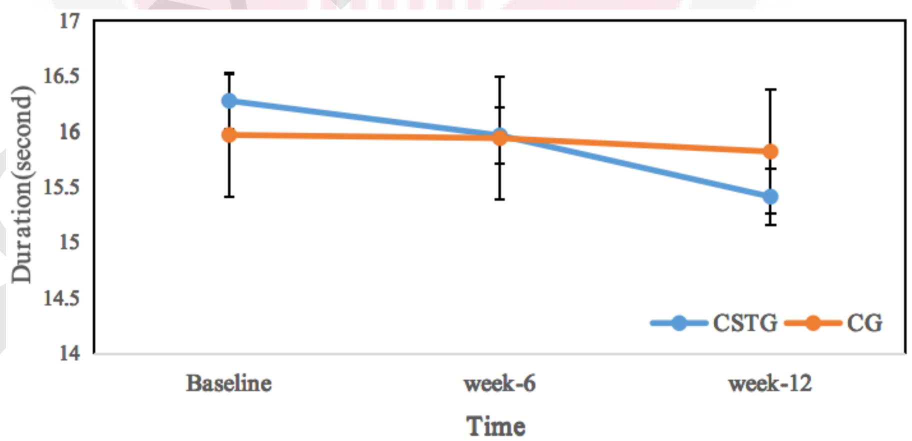

Figure 4.10 : The Mean Scores Changes of Left Arrow Run across the Times for Both Groups

Figure 4.11 shows the mean agility score over time (RART). At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the RART time decreased for both groups, and after core strength training, the mean total RART time decreased for the CSTG compared to the CTG in week 12.

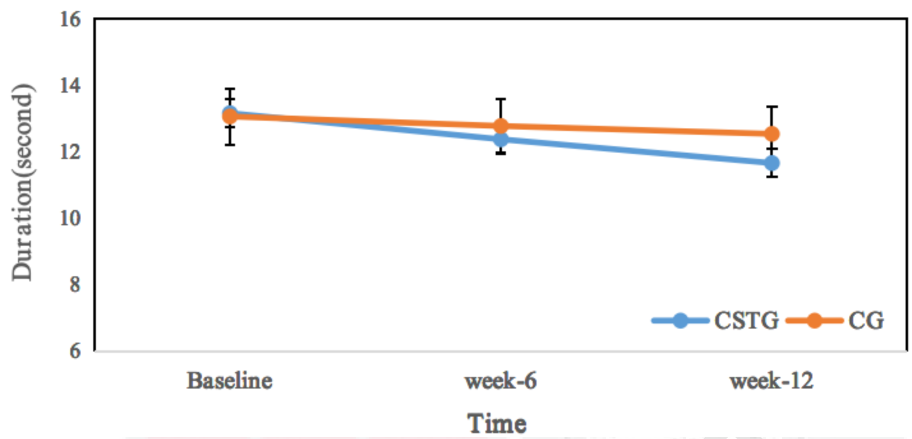

Figure 4.11 : The Mean Scores Changes of Right Arrow Run across the Times for Both Groups

4.5.6 Flexibility

The fifth physical fitness domain was flexibility, and the effects of the core strength training intervention on the SART variables were investigated using the SART. Table 4.23 provides descriptive statistics, including means and standard deviations (SD).

Table 4.23 : Descriptive Statistics (Mean and SD) of Flexibility for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
SART	CSTG	12.063(1.187)	12.221(1.099)	12.504(1.176)
	CG	12.217(1.040)	12.329(0.852)	12.388(1.134)

Noted: SART: sit and reach test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

Table 4.23 summarises the descriptive statistics of the SART variables at different time points for the core strength training group (CSTG) and the control group (CTG). The table covers three periods: baseline, six weeks, and 12 weeks. The data show that the baseline mean SART of the CSTG group was M=12.063 (SD=1.187), which increased to M=12.221 (SD=1.099) at week six and further increased to M=12.504 (SD=1.176) at week 12. In contrast, the baseline mean SART of the CTG group was M=12.217 (SD=1.040), which slightly increased to M=12.329 (SD=0.852) at week 6 and remained almost stable at M=12.388 (SD=1.134) at week 12.

In the flexibility (SART) test, data analysis showed that the time change on SART reached statistical significance (X^2=10.726, p=0.005), indicating that the participants' flexibility performance improved significantly throughout the experiment. In addition, no significant inter-group differences were observed between the core strength training group (CSTG) and the control group (CTG) (X^2=0.028, p=0.867). The interaction between time and group failed to show statistical significance (X^2=1.980, p=0.372), which means that the average performance of the two groups in the flexibility test was similar and did not show significant differences. For more information, see Table 4.24.

Table 4.24 : Results of GEE on Flexibility Score

Variables	Source	Wald-Chi Square	df	p-value
SART	Time	10.726*	2	0.005
	Groups	0.028	1	0.867
	Time * Groups	1.980	2	0.372

Noted: df: degree of freedom; SART: sit and reach test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 significance level.

To evaluate the differences in flexibility (SART) at different time points in the youth male field hockey players, the study used a Bonferroni post hoc test, and the results are shown in Table 4.25. The analysis showed that in the core strength training group (CSTG), the differences in the SART test between baseline and week six (p=0.008),

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baseline and week 12 ($p<0.001$), and week six and week 12 ($p=0.004$) all reached statistical significance. However, in the control group (CTG), the differences between baseline and week six ($p=0.307$), baseline and week 12 ($p=0.250$), and week six and week 12 ($p=0.705$) also failed to show statistical significance. It is worth noting that at week 12, the effect size of the CSTG group was medium ($d=0.37$), while the effect size of the control group was small ($d=0.15$).

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Table 4.25 : Pairwise Comparison of within Group on Flexibility Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
SART	CSTG	Baseline	Week-6	-0.158*	0.059	1	0.008	-0.275	-0.042	0.37(M)
		Baseline	Week-12	-0.442*	0.126	1	<0.001	-0.690	-0.194	
		Week-6	Week-12	-0.283*	0.097	1	0.004	-0.475	-0.092	
	CTG	Baseline	Week-6	-0.112	0.110	1	0.307	-0.328	0.103	0.15(S)
		Baseline	Week-12	-0.171	0.148	1	0.250	-0.462	0.121	
		Week-6	Week-12	-0.058	0.154	1	0.705	-0.361	0.244	

Noted: SART: sit and reach test; CSTG: core strength training group; CTG: control training group; *$p<0.05$ significance level.

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To compare the changes in SART performance between the core strength training group (CSTG) and the control group (CTG) at different time points (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test. According to the results in Table 4.26, the difference in flexibility between the two groups did not reach statistical significance at baseline (p=0.625) and week six (p=0.697). In addition, at week 12, the difference in SART between CSTG and CTG was still insignificant (p=0.721). The effect size analysis further supported this result: at baseline, the effect size was small (d=0.14), the effect size was still small at week six (d=0.11), and the effect size was still small at week 12 (d=0.10).

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Table 4.26 : Pairwise Comparison of between Group on Flexibility Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
SART	Baseline	CSTG	CTG	-0.154	0.315	1	0.625	-0.773	0.464	0.14(S)
	Week-6	CSTG	CTG	-0.108	0.277	1	0.697	-0.653	0.436	0.11(S)
	Week-12	CSTG	CTG	0.117	0.326	1	0.721	-0.523	0.757	0.10(S)

Noted: SART: sit and reach test; CSTG: core strength training group; CTG: control training group; *$p<0.05$ significance level

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Figure 4.12 shows the mean flexibility scores (SART) over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the SART distance increased in both groups and after core strength training, the mean total SART distance of the CSTG increased compared to the CTG in week 12.

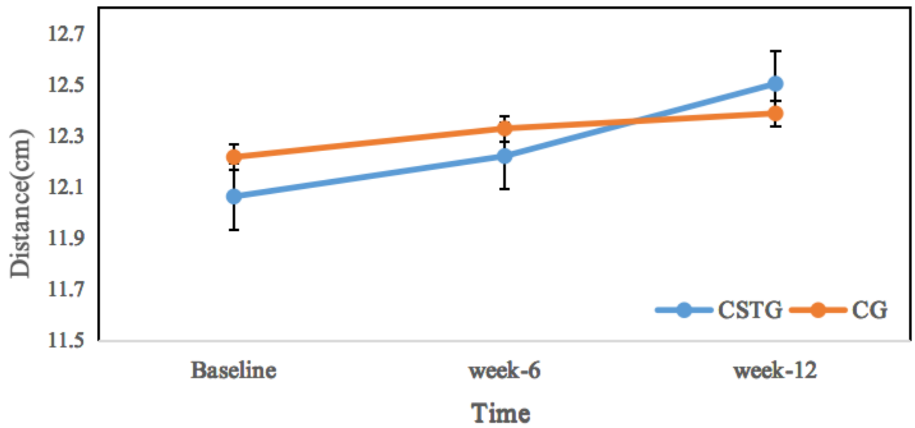

Figure 4.12 : The Mean Scores Changes of Sit and Reach across the Times for Both Groups

4.6 Effects of Core Strength Training on Field Hockey Skills Variables

This section responds to analysing the four hypotheses under the second objective (H07-H010). GEE techniques were applied to evaluate the effects of the intervention on skill changes in adolescent male hockey players and to decide whether to reject or reject the hypotheses.

4.6.1 Dribbling

The first skill area was dribbling, and the SDT test was used to observe the effects of the core strength training intervention on dribbling variables. Table 4.27 provides descriptive statistics, including means and standard deviations (SD).

Table 4.27 : Descriptive Statistics (Mean and SD) of Dribbling for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
SDT	CSTG	25.354 (0.867)	23.969(0.989)	23.003(0.931)
	CG	25.185(0.812)	24.997(0.869)	24.806(0.856)

Noted: SDT: slalom dribble test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

Table 4.27 shows the descriptive statistics of the SDT variables of the core strength training group (CSTG) and the control group (CTG) at different time points, including the mean and standard deviation (SD). The table covers three periods: baseline, six weeks, and 12 weeks. The data show that the baseline mean SDT of the CSTG group was M=25.354 (SD=0.867), which decreased to M=23.969 (SD=0.989) at week six and further decreased to M=23.003 (SD=0.931) at week 12, showing a trend of gradual improvement. In contrast, the mean SDT of the CTG group at baseline was M=25.185 (SD=0.812), which decreased slightly to M=24.997 (SD=0.869) at week six and slightly decreased to M=24.806 (SD=0.856) at week 12, showing a relatively stable change.

In this study, the results of the dribbling test showed that time had a significant effect on the change in SDT performance (X^2=564.579, p<0.001), which means that the participants' SDT performance has significantly improved over time. In addition, the average SDT performance between the two groups (core strength training group and control group) showed a significant difference (X^2=13.374, p<0.001), indicating that there are statistically significant differences between the different groups. More importantly, the interaction between time and group is also statistically significant (X^2=287.613, p<0.001), indicating that the SDT performance of the two groups at different time points (baseline, week six, and week 12) has a significantly different

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trend of change. For more information, see Table 4.28.

Table 4.28 : Results of GEE on Dribbling Score

Variables	Source	Wald-Chi Square	df	p-value
	Time	564.579	2	<0.001
SDT	Groups	13.374	1	<0.001
	Time * Groups	287.613	2	<0.001

Noted: df: degree of freedom; SDT: slalom dribble test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 significance level.

To evaluate the differences in ball dribbling (SDT) among young male field hockey players at different time points, this study used the Bonferroni post hoc test, and the results are shown in Table 4.29. The analysis showed that in the core strength training group (CSTG), the differences in SDT test between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) were statistically significant. Similarly, in the control group (CTG), the differences between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) were also statistically significant. Notably, the effect size was larger in the CSTG group at week 12 ($d=2.61$), indicating that core strength training significantly affected SDT over time. Similarly, the effect size for the control group was also medium ($d = 0.45$).

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Table 4.29 : Pairwise Comparison of within Group on Dribbling Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
SDT	CSTG	Baseline	Week-6	1.385*	0.123	1	<0.001	1.143	1.627	2.61(L)
		Baseline	Week-12	2.350*	0.111	1	<0.001	2.131	2.569	
		Week-6	Week-12	0.965*	0.083	1	<0.001	0.800	1.129	
	CTG	Baseline	Week-6	0.187*	0.036	1	<0.001	0.116	0.258	0.45(M)
		Baseline	Week-12	0.378*	0.045	1	<0.001	0.289	0.468	
		Week-6	Week-12	0.191*	0.027	1	<0.001	0.136	0.246	

Noted: SDT: slalom dribble test; CSTG: core strength training group; CTG: control training group; *$p<0.05$ significance level

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To compare the changes in SDT performance between the core strength training group (CSTG) and the control group (CTG) at different time points (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test. According to the results in Table 4.30, the SDT differences between the two groups were statistically significant at baseline ($p=0.476$) and week six ($p<0.001$). In addition, at week 12, the SDT difference between CSTG and CTG was still significant ($p<0.001$). The effect size analysis further supported this result: at baseline, the effect size was small ($d=0.20$), and the effect size increased significantly to ($d=1.10$) at week six and further increased to ($d=2.01$) at week 12.

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Table 4.30 : Pairwise Comparison of between Group on Dribbling Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
SDT	Baseline	CSTG	CTG	0.169	0.237	1	0.476	-0.296	0.634	0.20(S)
	Week-6	CSTG	CTG	-1.028*	0.263	1	<0.001	-1.544	-0.513	1.10(L)
	Week-12	CSTG	CTG	-1.802*	0.252	1	<0.001	-2.298	-1.306	2.01(L)

Noted: SDT: slalom dribble test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

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Figure 4.13 shows the mean dribbling score over time (SDT). At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the SDT time decreased in both groups, and after core strength training, the mean total SDT time of the CSTG decreased compared to the CTG in week 12.

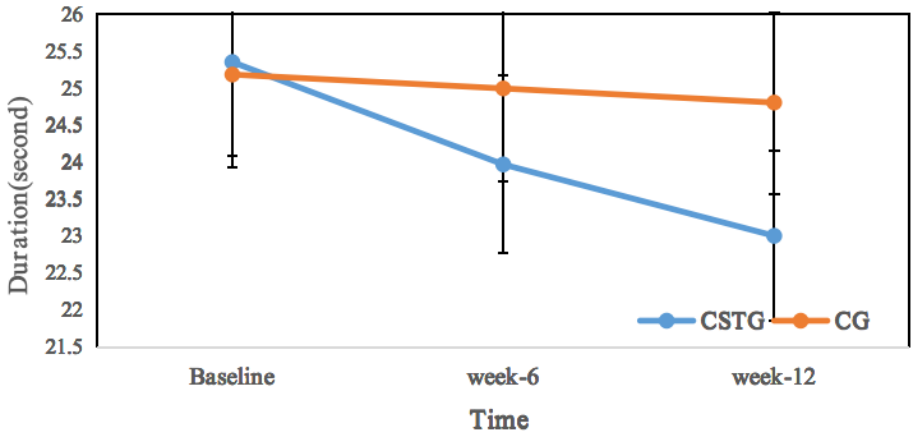

Figure 4.13 : The Mean Scores Changes of Dribbling across the Times for Both Groups

4.6.2 Pulling

The second skill area was the ball pull, and the OMPT test was used to observe the effects of the core strength training intervention on the OMPT variables. Table 4.31 provides descriptive statistics, including means and standard deviations (SD).

Table 4.31 : Descriptive Statistics (Mean and SD) of Pulling for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
OMPT	CSTG	130.583 (10.479)	133.166(10.050)	138.708(9.507)
	CTG	133.500(8.792)	134.458(8.510)	136.833(7.850)

Noted: OMPT: one meter pull test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

Table 4.31 shows the descriptive statistics of the OMPT variables of the core strength training group (CSTG) and the control group (CTG) at different time points, including the mean and standard deviation (SD). The table covers three periods: baseline, six weeks, and 12 weeks. The data showed that the baseline mean OMPT of the CSTG group was M=130.583 (SD=10.479), which increased to M=133.166 (SD=10.050) at week six and further increased to M=138.708 (SD=9.507) at week 12, showing a trend of gradual improvement. In contrast, the mean OMPT of the CTG group at baseline was M=133.500 (SD=8.792), which increased slightly to M=134.458 (SD=8.510) at week six and increased to M=136.833 (SD=7.850) at week 12.

In this study, the results of the ball pull (OMPT) test showed that the OMPT performance improved significantly over time ($X^2=92.006$, $p<0.001$), which means that the performance of the participants changed significantly at each time point of baseline, week six, and week 12. However, the difference in the average OMPT performance between the core strength training group (CSTG) and the control group (CTG) did not reach statistical significance ($X^2=0.094$, $p=0.759$), indicating that there was no significant difference in the overall performance between the two groups. More importantly, the interaction between time and group was statistically significant ($X^2=16.121$, $p<0.001$), indicating that there were significantly different trends in the OMPT performance of the two groups at various time points (baseline, week six, and week 12). For more information, see Table 4.32.

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Table 4.32 : Results of GEE on Pulling Score

Variables	Source	Wald-Chi Square	df	p-value
OMPT	Time	92.006	2	<0.001
	Groups	0.094	1	0.759
	Time * Groups	16.121*	2	<0.001

Noted: df: degree of freedom; OMPT: one meter pull test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 significance level.

To evaluate the differences in OMPT in youth male field hockey players at different time points, the study used a Bonferroni post hoc test, and the results are shown in Table 4.33. The analysis showed that in the core strength training group (CSTG), the differences in the OMPT test between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) all reached statistical significance. In contrast, in the control group (CTG), the difference in the OMPT test between baseline and week six ($p=0.103$) did not reach statistical significance. However, the differences in the test between baseline and week 12 ($p<0.001$) and week six and week 12 ($p=0.006$) also showed statistical significance. Notably, at week 12, the effect size was larger in the CSTG group ($d=0.81$), indicating that core strength training had a more significant effect on OMPT over time. Likewise, the effect size for the control group was moderate ($d=0.40$), indicating that both groups showed significant improvements in OMPT during the study period.

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Table 4.33 : Pairwise Comparison of within Group on Pulling Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
OMPT	CSTG	Baseline	Week-6	-2.583*	0.659	1	<0.001	-3.874	-1.292	0.81(L)
		Baseline	Week-12	-8.125*	0.826	1	<0.001	-9.743	-6.506	
		Week-6	Week-12	-5.541*	0.759	1	<0.001	-7.029	-4.053	
	CTG	Baseline	Week-6	-0.958	0.588	1	0.103	-2.110	0.193	0.40(M)
		Baseline	Week-12	-3.333*	0.863	1	<0.001	-5.025	-1.641	
		Week-6	Week-12	-2.375*	0.864	1	0.006	-4.067	-0.682	

Noted: OMPT: one meter pull test; CSTG: core strength training group; CTG: control training group; *$p<0.05$ significance level

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To compare the changes in OMPT performance between the core strength training group (CSTG) and the control group (CTG) at different time points (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test. According to the results in Table 4.34, the difference in the OMPT test between CSTG and CTG did not reach statistical significance at baseline (p=0.286) and week six (p=0.624). In addition, at week 12, the difference in OMPT between the two groups still did not reach a significant level (p=0.447). The effect size analysis further verified this result: the effect size was medium at baseline (d=0.30), while the effect size decreased to (d=0.14) at week six and remained small at week 12 (d=0.21).

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Table 4.34 : Pairwise Comparison of between Group on Pulling Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
OMPT	Baseline	CSTG	CTG	-2.916	2.733	1	0.286	-8.274	2.440	0.30(M)
	Week-6	CSTG	CTG	-1.291	2.632	1	0.624	-6.449	3.886	0.14(S)
	Week-12	CSTG	CTG	1.875	2.464	1	0.447	-2.953	6.703	0.21(S)

Noted: OMPT: one meter pull test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

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Figure 4.14 shows the mean pull-up scores (OMPT) over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the number of OMPTs increased in both groups and after core strength training, the CSTG's mean total OMPT repetitions increased compared to the CTGs in week 12.

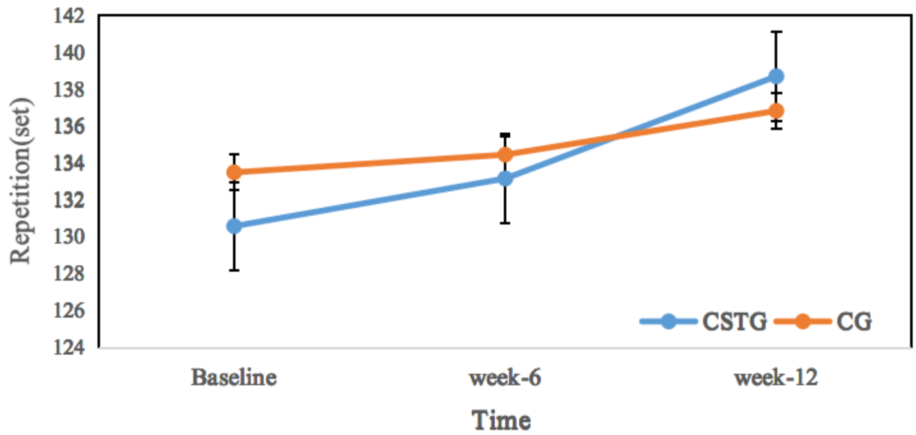

Figure 4.14 : The Mean Scores Changes of Pulling across the Times for Both Groups

4.6.3 Passing

The third skill area was passing, and the effects of the core strength training intervention on passing variables were observed through the forehand passing (FPT) and backhand passing (BPT) tests. Table 4.35 provides descriptive statistics, including means and standard deviations (SD).

Table 4.35 : Descriptive Statistics (Mean and SD) of Passing for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
FPT	CSTG	10.458(1.413)	10.666(1.606)	11.250(1.188)
	CG	11.041(1.301)	11.166(1.609)	11.375(1.636)
BPT	CSTG	9.125(1.075)	9.541(1.020)	10.291(1.334)
	CG	8.708(1.731)	9.333(1.404)	9.667(1.633)

Noted: FPT: forehand pass test; BPT: backhand pass test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

Table 4.35 shows the descriptive statistics of the FPT variable at different time points for the core strength training group (CSTG) and the control group (CTG), including the mean and standard deviation (SD). The table covers three periods: baseline, six weeks, and 12 weeks. The data show that the mean FPT of the CSTG group at baseline was M=10.458 (SD=1.413), slightly increased to M=10.666 (SD=1.606) at week six and rose to M=11.250 (SD=1.188) at week 12. In contrast, the mean FPT of the CTG group at baseline was M=11.041 (SD=1.301), remained almost unchanged at week six, at M=11.166 (SD=1.609), and slightly increased to M=11.375 (SD=1.636) at week 12.

Table 4.35 shows the descriptive statistics of the BPT variables at different time points for the core strength training group (CSTG) and the control group (CTG), including the mean and standard deviation (SD). The table covers three periods: baseline, six weeks, and 12 weeks. The data showed that the mean BPT of the CSTG group at baseline was M=9.125 (SD=1.075), which increased to M=9.541 (SD=1.020) at week six, and further increased to M=10.291 (SD=1.334) at week 12. In contrast, the mean BPT of the CTG group at baseline was M=8.708 (SD=1.731), which increased to M=9.333 (SD=1.404) at week six and slightly increased to M=9.667 (SD=1.633) at week 12.

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The forehand pass (FPT) test results showed that FPT performance improved significantly over time (X^2=10.878, p=0.004), which means that the participants' performance changed substantially at each time point of baseline, week six, and week 12. However, the difference in the average FPT performance between the core strength training group (CSTG) and the control group (CTG) did not reach statistical significance (X^2=1.241, p=0.265), indicating that there was no significant difference in overall performance between the two groups. More importantly, the interaction between time and group did not show statistical significance (X^2=1.994, p=0.368), indicating significantly different trends in the FPT performance of the two groups at various time points (baseline, week six, and week 12). For more information, see Table 4.36.

Table 4.36 : Results of GEE on Passing Score

Variables	Source	Wald-Chi Square	df	p-value
	Time	10.878*	2	0.004
FPT	Groups	1.241	1	0.265
	Time * Groups	1.994	2	0.368
	Time	48.014*	2	<0.001
BPT	Groups	1.305	1	0.253
	Time * Groups	4.270	2	0.118

Noted: df: degree of freedom; FPT: forehand pass test; BPT: backhand pass test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 significance level.

The results of the backhand pass (BPT) test showed that BPT performance improved significantly over time (X^2=48.014, p<0.001), which means that the performance of the participants changed substantially at each time point of baseline, week six, and week 12. However, the difference in the average BPT performance between the core strength training group (CSTG) and the control group (CTG) did not reach statistical significance (X^2=1.305, p=0.253), indicating that there was no significant difference

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in overall performance between the two groups. In addition, the interaction between time and group was not statistically significant (X^2=4.270, p=0.118), indicating significantly different trends in the BPT performance of the two groups at various time points (baseline, week six, and week 12). For more information, see Table 4.36.

To evaluate the differences in forehand passing (FPT) among young male field hockey players at different time points, this study used the Bonferroni post hoc test, and the results are shown in Table 4.37. The analysis results showed that in the core strength training group (CSTG), the differences in FBT between baseline and week six (p=0.054) and week six and week 12 (p=0.056) were not statistically significant. However, the difference in FBT between baseline and week 12 (p=0.007) was statistically significant. For the control group (CTG), the differences in FPT between baseline and week six (p=0.509), baseline and week 12 (p=0.112), and week six and week 12 (p=0.113) were also not statistically significant. In addition, at week 12, the effect size of the CSTG group was medium (d=0.60), while the effect size of the CTG group was small (d=0.22).

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Table 4.37 : Pairwise Comparison of within Group on Passing Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
FPT	CSTG	Baseline	Week-6	-0.208	0.312	1	0.054	-0.819	0.402	0.60(M)
		Baseline	Week-12	-0.791	0.295	1	0.007	-1.368	-0.214	
		Week-6	Week-12	-0.583	0.306	1	0.056	-1.182	0.015	
	CTG	Baseline	Week-6	-0.125	0.189	1	0.509	-0.495	0.245	0.22(S)
		Baseline	Week-12	-0.333	0.210	1	0.112	-0.744	0.077	
		Week-6	Week-12	-0.208	0.131	1	0.113	-0.466	0.049	
BPT	CSTG	Baseline	Week-6	-0.416*	0.176	1	0.018	-0.761	-0.071	0.96(L)
		Baseline	Week-12	-1.167*	0.248	1	<0.001	-1.652	-0.681	
		Week-6	Week-12	-0.750*	0.189	1	<0.001	-1.119	-0.380	
	CTG	Baseline	Week-6	-0.625*	0.142	1	<0.001	-0.903	-0.346	0.57(M)
		Baseline	Week-12	-0.958*	0.181	1	<0.001	-1.313	-0.602	
		Week-6	Week-12	-0.333*	0.113	1	0.003	-0.554	-0.112	

Noted: FPT: forehand pass test; BPT: backhand pass test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

To evaluate the differences in backhand passing (BPT) among young male field hockey players at different time points, this study used the Bonferroni post hoc test, and the results are shown in Table 4.37. The results showed that in the core strength training group (CSTG), the differences in BPT between baseline and week six ($p=0.018$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.001$) were all statistically significant. For the control group (CTG), the differences in BPT between baseline and week six ($p<0.001$), baseline and week 12 ($p<0.001$), and week six and week 12 ($p<0.003$) were statistically significant. At week 12, the effect size of the CSTG group was large ($d=0.96$), indicating that core strength training significantly improved BPT. In contrast, the effect size of the CTG group was medium ($d=0.57$), suggesting that its BPT improvement effect was relatively limited.

To compare the FPT scores of the two groups at different periods (baseline, week six, and week 12), this study used the Bonferroni post hoc test, as shown in Table 4.38. The results showed that there w as no significant statistical difference in the FPT scores between the CSTG and CTG groups at baseline ($p=0.129$), week six ($p=0.271$), and week 12 ($p=0.757$). Further analysis of the effect size at different time points showed that the effect size at baseline ($d=0.43$) and week six ($d=0.31$) was moderate, while at week 12, the effect size was small ($d=0.10$).

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Table 4.38 : Pairwise Comparison of between Group on Passing Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
FPT	Baseline	CSTG	CTG	-0.583	0.384	1	0.129	-1.335	0.169	0.43(M)
	Week-6	CSTG	CTG	-0.500	0.454	1	0.271	-1.389	0.389	0.31(M)
	Week-12	CSTG	CTG	-0.125	0.404	1	0.757	-0.917	0.667	0.10(S)
BPT	Baseline	CSTG	CTG	0.416	0.407	1	0.306	-0.381	1.215	0.29(S)
	Week-6	CSTG	CTG	0.208	0.347	1	0.548	-0.471	0.888	0.17(S)
	Week-12	CSTG	CTG	0.625	0.421	1	0.138	-0.201	1.451	0.42(M)

Noted: FPT: forehand pass test; BPT: backhand pass test; CSTG: core strength training group; CTG: control training group; *$p<0.05$ significance level.

To compare the BPT scores of the two groups at different time points (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test, and the results are shown in Table 4.38. The analysis results showed that there was no significant statistical difference in the BPT scores between CSTG and CTG at baseline (p=0.306), week six (p=0.548), and week 12 (p=0.138). The effect size was further calculated, and the effect size was small at baseline (d=0.29) and week 6 (d=0.17), and by week 12, the effect size was medium (d=0.42).

Figure 4.15 shows the average forehand pass points (FPT) over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, at week 6, FPT increased in both groups, while at week 12, there was no statistically significant difference between the CSTG and CTG groups.

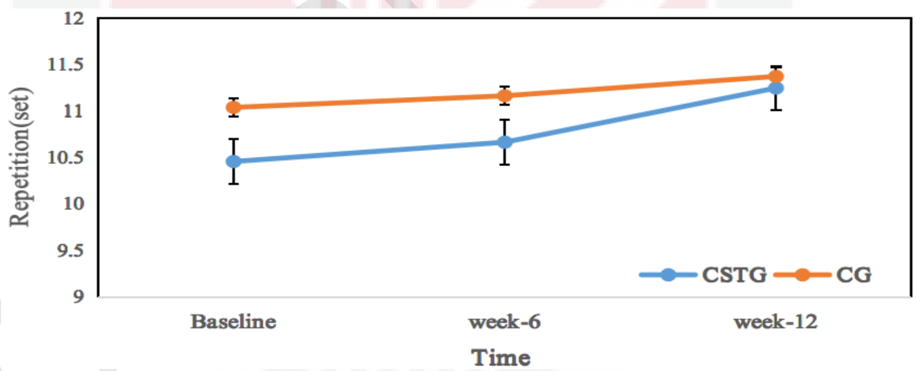

Figure 4.15 : The Mean Scores Changes of Forehand Pass across the Times for Both Groups

Figure 4.16 shows the average backhand pass score (BPT) over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the BPTs increased in both groups and after core strength training, the average total BPTs increased in the CSTG compared to the CTG in week 12.

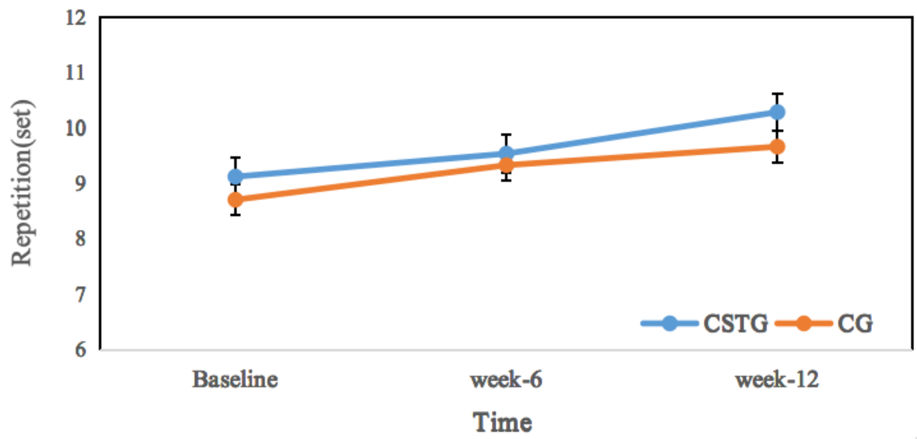

Figure 4.16 : The Mean Scores Changes of Backhand Pass across the Times for Both Groups

4.6.4 Shooting Accuracy

The fourth skill area was shooting accuracy, and the effect of the core strength training intervention on the shooting accuracy variable was observed through the SAT. Table 4.39 provides descriptive statistics, including means and standard deviations (SD).

Table 4.39 : Descriptive Statistics (Mean and SD) of Shooting Accuracy for Both Groups across the Time

Variable	Groups	Baseline	6-week	12-week
SAT	CSTG	2.625 (1.172)	2.916(0.974)	4.083(0.880)
	CG	2.875(0.947)	3.041(1.082)	3.125(1.076)

Noted: SAT: shooting accuracy test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

Table 4.39 shows the descriptive statistics of the SAT variable at different time points for the core strength training group (CSTG) and the control group (CTG), including the mean and standard deviation (SD). The table covers three periods: baseline, six weeks, and 12 weeks. The data show that the mean SAT of the CSTG group at baseline was M=2.625 (SD=1.172), which increased to M=2.916 (SD=0.974) at week six and further increased to M=4.083 (SD=0.880) at week 12, showing a trend of gradual

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improvement. In contrast, the mean SAT of the CTG group at baseline was M=2.875 (SD=0.947), which increased slightly to M=3.041 (SD=1.082) at week six and remained relatively stable at M=3.125 (SD=1.076) at week 12.

In this study, the results of the SAT showed that the shooting accuracy performance improved significantly over time (X^2=38.134, $p<0.001$), which means that the participants' shooting performance changed significantly at baseline, week six, and week 12. However, the difference in the average shooting accuracy performance between the core strength training group (CSTG) and the control group (CTG) did not reach statistical significance (X^2=0.627, $p=0.428$), indicating that there was no significant difference in the overall performance between the two groups. More importantly, the interaction between time and group was statistically significant (X^2=23.054, $p<0.001$), indicating that the SAT performance of the two groups at different time points (baseline, week six, and week 12) had significantly different trends. For more information, see Table 4.40.

Table 4.40 : Results of GEE on Shooting Accuracy Score

Variables	Source	Wald-Chi Square	df	p-value
	Time	38.134*	2	<0.001
SAT	Groups	0.627	1	0.428
	Time * Groups	23.054*	2	<0.001

Noted: df: degree of freedom; SAT: shooting accuracy test; CSTG: core strength training group; CTG: control training group; SD: standard deviation; *p<0.05 significance level.

To evaluate the differences in SAT at different time points in the youth male field hockey players, the study used the Bonferroni post hoc test, and the results are shown in Table 4.41. The analysis showed that in the core strength training group (CSTG), the difference in the SAT between baseline and week six ($p=0.070$) did not reach

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statistical significance. However, the differences in SAT between baseline and week 12 ($p<0.001$) and between week six and week 12 ($p<0.001$) reached statistical significance. In contrast, in the control group (CTG), the differences in SAT between baseline and week six ($p=0.408$) and baseline and week 12 ($p=0.261$) and week six and week 12 ($p=0.653$) did not reach statistical significance. Notably, at week 12, the effect size was larger in the CSTG group ($d = 1.40$), indicating that time had a large effect on SA, whereas the magnitude effect size in the CTG was smaller ($d = 0.24$).

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Table 4.41 : Pairwise Comparison of within Group on Shooting Accuracy Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
SAT	CSTG	Baseline	Week-6	-0.291	0.161	1	0.070	-0.607	0.024	1.40(L)
		Baseline	Week-12	-1.458*	0.195	1	<0.001	-1.841	-1.075	
		Week-6	Week-12	-1.166*	0.163	1	<0.001	-1.486	-0.846	
	CTG	Baseline	Week-6	-0.166	0.201	1	0.408	-0.561	0.227	0.24(S)
		Baseline	Week-12	-0.250	0.222	1	0.261	-0.685	0.185	
		Week-6	Week-12	-0.083	0.186	1	0.653	-0.447	0.280	

Noted: SAT: shooting accuracy test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level.

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To compare the changes in SAT performance between the core strength training group (CSTG) and the control group (CTG) at different time points (baseline, week six, and week 12), the researchers used the Bonferroni post hoc test. According to the results in Table 4.42, the difference in SAT between CSTG and CTG did not reach statistical significance at baseline (p=0.407) and week six (p=0.668). However, at week 12, the SAT difference between the two groups reached a significant level (p=0.001). The effect size analysis further verified this result: the effect size at baseline was larger than smaller (d=0.23), the effect size at week six was smaller (d=0.12), and the effect size at week 12 was larger (d=0.97).

Table 4.42 : Pairwise Comparison of between Group on Shooting Accuracy Score

Variables	Test	(I) Test	(J) Test	Mean Difference (I-J)	SE	df	p-value	95%CIFor Difference		d
								LB	UB	
SAT	Baseline	CSTG	CTG	-0.250	0.301	1	0.407	-0.840	0.340	0.23(S)
	Week-6	CSTG	CTG	-0.125	0.291	1	0.668	-0.695	0.445	0.12(S)
	Week-12	CSTG	CTG	0.958*	0.278	1	0.001	0.413	1.502	0.97(L)

Noted: SAT: shooting accuracy test; CSTG: core strength training group; CTG: control training group; *p<0.05 significance level

Figure 4.17 shows the mean shooting accuracy scores (SAT) over time. At baseline, there was no statistically significant difference between the CSTG and CTG groups. However, in week six, the SAT scores of both groups increased, and after core strength training, the CSTG's mean total SAT scores increased compared to the CTG's in week 12.

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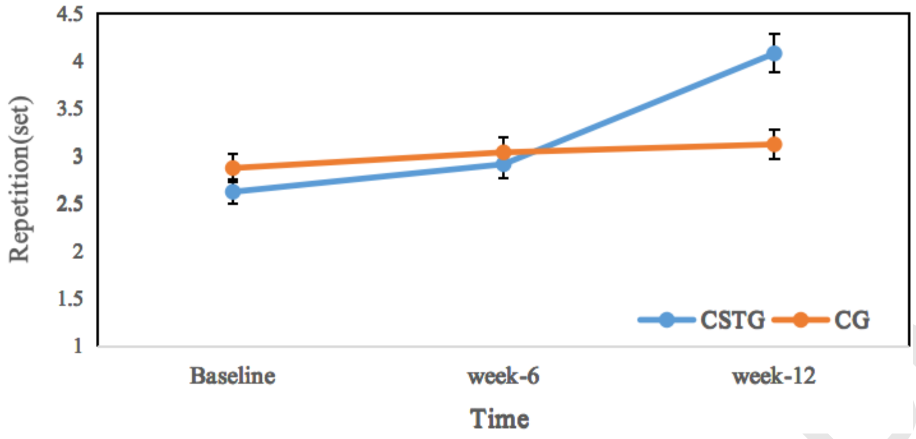

Figure 4.17 : The Mean Scores Changes of Shooting Accuracy across the Times for Both Groups

4.7 Comparisons of the Effect Size between Groups

Effect size is a quantitative measure that reflects the magnitude of a difference or relationship between variables, independent of the sample size. While p-values are commonly used to assess whether a result is statistically significant, they do not indicate the practical importance of an observed effect. In contrast, effect size offers insight into the real-world relevance and practical impact of the intervention outcomes, especially in experimental and applied research settings (Lakens, 2022).

Table 4.43 summarises the effects on physical fitness and hockey skill variables. This study calculated 163mphasized163d mean differences to compare baseline and post-training values. Cohen (1988) defined effect sizes as "small, d = .2," "medium, d = .5," and "large, d = .8." Larger effect sizes were observed in all physical fitness and hockey skill variables in the CSTG compared to the CTG, see Table 4.43 for details. However, larger effect sizes were observed in the physical fitness variables (strength: d = 3.63) and the field hockey skill variables (dribbling: d = 2.61). Effect sizes for physical fitness and hockey skill variables in the CTG ranged from small to large (d =

0.15-0.80). See Table 4.43 for details. This study showed that a 12-week core strength training intervention showed large effect sizes and statistically significant results compared to the control training group.

Table 4.43 : Comparisons of the Effect Size between CSTG and CTG at Baseline and Week 12

Variables		Groups	Baseline	Week-12	Effect
			Mean (SD)	Mean(SD)	Sized
Physical Fitness	Strength (PU)	CSTG	47.875(1.895)	51.500(2.340)	1.70(L)
		CTG	47.333(1.857)	48.750(1.750)	0.66(M)
	Strength (SU)	CSTG	48.166(1.880)	54.125(1.361)	3.63(L)
		CTG	48.250(1.594)	48.875(1.585)	0.39(M)
	Strength (BS)	CSTG	76.458(7.868)	87.083(8.189)	1.32(L)
		CTG	75.833 (6.19)	80.833(6.702)	0.80(L)
	Power (LGB)	CSTG	10.623(1.004)	11.833(1.054)	1.17(L)
		CTG	10.903(0.933)	11.110(1.008)	0.21(M)
	Power (RGB)	CSTG	11.112(0.816)	11.939(1.030)	0.90(L)
		CTG	11.039(0.811)	11.208(0.851)	0.20(S)
	Power (SLJ)	CSTG	248.250(4.927)	258.416(4.853)	2.07(L)
		CTG	250.250 (4.336)	253.041(5.691)	0.55(M)
	Speed (25-yards sprint)	CSTG	3.859(0.066)	3.816(0.065)	0.66(M)
		CTG	3.863(0.074)	3.851(0.073)	0.16(S)
	Speed (50-yards sprint)	CSTG	6.863(0.106)	6.694(0.085)	1.75(L)
		CTG	6.822(0.120)	6.797(0.124)	0.20(S)
	Endurance(300-yards)	CSTG	1.105(0.022)	1.077(0.020)	1.33(L)
		CTG	1.102(0.015)	1.097(0.018)	0.30(M)
	Agility (LAR)	CSTG	16.279(0.570)	15.414(0.501)	1.61(L)
		CTG	15.971(0.553)	15.821(0.560)	0.27(M)
	Agility (RAR)	CSTG	13.163(0.960)	11.661(0.891)	1.62(L)
		CTG	13.065(0.842)	12.540(0.803)	0.64(M)
	Flexibility (SAR)	CSTG	12.063(1.187)	12.504(1.176)	0.37(M)
		CTG	12.217(1.040)	12.388(1.134)	0.15(S)
Hockey Skills	Dribbling (SDT)	CSTG	25.354 (0.867)	23.003(0.931)	2.61(L)
		CTG	25.185(0.812)	24.806(0.856)	0.45(M)
	Pulling (OMPT)	CSTG	130.583 (10.479)	138.708(9.507)	0.81(L)
		CTG	133.500(8.792)	136.833(7.850)	0.40(M)
	Passing (FPT)	CSTG	10.458(1.413)	11.250(1.188)	0.60(M)
		CTG	11.041(1.301)	11.375(1.636)	0.22(S)
	Passing (BPT)	CSTG	9.125(1.075)	10.291(1.334)	0.96(L)
		CTG	8.708(1.731)	9.667(1.633)	0.57(M)
	Shooting accuracy (SA)	CSTG	2.625 (1.172)	4.083(0.880)	1.40(L)
		CTG	2.875(0.947)	3.125(1.076)	0.24(M)

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CHAPTER 5

DISCUSSION, CONCLUSION, IMPLICATION, AND RECOMMENDATION FOR FUTURE STUDY

5.1 Introduction

This chapter discusses the results (physical fitness and field hockey skills), conclusion, implication, and recommendations for future study.

5.2 Discussion on Physical Fitness Variables

The primary purpose of this section is to analyse the results of the six variables in detail in the context of the study's first objective. To the best of our knowledge, this study marks the initial assessment of the effects of core strength training on the physical performance of young male field hockey players. Therefore, this section focuses on analysing the effects of core strength training on the physical performance of youth male field hockey players in China and comparing the results with the existing literature. At the same time, possible explanations for these results and their application in improving physical fitness levels are explored. The discussion starts with strength and then gradually discusses power, speed, endurance, agility, and flexibility.

5.2.1 Discussion on Strength

The results of strength showed that there was no statistically significant difference between baseline and week six ($P>0.05$), and only SU at week six showed a statistically significant difference ($P<0.05$). In addition, in CSTG and CTG, PU, SU, and BS showed substantial differences between baseline and week six, between

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baseline and week 12, and between week six and week 12 (P<0.05). The following discussion will give a more detailed explanation.

Studies have yet to report the effects of core strength training on hockey players' strength. However, this study showed that core strength training positively affected strength performance in adolescent male hockey players, especially between the sixth and twelfth weeks. This means that core strength training for adolescent male hockey players should be continued for at least twelve weeks. In addition, there was also a significant increase in SU between the sixth and twelfth weeks.

In their study, Manna et al. (2010) 166mphasized that upper body strength is vital in powerful hitting, shooting, and passing. Hockey players must adopt a half-squat or lunge posture to perform many movements effectively. Both postures require strength in the waist, abdomen, and lower limbs. Therefore, the results of this study do not support the view that a six-week core strength training intervention can improve strength levels (except for SU). Regarding the core strength training intervention program, the strength of hockey players still needs to be explored. Some studies have shown that four to six weeks of intervention can significantly improve athletes' strength performance. For example, Akbulut et al. (2020) conducted a four-week core strength training program, and the results showed that it can significantly improve the performance of professionally trained male athletes aged between 19 and 27 years old. The same results were reported in the study of Prieske et al. (2016), who found that a six-week core strength training program significantly improved the strength of elite adolescent male soccer players. Allen et al. (2014) conducted a six-week core strength training program to enhance substantially adolescents' abdominal strength. These

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studies' results differ from those of the present study, and the inconsistent results may be due to the diversity of athlete types and training backgrounds.

However, a previous study confirmed that a core strength training program lasting eight weeks or longer significantly affects the strength performance of athletes. After eight weeks of core strength training, Jing (2023) documented significant differences in lower extremity strength performance in professional Taekwondo athletes. In addition, Hong's study showed significant differences in upper extremity strength performance (assessed by pull-ups and grip strength tests) in male collegiate athletes after completing a ten-week core strength training program (Hong, 2020). Therefore, these studies conclude that core strength training can significantly improve athlete strength performance. In addition, it is worth noting that these studies all adopted a three-times-per-week approach (Hong, 2020; Jing, 2023). Therefore, the results of this study indicate that a 12-week, three-times-per-week core strength training intervention can significantly improve the strength performance of adolescent male hockey players.

5.2.2 Discussion on Power

The power data showed no statistically significant difference between the groups at baseline and week six (P>0.05). However, in week 12, there was a statistically significant difference between the groups in gravity ball (LGB and RGB) and standing long jump (SLJ) (P<0.05). In addition, there were statistically significant differences in CSTG and CTG between baseline and week six, between baseline and week 12, and between weeks six and 12 (P<0.05). CTG did not differ significantly between week six and week 12 of LGB (P>0.05). The following discussion will give a more detailed explanation.

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Upper body power is crucial in hockey; whether it is breaking through the defence, advancing with the ball, or stealing the ball from the opponent's stick, it depends on strong upper body power. Upper solid bodies can also help players exert more force when shooting while increasing the distance and accuracy of passing (Naicker et al., 2016). This study specifically tested upper body power using a gravity ball (left and right). The results positively affect upper body power, indicating that core strength training is beneficial. Kaur et al. (2018) found that medicine ball throwing was a significant predictor of performance in hockey. This study included core strength training of the upper body through various medicine ball exercises, which may play a key role in enhancing upper body power in adolescent male hockey players.

Previous studies have shown that core strength training significantly improves athletes' upper limb power. For example, Jha et al. (2022) found that five weeks of core strength training significantly enhanced the upper limb power of college athletes. Similarly, Shinkle et al. (2012) pointed out that after eight weeks of core strength training, professional football players' upper limb strength was significantly improved. In a study, Kim tested the tee performance of 17 female professional golfers after twelve weeks of core strength training, and the results showed that their ball speed, club head speed, and flight distance were significantly improved (Kim, 2010). In addition, Bejan et al. (2013) revealed the biomechanical similarities between golf and hockey in upper limb power generation. Both sports rely on generating rotational force through the kinetic chain from the lower body, core to the upper body to achieve powerful shots. These studies further support the conclusion of this study that core strength training is significantly effective in improving youth hockey players' upper limb power performance.

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In terms of lower extremity muscle power in the standing long jump (SLJ), this study is consistent with previous studies that demonstrated the positive effects of core strength training on athletes' standing long jump (SLJ) performance. In a study, Granacher et al. (2014) showed that 13 adolescents showed significant improvements in SLJ test performance after a six-week core strength training intervention. Similarly, Taskin (2016) studied the effects of core training on the physical fitness of professional female soccer players and found that 20 female soccer players had significant improvements in SLJ performance after eight weeks of training. Dinç and Ergin (2019) also observed that 15 professional athletes had significantly improved SLJ performance after eight weeks of core strength training. Hong (2020) further supported this finding, reporting that male college students had improved considerably SLJ performance after ten weeks of core strength training.

In addition, the results of this study are consistent with previous studies, further demonstrating the positive effects of 12 weeks of core strength training on athletes' power performance. Kumar and Zemková (2022) showed that 12 weeks of core strength training was efficient and timesaving and significantly enhanced the muscle power of school-age athletes. Similarly, Shu's study concluded that a 12-week core strength training intervention effectively improved the muscle strength of martial arts athletes (Shu, 2022). Wei (2023) study also supported this conclusion, pointing out that a 12-week core strength training program significantly improved the muscle power of badminton players. Together, these studies have demonstrated that 12 weeks of core strength training has an essential impact on muscle power and strength in various sports, supporting this study's results.

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Although much literature has explored the effects of core strength training on athletes' physical fitness (Feng et al., 2024; Mossa, 2022; Ozmen & Aydogmus, 2016; Yılmaz, 2022), few studies directly study the effects of core strength training on adolescent male hockey players. This study further confirmed the effectiveness of core strength training in improving the power performance of adolescent male hockey players through empirical data. This finding fills the gap in the existing literature and provides a basis for conducting more empirical research in this field in the future.

5.2.3 Discussion on Speed

In the speed tests (25 and 50 yards), the results showed that the inter-group differences in the 25-yards sprint test did not reach statistical significance in any of the three tests ($p>0.05$). However, the results of the within-group test showed significant differences ($p<0.05$). For the 50-yard test, no statistical significance was found in the inter-group comparison between baseline and week six ($p>0.05$), but by week 12, the inter-group differences reached statistical significance ($p<0.05$). In addition, the experimental group (CSTG) showed significant differences in speed improvement between baseline to week six, baseline to week 12, and week six to week 12 ($p<0.05$).

This study showed that the core strength training intervention did not produce a statistically significant difference in the 25-yards sprint performance of adolescent male hockey players throughout six to 12 weeks. This suggests that core strength training does not provide additional advantages in improving 25-yards sprint performance compared with standard training. However, the effect size analysis showed that CSTG ($d=0.66$) showed a moderate time effect in the 25-yards sprint test, while CTG ($d=0.16$) showed only a tiny time effect. Therefore, core strength training

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is superior to standard training in improving the 25-yards sprint performance of adolescent male hockey players.

In contrast, the results of the 50-yard speed test showed statistically significant differences within the same period, indicating that core strength training significantly improved the 50-yards sprint performance of adolescent male hockey players. Effect size analysis further supported this conclusion, with CSTG (d=1.75) showing a significant time effect in the 50-yards sprint test, while CTG (d=0.20) had a relatively small-time effect. Therefore, the results indicate that core strength training is significantly superior to standard training in improving athletes' speed performance, especially in the 50-yards sprint test.

In the research on the effect of core strength training on speed performance, much literature has shown that short-term interventions (four weeks or eight weeks) have no significant effect on short-distance sprint speed. For example, the study by Yılmaz (2022) showed that the 20-meter speed run did not show a significant difference after a four-week core strength training intervention. Similarly, Genç and Ciğerci (2020) found that eight weeks of core strength training had no significant difference in young football players' 10-meter and 30-meter speed runs. The study by Sever and Zorba (2018) also concluded that eight weeks of core strength training failed to significantly improve football players' 10-meter to 30-meter sprint speed.

The results of this study are consistent with these previous studies, further suggesting that short-term core strength training has limited direct effects on very short-distance sprint performance. This result can be partially attributed to the researchers' design

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intention to simulate the actual environment in competitive sports as much as possible (Tomljanović et al., 2011). Studies have shown that short distance sprinting mainly evaluates the acceleration phase and relies on lower limb explosive power and initial stride length, while the main effect of core strength training is to improve overall stability and force transfer. The effect of core strength training on explosive power in very short periods is relatively limited (Doğanay et al., 2020). This explains why core strength training failed to produce significant differences in short-distance sprinting and supports the conclusions of this study.

However, another measure of speed testing is the 50-yard dash. This study's results support previous studies (Afyon et al., 2017; Mossa, 2022; Taskin, 2016; Wang, 2022). These studies have shown that core strength training can help athletes maintain higher speeds and better energy transfer efficiency during long-distance sprints by enhancing core stability and force transfer. Researchers have found that core strength training can increase the sprint speed of football players (Bayrakdar et al., 2020; Doğan et al., 2016; Yapici, 2016). In addition, core strength training programs have been shown to increase running speed in male college athletes(Hong, 2020).

According to a cross-sectional study by Koçak et al. (2022), core strength training was superior to traditional strength training in improving repeated sprint performance in soccer players. However, Prieske et al. (2016) found that combining core strength training with other forms of exercise (e.g., unstable surface (CSTU) + core strength training) resulted in more significant improvements in speed than core strength training alone. Participants in the combined training group may have received more training than those in the other groups; in other words, the total workload may not

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have been balanced between the groups (Villarreal et al., 2015). Several studies have shown that core strength training should last at least eight weeks to improve athletes' speed performance (Afyon et al., 2017; Aslan & Kahraman, 2023; Kabadayı et al., 2022; Wondale et al., 2021).

Numerous studies have demonstrated the effectiveness of core strength training in improving speed performance in athletes. Sofuoğlu et al. (2024) showed that a 12-week core strength training program significantly improved sprint speed in adolescent male soccer players. Mossa (2022) reached similar conclusions, reporting increased sprint speed in soccer players after 12 weeks of core strength training. Similarly, Lu et al. (2022) observed significant improvements in speed performance in adolescents after 12 weeks of core strength training. Consistent with these findings, the present study demonstrated that a 12-week core strength training program can improve 50-meter sprint speed in adolescent male hockey players.

5.2.4 Discussion on Endurance

In the endurance (300-yards switchback run) test results of this study, the intergroup comparison between the experimental group (CSTG) and the control group (CTG) did not show statistically significant differences between baseline and week six ($P>0.05$). However, after completing the 12-week training, the intergroup differences reached statistical significance ($P<0.05$). Further analysis showed that CSTG was significantly improved between baseline and week 6 ($P<0.05$), while CTG of standard training did not show significant differences at the same time points ($P>0.05$). In addition, CSTG and CGT also showed statistically significant differences between baseline and week 12 and between week six and week 12 ($P<0.05$). The following discussion will give a

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more detailed explanation.

The results showed that six weeks of core strength training had a significant effect on improving the endurance of adolescent male hockey players, which was verified in the CSTG group. After 12 weeks of training, the endurance scores of the groups were significantly different, further supporting the hypothesis that "core strength training can significantly improve the endurance level of adolescent male hockey players." Both core strength training and standard training methods positively impacted the participants' endurance performance, and each produced additional benefits on different aspects of endurance and brought additional benefits on specific components of endurance levels (Lu et al., 2022).

In this study, the endurance level of adolescent male hockey players is expected to improve after standard training because studies have shown that standard training programs can effectively enhance endurance levels (Manna et al., 2010). Although there was no significant difference in the baseline data between the two groups ($p>0.05$), the average endurance level of the core strength training group (CSTG) was significantly higher than that of the control group (CTG) at the 6th and 12th weeks under the same intervention time. The relevant literature also supports this finding. A study by Clark reported that a six-week core strength training program significantly improved the aerobic endurance level of high school students (Clark et al., 2017). The study by Anant et al. (2014) showed that eight weeks of core strength training also significantly improved the endurance of male college athletes. Similar results were also found in the study by Demir and Serin (2023), where eight weeks of core strength training had a significant effect on the aerobic endurance of adolescent male

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taekwondo athletes. Research has also shown that the endurance of adolescent male athletes increases with age and that elite athletes generally improve more than average athletes (Armstrong & Barker, 2011). Therefore, future research should further explore the specific effects of core strength training on the endurance performance of elite male hockey players.

The results of this study showed that a 12-week core strength training program significantly improved the endurance level of adolescent male hockey players. This is consistent with previous research. For example, Lu et al. (2022) showed that 12 weeks of core strength training significantly enhanced the endurance of adolescents. Similarly, Nan (2022) showed that 12 weeks of core strength training also improved the aerobic endurance of adolescent middle- and long-distance runners. This view is further supported by the research of Kumar and Zemková (2022), who reported that 12 weeks of core strength training effectively improved the aerobic endurance of school-age athletes.

It is not difficult to explain that studies have shown that as athletes' endurance and strength gradually deplete, the decline in core stability will affect their running posture and overall performance. Core strength training can enhance the stability of the trunk, abdomen, lower back, and hips, which can help athletes maintain good posture and physical performance during long-term aerobic exercise, thereby reducing energy waste and improving endurance performance (Hong, 2020; Nan, 2022). Therefore, the results of this study are consistent with previous studies, showing that core strength training is more effective than standard training in improving the endurance level of young male hockey players.

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5.2.5 Discussion on Agility

The agility data (LART and RART) showed that no statistical significance was found in the intergroup comparison between baseline and week six ($p>0.05$). However, by week 12, the difference between the groups reached statistical significance ($p<0.05$). In addition, the improvement of LART and RART between baseline to week 6, baseline to week 12, and week six to week 12 in CSTG and CTG within the group showed significant differences ($p<0.05$). The following discussion will give a more detailed explanation.

In this study, we observed the effects of core strength training on agility in adolescent male hockey players, especially during weeks 6–12. At the end of 12 weeks, there was a significant difference between CSTG and CTG, although there was no significant difference between agility performances after six weeks. This improvement suggests that core strength training should be performed for at least 12 weeks to improve agility performance in adolescent male hockey players.

In previous studies, the minimum time required to observe significant differences in agility performance after core strength training was four weeks. The effects of a core strength training intervention on pre-adolescent basketball players were examined. Analysis of agility data collected within four weeks revealed significant differences (Yılmaz, 2022). However, conflicting findings suggest that a 6-week core strength training program improved dynamic balance and core endurance in adolescent male badminton players but did not improve their agility performance (Ozmen & Aydogmus, 2016). However, researchers need to be aware that this core strength training program mainly used stable surface limb movements and weight-bearing

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exercises (Ozmen & Aydogmus, 2016), while the intervention program in this study was incremental from static training to dynamic training. Therefore, it is unlikely that the improvement in agility performance after a six-week core strength training intervention was in some way related. To better explain why the agility performance of adolescent male hockey players did not significantly improve after a six-week core strength training intervention, this may be mainly due to intervention failure. Six weeks of core strength training did not directly stimulate the proprioceptive properties of the knees, hips, and trunk to improve athletes' postural control and agility (Marković et al., 2007).

Additionally, one study showed that an eight-week core strength training program improved agility performance in adolescent soccer players (Afyon et al., 2017). However, it is worth noting that other core strength training studies have shown that agility performance in athletes was improved through core strength training interventions of more than six weeks (Aslan & Kahraman, 2023; Tınkır & Uzun, 2022; Wondale et al., 2021). Wondale et al. (2021) conducted a study that examined the effects of an eight-week core strength training intervention and found that agility performance was significantly improved in adolescent male soccer players. Similarly, Aslan and Kahraman (2023) reported that an eight-week core strength training intervention significantly improved agility performance in professional soccer players. Mossa (2022) conducted a study on a 12-week core strength training intervention and found that it statistically improved agility in athletes. It is worth noting that most of these studies used three sessions per week (Aslan & Kahraman, 2023; Feng et al., 2024; Tınkır & Uzun, 2022; Wondale et al., 2021). Therefore, based on the results of this study, a 12-week, three-times-per-week core strength training intervention can

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significantly improve agility performance in adolescent male hockey players.

5.2.6 Discussion on Flexibility

The flexibility (SAR) data showed no statistically significant difference between the groups at baseline and week six ($p>0.05$), and the sit-and-reach (SAR) data showed no statistically significant difference at week 12 ($p>0.05$). In addition, there was no significant difference in CSTG and CTG between the groups from baseline to week six ($p>0.05$). However, the SAR improvement between CSTG from baseline to week 12 and from week six to week 12 showed significant differences ($p<0.05$). The following discussion will give a more detailed explanation.

Although several studies have reported significant improvements in flexibility following core strength training interventions, the findings of this study did not show a statistically significant difference in flexibility among adolescent male field hockey players after twelve weeks of training. For instance, Kabadayı et al. (2022), found that an eight-week core strength training program significantly improved sit-and-reach (SAR) scores in adolescent karate athletes. Similarly, Kumar and Zemková (2022) reported that a 12-week core strength training intervention positively affected flexibility performance in athletes, suggesting that the training's adaptability may contribute to improvements in joint mobility (Kumar & Zemková, 2022). Moreover, Luo et al. (2022) emphasized that core training involving multi-joint, multi-directional movements can improve both strength and flexibility through synergistic muscular activation. These studies underscore the potential of core strength training to enhance flexibility under specific conditions.(Luo et al., 2022).

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However, the present study's findings did not align with these outcomes. A key reason may lie in the absence of flexibility-specific elements, such as static stretching or proprioceptive neuromuscular facilitation (PNF), within the training protocol. While dynamic core exercises can indirectly support flexibility by improving posture and muscular control, they may not be sufficient to elicit measurable gains in joint range of motion without targeted stretching components (Behm et al., 2016). Furthermore, the assessment method employed—namely, the sit-and-reach test—primarily evaluates posterior chain extensibility, which may not directly reflect the functional adaptations gained from trunk stability and anti-rotational core training. Additionally, adolescent field hockey players typically possess relatively good baseline flexibility, which may have reduced the potential for observable improvements over a short training duration.

Evidence suggests that core strength training has limited direct effects on flexibility performance. For example, after six weeks of core strength training, the flexibility of adolescents did not improve significantly (Granacher et al., 2014). Similarly, Hong (2020) pointed out that 12 weeks of core strength training did not significantly improve the flexibility of male college students. This may be because improving flexibility requires whole-body or local stretching training, which can effectively stretch the tendons, improve the elasticity of muscles and tendons, and enhance ligament tension. Since the experimental group mainly performed core strength training without stretching exercises, the changes in flexibility between the groups were not noticeable. However, the results of this study are consistent with those of previous studies, further indicating that the direct effect of core strength training on flexibility is relatively limited. Future studies should further explore whether core

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strength training can significantly improve the flexibility performance of adolescent male hockey players under a core strength training program three times a week for 12 weeks to fill this research gap.

5.3 Discussion on Field Hockey Skills Variables

This section aims to conduct an in-depth analysis of the findings on the four variables in response to the second objective of this study. To the best of our knowledge, this study is the first to preliminarily evaluate the effects of core strength training on the skill performance of adolescent male ice hockey players. Therefore, we will focus on the impact of core strength training on the skill performance of Chinese adolescent male ice hockey players and compare and analyse these results with those of the existing literature. This section will also explore the potential explanations for these results and their application in improving sports skills. The discussion will start with dribbling skills and then gradually analyse the pulling, passing, and shooting techniques.

5.3.1 Discussion on Dribbling

The results of dribbling (SDT) showed that the comparison between the groups was not statistically significant at baseline ($p>0.05$) but was statistically significant ($p<0.05$) at weeks six and 12. In addition, within-group CSTG and CTG showed statistically significant differences between baseline and week six, between baseline and week 12, and between week six and week 12 ($p<0.05$), and the following discussion will provide a more detailed explanation.

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This study demonstrated that core strength training significantly improved dribbling skills in adolescent male field hockey players. However, more specific research on the relationship between dribbling skills and core strength training in field hockey players makes it easier to compare these results with similar studies. Nonetheless, studies on other athletes have demonstrated the positive effects of core strength training on skill performance, including improving athletes' dribbling ability. These results further support the applicability of core strength training to improve sports skills in general.

For example, a study by Ahmed showed that after four weeks of core strength training, male soccer players' speed dribbling skills significantly improved (Ahmed et al., 2022). Similarly, a study by Li (2022) reported that six weeks of core strength training significantly improved the performance of fast dribbling skills in basketball players. In addition, a study by Bavli and Koç found that eight weeks of core strength training reduced dribbling time in young soccer players (Bavli & Koç, 2018). Feng et al. (2024) studied the effects of core strength training on dynamic balance, agility, and dribbling skills in adolescent basketball players, and the results showed that after twelve weeks of training, the players' dribbling skills significantly improved. Together, these studies suggest that core strength helps improve an athlete's balance and postural control, promoting the improvement of dribbling skills. Studies have shown that core muscles help maintain balance and postural control, which may contribute to acquiring and improving players' skills. The advantages observed in the study were confirmed by implementing a carefully regulated movement pattern when performing dribbling actions (Wollesen et al., 2022).

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In field hockey, dribbling skills are critical, and players need to rotate their bodies frequently (Antara et al., 2023). Strengthening the core strength not only improves the player's pelvic and trunk stability but also improves their coordination and shortens the turning time. Strengthening the core muscles is significant in high-intensity games and helps optimize the player's overall sports performance. The results of this study showed that core strength training three times a week for six to twelve weeks significantly improved the dribbling skills of adolescent male hockey players, especially in skill development training (SDT). Therefore, core strength training is essential in improving sports skills, especially in dribbling skills requiring high coordination and control.

5.3.2 Discussion on Pulling

The results of OMPT showed that the comparison between the groups was not statistically significant at baseline ($p>0.05$), and similarly, it was not statistically significant at weeks six and 12 ($p>0.05$). In addition, within-group CSTG and CTG showed statistically significant differences between baseline and week six, between baseline and week 12, and between weeks six and 12 ($p<0.05$). At the same time, there was no improvement in CTG between baseline and week 6. The following discussion will provide a more detailed explanation.

Results of this study showed that a core strength training intervention did not produce statistically significant differences in the performance of the pull-the-ball technique (OMPT) in adolescent male hockey players throughout six to 12 weeks. This suggests that core strength training did not provide additional benefits in improving OMPT performance compared with standard training. However, effect size analysis showed

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that CSTG (d=0.81) had a large time effect on the OMPT test, while CTG (d=0.40) showed only a moderate effect. Therefore, core strength training is superior to standard training in improving OMPT performance in youth male field hockey players.

However, due to the lack of specific research on the relationship between sports skills and core strength training in hockey players, comparing these results with similar studies is difficult. The conclusion that core strength training can significantly improve athletes' skill performance has been confirmed in other types of athletes. For example, in volleyball, the authors studied the effects of a six-week core strength training program on the skill performance of volleyball players. The results showed that core strength training can significantly improve the performance of volleyball players (Yapıcı, 2019). Another author reported on six weeks of core strength training for Muay Thai athletes and pointed out that core strength training can significantly improve the skill performance of Muay Thai athletes (Lee & McGill, 2017). Similarly, a study by Manchado et al. (2017) showed that a 10-week core strength training program can significantly improve the skill performance of professional handball players. In addition, 12 weeks of core strength training can significantly improve the specific skill performance of adolescent gymnasts (Abuwarda, 2014). These results show that core strength training programs can substantially improve athletes' skill performance.

In interpreting the results of this study, one possible explanation is the specificity principle of core strength training, which is performed in a way that simulates the target sport and promotes the progress of the target sport itself rather than specific muscles (Dong et al., 2023; Stone et al., 2022). However, the training was performed

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with exercises that increased muscle strength and endurance. These exercises were performed unidirectionally, mainly using the sagittal axis, so only the relevant muscles can improve rapidly under heavy loads (Schoenfeld et al., 2021). In addition, hockey skills are developed in multiple axes using multiple muscle groups and joints simultaneously, which is an important reason why core strength training is superior to standard training to improve the performance of hockey players.

The study's results showed that core strength training improved hockey skills in adolescent male hockey players. Based on these results, it is reasonable to conclude that core strength training is essential for pulling the ball. Therefore, core strength training performed three times per week for at least twelve weeks has improved hockey skills in adolescent male hockey players.

5.3.3 Discussion on Passing

The results of the pass (FPT and BPT) showed that the inter-group comparison was not statistically significant at baseline ($p>0.05$). Similarly, it was not statistically significant at week six and week 12 ($p>0.05$). However, within-group CSTG and CTG showed statistically significant differences between baseline and week six, between baseline and week 12, and between week six and week 12 for BPT ($p<0.05$). In addition, within-group CSTG and CTG showed statistically significant differences between baseline and week 12 for FPT ($p<0.05$), while CTG showed no significant difference. The following discussion will provide a more detailed explanation.

This study showed that the core strength training intervention did not produce statistically significant differences from the control group in terms of passing skill

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performance (FPT and BPT) from baseline to 12 weeks. However, effect size analysis showed that the CSTG's FPT (d=0.60) showed a medium time effect size on the FPT test, while the CTG (d=0.22) showed only a small time effect size. On the other hand, the CSTG's BPT (d=0.96) showed a large time effect size on the BPT test, while the CTG (d=0.57) showed only a medium time effect size. Therefore, core strength training is superior to standard training in improving passing skill performance in adolescent male hockey players.

Although core strength training is known to improve trunk stability, postural control, and neuromuscular coordination(Zemková & Zapletalová, 2022). The results of this study showed no statistically significant improvement in passing skill performance among adolescent male field hockey players following a 12-week intervention. This outcome can be better understood through a biomechanical lens: passing in field hockey is a complex, sport-specific motor skill that involves precise timing, hand-eye coordination, anticipatory control, and high-speed limb segment sequencing, especially in the upper body and distal joints (Hughes et al., 2015). In contrast, core training typically focuses on enhancing proximal stability and general trunk control (Sasaki et al., 2019). Which may support gross motor functions like running or balance but not necessarily the fine motor control required for accurate passing (Seid, 2022).

Furthermore, the principle of training specificity suggests that for skill transfer to occur, training must closely mirror the movement patterns, neuromuscular activation, and cognitive demands of the target activity (Wirth et al., 2017). Since core strength training does not replicate the limb velocity, limb coordination, and perceptual-motor integration needed in field hockey passing, its benefit may remain indirect.

Additionally, adolescent athletes are still undergoing neuromuscular development, and may require more integrated, sport-specific training to see meaningful improvements in technical skills (Kumahara et al., 2021). This is further complicated by the nature of the sport: in fast-paced, externally unpredictable games like field hockey, decision-making and visual-motor tracking are critical to passing success—elements not targeted by isolated core exercises.

Based on the results of this study, future studies should further explore whether core strength training can significantly improve the passing skill performance of adolescent male hockey players under a core strength training program three times a week for 12 weeks to fill this research gap.

5.3.4 Discussion on Shooting

Shooting accuracy (SA) results showed that the comparison between the groups was not statistically significant at baseline ($p>0.05$), and similarly, it was not statistically significant at week six ($p>0.05$). However, it significantly differed at week 12 ($P<0.05$). In addition, within-group CSTG showed statistically significant differences between baseline and week six, between baseline and week 12, and between weeks six and 12 ($p<0.05$), while CTG did not improve significantly. The following discussion will provide a more detailed explanation.

This study confirmed that core strength training significantly improved the shooting accuracy of young male field hockey players. However, due to the scarcity of research on the relationship between shooting skills and core strength training in hockey players, direct comparison of the results faces specific difficulties. Nevertheless,

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previous studies have shown that core strength training positively affects shooting skill performance in other sports. These results further support the broad applicability of core strength training in improving sports skills.

Several studies have demonstrated that core strength training significantly improves an athlete's shooting performance. For example, an experimental research on male handball players found that after an eight-week core strength training intervention, the athletes' spot-up shooting performance was significantly improved (Akçinar & Macit, 2020). Similarly, a study by Mahmoud (2018) reported that adolescent soccer players improved their shooting skills considerably after ten weeks of core training. In addition, a study on adolescent female handball players showed that their long-distance jump shot accuracy was significantly improved after ten weeks of core strength training three times a week (Mahmoud, 2021). Another study on male college soccer players came to a similar conclusion: after twelve weeks of core strength training, the subjects' shooting skills were significantly enhanced (Mathavan & Praveen, 2015).

Research has shown that core strength training not only improves the strength and ability of the arms and legs but also enhances the overall performance of athletes when performing complex skills such as shooting. The training of the core muscles directly affects the strength development of the trunk muscles, which is essential for the stability and force transfer of movements. Core strength training promotes the transfer of force from the lower to the upper limbs by strengthening the trunk muscles, thereby improving shooting power, speed, and accuracy (Mahmoud, 2021). Wadi (2015) further supports this view, emphasising that shooting performance relies on the

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strength of the arms and shoulders and requires the coordinated participation of other muscle groups in the body. This force transfer is transmitted from the feet to the arms through the trunk, ensuring the ball can be released with maximum speed and force when it leaves the shooting hand. Improving core strength enables athletes to achieve higher shooting efficiency and accuracy by optimising this force transfer process.

Based on the results of this study, it is reasonable to conclude that core strength training is essential in shooting skill performance. Therefore, core strength training performed thrice per week for at least 12 weeks has improved shooting skill performance in youth male field hockey players.

5.4 Conclusion

The results showed that the core strength training group (CSTG) and the standard training group (CTG) positively affected adolescent male hockey players' physical fitness and skill performance. However, core strength training showed a more significant effect in improving athletes' physical fitness and skills. Based on these findings, this study concluded that core strength training effectively enhances male hockey players' comprehensive ability and helps optimise their overall sports performance.

5.4.1 Physical Fitness Variables

This section summarises the results of a 12-week core strength training program for adolescent male hockey players in Gansu Province, China. The study showed that the fitness variables within the group showed significant changes during the training process ($p<0.05$). In the inter-group comparison, the selected physical variables from

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baseline to week six did not show significant differences ($p>0.05$), and only the sit-up (SU) variable reached statistical significance at week 6 ($p<0.05$). However, by week 12, all selected fitness variables showed significant differences ($p<0.05$), except for the speed 25 yards and flexibility (SAR) variables, indicating that core strength training had a significant effect on the overall improvement of the physical fitness of adolescent hockey players.

Additionally, this study's findings add to the literature on the effects of core strength training on multiple physical fitness variables, including improvements in strength, power, speed, endurance, agility, and flexibility. The results provide strong evidence that three times per week of core strength training significantly improves these key physical fitness measures within 12 weeks. These results support the hypothesis that core strength training enhances strength, power, speed, endurance, agility, and flexibility in adolescent male hockey players.

5.4.2 Field Hockey Skills Variables

The second objective of this study was to evaluate the effects of 12 weeks of core strength training on skill performance in adolescent male hockey players. This section summarises the intervention effects of core strength training on hockey skills. The results showed that hockey skill variables (dribbling and shooting) showed significant differences between baseline and week 12 ($p<0.05$), indicating that core strength training effectively improved these skills. However, pulling (OMPT) and passing (FPT and BPT) did not show significant changes between baseline and week 12 ($p>0.05$). Nevertheless, the hockey skills between baseline and week six and between week six and week 12 were statistically significant ($p>0.05$). In addition, passing

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(FPT) and shooting accuracy (SA) did not show significant differences between baseline and week six ($p>0.05$). In addition, the results of this study add new content to the literature on the intervention effects of core strength training on sports skills such as dribbling, pulling, passing, and shooting accuracy. Research has demonstrated that core strength training three times per week for six to twelve weeks is an effective training strategy to help improve the performance of young male hockey players.

In summary, this study reviewed and determined that CSTG participants benefited from statistically significant improvements in some hockey skills compared to CTG participants. The exception was passing skills, where the results were not statistically significant. However, the results for physical fitness variables conducted through speed (25 yards) and flexibility (SAR) were not statistically significant. There were statistically significant differences in strength, power, speed (50 yards), endurance, agility, and flexibility.

5.5 Research Implications

The implications of the results of this study are to be discussed in terms of theory and practical implications.

5.5.1 Theoretical Implications

This study used the sports training process model as a theoretical framework and focused on the types of exercises in the core strength model proposed by Hibbs et al. (2008). The model uses a high-load dynamic training mode to promote the growth of muscle strength and density by increasing muscle thickness and enhancing neural activation of motor units. This growth further improves core strength, improving

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sports performance, especially in speed, agility, and strength (Hibbs et al., 2008). The main findings of this study show that core strength training is more effective than standard training methods in improving adolescent male hockey players' physical fitness and skill performance. Although research results on the core strength training model proposed by Hibbs et al. (2008) for adolescent male hockey players have yet to be published, the results of this study provide crucial empirical support in this field. The core strength training intervention significantly improved hockey players' physical fitness (strength, explosive power, speed, endurance, agility, and flexibility) and significantly affected hockey skills (dribbling, pulling, passing, and shooting).

This finding not only supports the widespread application of core strength training as an effective training strategy but also provides a theoretical basis for further research on the applicability of this model in different sports in the future.

5.5.2 Practical Implications

According to this study's results, core strength training had superior training effects. Twelve weeks of core strength training were more effective than standard training in improving elite adolescent athletes' physical fitness and hockey skills. This study provides new evidence in this field, proving that core strength training can significantly improve athletes' strength, explosive power, speed, endurance, agility and flexibility, and dribbling, pulling, passing, and shooting skills.

The findings of this study provide crucial practical evidence for coaches, researchers, and sports administrators, who are advised to implement a core strength training program during training to optimise athletes' physical fitness and skill development.

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The study showed that the 12-week core strength training program suits young male hockey players. It can be widely used in other youth groups of hockey sports, especially those who want to improve their overall performance through systematic training. In addition, core strength training provides a variety of training prescriptions for strength and conditioning practitioners, further expanding the effective strategies of sports training.

5.6 Recommendations for Future Studies

Based on the findings, several recommendations for potential future research are listed.

1. This study yielded valuable insights into the physical fitness and hockey skills of male field hockey athletes in Gansu Province, China. To validate these findings, future research should investigate athletes of different genders to determine if core strength training produces consistent results across these groups. Further studies should also include other populations of hockey players, such as university athletes, untrained individuals, and amateurs. Incorporating these groups would help establish the broader applicability of core strength training and assess its effectiveness across different skill levels. Additionally, extending core strength training programs to field hockey and other team sports could be beneficial, given their proven impact on athletic performance. Such research would provide comprehensive data support for athletic training and further clarify the role of core strength training in enhancing sports performance.

2. This study showed that although the 25-yards sprint, flexibility, and passing skills performance tests did not significantly improve after core strength training, the group-time interaction effect and the time effect did. The effects of core strength training on these techniques vary greatly over time. Therefore, researchers should extend the intervention time to examine whether core strength training can improve these skills.

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3. This study utilised a Chinese Hockey Association (CHA) - approved fitness testing protocol and field hockey skills testing protocol outlined in previous studies. The fitness assessment focused on strength, power, speed, power, agility, endurance, and flexibility. Meanwhile, the field hockey skills assessment was limited to accuracy in dribbling, passing, pulling, and shooting. The study did not address other fitness factors, such as reaction time, balance, and coordination, nor did it assess all aspects of skill performance, such as pulling shooting technique for short corner kicks. Therefore, it is recommended that future studies investigate whether core strength training affects other key fitness elements not currently included in the CHA test and evaluate its effects on other skill parameters in young male field hockey players.

5.7 Limitation of the Study

This study exhibits a few limitations, outlined as follows:

Previous studies have indicated that demographic variables may constrain the efficacy of interventions in the field (Fernandez-Fernandez et al., 2020). To account for this, the researcher incorporated demographic factors, including age, height, weight, and training background, as covariates in the analysis. Therefore, this study set strict standards for age and years of training when recruiting subjects. The specific inclusion criteria are detailed in Section 3.4 of Chapter 3. In addition, if these demographic information are significantly different between groups, they will be included in the model as covariates for analysis to ensure the accuracy and scientificity of the results.

Ball speed is an essential indicator for evaluating the performance of hockey players (Starkes, 1987). In this sport, key elements include identifying and tracking players' positions and the ball, analysing player movements, and predicting the trajectory of the ball (Neher et al., 2017; Rangasamy et al., 2020; Sozykin et al., 2018). Although

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multiple high-speed cameras are the most accurate method for measuring speed (Naik et al., 2022), their practical application is limited due to the high equipment cost and complex installation. Therefore, many studies choose field assessment methods to measure skill levels (Anders & Myers, 2008; Keogh et al., 2003; Lemmink, 2004). This field-based testing method is widely accepted by researchers worldwide for measuring key performance indicators due to its high accessibility and relative reliability (Bartolomei et al., 2019; Mohan et al., 2021; O'Neill & Miltenberger, 2020). This study adopted this method to assess the skill level of youth hockey players, which is consistent with existing research practices.

This study did not assess regular exercise and nutritional intake, and it was assumed that the participants did not use any performance-affecting drugs or supplements during the test period. All subjects were National U18 field Hockey Championship members and received the same dietary arrangements under the unified government dietary allowance. The government has strict regulations on the diet of these athletes to ensure that all participants have consistent nutritional intake. In addition, during the study, participants were told to maintain their original eating habits and avoid any dietary adjustments unrelated to the study. During the intervention, coaches regularly supervised and checked the participants' diets weekly to ensure they strictly followed the established dietary plan. Implementing this supervision mechanism further ensured the reliability and consistency of the research data.

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APPENDICES

Appendix A

Request Permission

Ethical approval was obtained from the Medical Ethics Review Committee of Sichuan Nursing Vocational College, China

Approval Form for Medical Ethics Review Committee of Sichuan Nursing Vocational College

1. General Information on the Project

Protocol Name	Effects of Core Strength Training on Physical Fitness and Field Hockey Skills Performance Among Youth Male Field Hockey Players in Gansu, China				
Project Leader	Ma Hucheng	**Research Direction**	Physical education	**Technical Post**	No
Department	Department of basic courses	**Tel**	+86 13909492013	**E-mail**	875803848@qq.com
Project No	2023006				

2. Protocol Source of Funds

☐ Vertical Project ☐ Horizontal Project ☐ College Funded Project ☑Other: Doctoral research projects

3. Research Information

Research Design (Multiple Choice): ☐Case Control Study ☐Cohort Study ☑Cross section study ☐Non Randomized Controlled Study ☑Randomized Controlled Study ☐Application Blind Method ☐Clinical Trials ☐Other:

4. Special Review Requirements

☐	Apply for exemption from signing a written informed consent document (please fill out the application form for exemption from informed consent)
☑	The research involves vulnerable groups → Please choose: ☑Children/minors, ☐Adults with cognitive impairment or inability to make informed consent due to health conditions, ☐Employees or students of applicants/researchers, ☐Individuals with low educational/economic status, ☐End stage patients with diseases, ☐Prisoners, ☐Pregnant women, ☐Other (optional):______
☐	The research involves the collection of biological specimens (body fluids, tissues, etc.), invasive examinations, and radiation examinations beyond routine medical/physical examinations, which are purely research purposes.
☐	Research involves the collection and preservation of human genetic resources (human genetic resources refer to organs, tissues, cells, nucleic acid products, and other resource materials containing the human genome, genes, and their products, as well as the information generated).

5. Subject Recruitment and Informed Consent Information

Recruiter (multiple options available)	☑Project Leader ☐Researcher ☐Doctor ☐Nurse ☐Other: ______
Recruitment Location	This study will be conducted at Gansu Provincial Sports School, located at No. 42 Jiayuguan East Road, Chengguan District, Lanzhou City, Gansu Province, China. The recruitment of subjects and exercise intervention venues can be conducted in outdoor hockey courts or indoor strength rooms.
Using Recruitment Materials	☐No ☑Yes →Please submit for review
Candidates for Implementing Informed Consent (multiple choices are allowed)	☑Project Leader ☐Researcher ☐Doctor ☐Nurse ☐Other: ______
Medical Examination and Treatment related to research	☑Free ☐Partial Free ☐Not Free ☐Not Applicable

Statement by the project leader: I will conduct this study in accordance with Chinese laws, international ethical standards, and the requirements of the College Ethics Committee.

Signature of project leader: Ma Huchen **Date:** 11/10/2023

Recommendation opinion from College Ethics Committee	The ethics committee of the college reviewed the implementation plan, design, subject recruitment, and informed consent of the project. The project fully considered the principles of safety and fairness, and the research process did not pose potential risks to the research subjects. The rights and interests of the research subjects were protected, and it was agreed to pass the ethical review. **Signature/Seal** **Date:** 27/10/2023

Appendix B

Sample Size Calculation

Table 1 : Effect Size Calculation for Research Variables

Variables	Pretest	Posttest	Effect size (f)	Reference
	Mean (SD)	Mean (SD)		
Strength	25.32(4.63)	27.68(4.40)	0.262	Tomljanovic et al., (2011)
Power	41.70(2.10)	42.60(1.80)	0.230	Fernandez-Fernandezet al., (2015)
Speed	4.106(0.15)	3.97(0.10)	1.060	Turna & Alp, (2020)
Endurance	25.68 (7.42)	30.06 (6.38)	0.630	Kazım & Revan, (2023)
Agility	16.34(1.15)	14.8(2.84)	0.335	Afyon et al., (2017)
Flexibility	19.60(5.50)	22.60(4.60)	0.296	Fagnani et al., (2006)
Dribbling	13.37 (0.63)	13.02 (0.85)	0.460	Kumar et al., (2014)
Pulling	15.90 (3.24)	22.60 (4.35)	0.297	Bostancı & Özdal, (2021)
Passing	2.94(0.930)	3.69(0.793)	0.278	Doğan & Savaş, (2021)
Shooting Accuracy	4.47 (2.16)	3.80 (2.45)	0.290	Pavlu˚ et al., (2021)

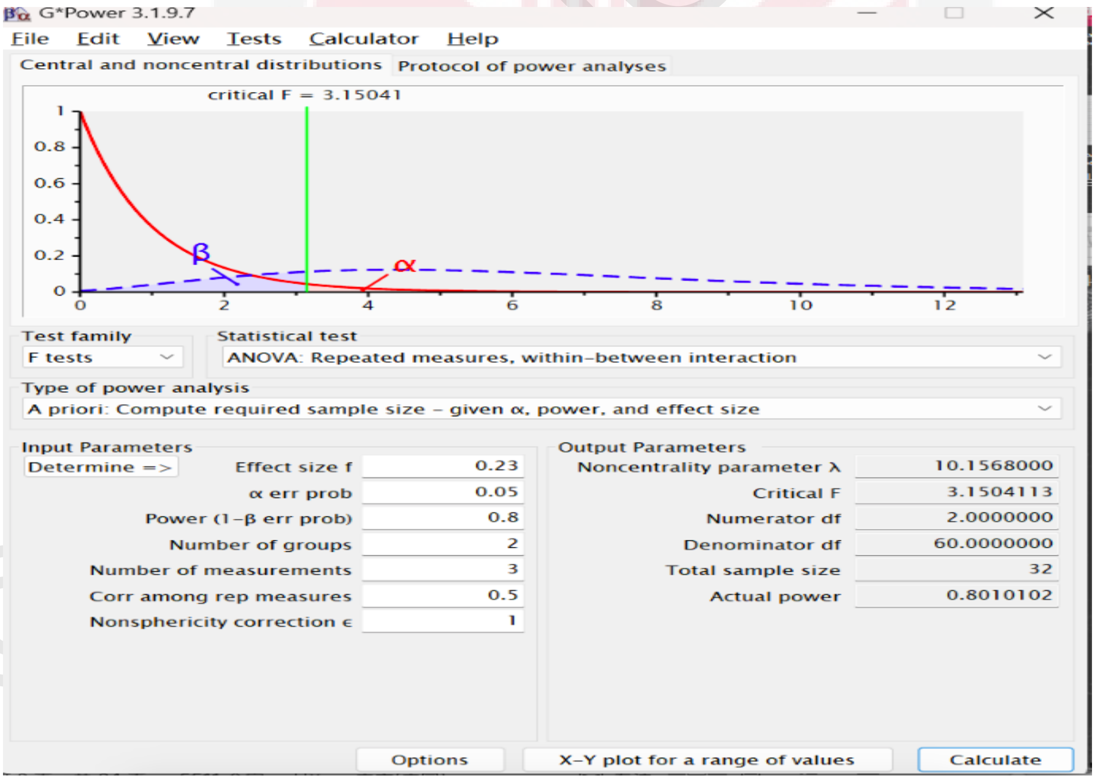

Figure 1 : Sample Size Calculation Based on the Repeated Measure Within-between Interaction

Appendix C

Respondent's Information Sheet and Informed Consent Form

Please read the following information carefully and do not hesitate to discuss any questions you may have with the researcher.

1. Study Title

Effects of Core Strength Training on Physical Fitness and Skills Performance Among Youth Male Field Hockey Players in Gansu, China

2. Introduction

We invite you to participate in an experimental study on the effects of core strength training on young male hockey players' physical fitness and field hockey skills in Gansu Province, China. Participants were divided into two groups: core strength training group (CSTG) and control group (CTG). First, the effects of the experimental 12-week core strength training intervention on the physical fitness variables of youth male field hockey players in Gansu Province, China, at baseline, week six, and week 12; second, the effects of the experimental 12-week core strength training intervention on the field hockey skill variables of youth male field hockey players in Gansu Province, China, at baseline, week six, and week 12.

Participation in this study is entirely voluntary. This informed consent form provides information to help you decide whether to participate in this study. Please read it carefully. If you have any questions, please ask the researcher in charge of the study. This study has been reviewed and approved by the Medical Ethics Committee of Sichuan Nursing Vocational College. Legal requirements determine some of the contents of this article. To protect the rights and interests of participants in the study, the Ethics Committee has reviewed and approved this article.

3. What will you have to do?

This study will conduct a test and comparative analysis of the participants' physical fitness and field hockey skills variables at baseline, week-6, week-12 the experiment through 12 weeks of core strength training and explore the effects of core strength training on physical fitness and field hockey skills among youth male field hockey players.

4. Who should not participate in the study?

The exclusion criteria of the samples in this study are: (1) Recently (less than one year) had knee, elbow, shoulder, have a history of rheumatoid disease or neurological damage, and are still receiving treatment (Yildiz et al., 2019; Barber-Westin et al., 2010); (2) Experience of core strength training in previous 12 months prior to the study were excluded; (3) Based on the coach's suggestion, select the participants who are hard-working, highly motivated, and have a desire to participate in the search and regularity until complete the experimental tasks (Xinhua & Xuhua, 2004); (4) About to stop field hockey training due to uncertain factors are directly excluded.

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5. What will be the benefits of the study:

a. To you as the participant?

Participation in this study may or may not have an impact on your physical fitness and field hockey skill variables. Information obtained from this study will help determine if core strength training can safely and effectively improve physical fitness and field hockey skills in youth male field hockey players.

b. To the investigator?

This study has two main benefits for researchers. First, it provides a theoretical basis and reference for core strength training of physical fitness and field hockey skills for youth male field hockey players, enriches the content of physical fitness and field hockey skills training for youth male field hockey players, and the theoretical content in this area can also provide theoretical support for the application and practice of core strength training.

Secondly, to verify whether core strength training can promote the improvement of physical fitness and field hockey skills of youth male field hockey players in Gansu Province, China. If it has a promoting effect, then this study can provide a reference for developing the physical fitness and field hockey skills of outstanding athletes in other sports.

6. What are the possible risks?

Adverse reactions may occur during the study. We will monitor all participants for any adverse reactions during the intervention training. If you experience any adverse reactions during the intervention training, please report them to your researcher or coach in a timely manner. At present, relevant studies have shown that the adverse effects of core strength training may include muscle soreness, exercise fatigue, etc. You need to tell your family or friends around you that you are participating in an exercise training intervention study, and they can pay attention to the above events. If they have questions about your participation in the study, you can tell them how to contact your researcher or coach.

7. Will the information that you provide, and your identity remain confidential?

Your health record will be kept at Universiti Putra Malaysia. Researchers, research authorities, and ethics committees will be allowed to access your health records. Any public report on the results of this research will not disclose your personal identity. We will make every effort to protect your personal privacy within the scope permitted by law. When you sign this informed consent form, you agree that your personal and health information will be used in the situations described above.

8. Who should you contact if you have additional questions during the research?

If you have any questions about this research or any physical discomfort during the research, you can always contact the researcher of this research.

Researcher's name: Ma Hucheng Mob: +60177321647 E-mail: mahucheng113@gmail.com/gs61909@student.upm.edu.my

Please initial here if you have read and understood the contents of this page. .____

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9. Consent

I……………………………………Identity Card No…………………………….

address……………………………………………………………………………

……………………..…………………………………………………………..hereby voluntarily agree to take part in the research stated above *(clinical/drug trial/video recording/focus group/interview-based/questionnaire-based).

I have been informed about the nature of the research in terms of methodology, possible adverse effects, and complications (as written in the Respondent's Information Sheet). I understand that I have the right to withdraw from this research at any time without giving any reason whatsoever. I also understand that this study is confidential, and all information provided regarding my identity will remain private and confidential.

I* wish/do not wish to know the results related to my participation in the research I agree/do not agree that the images/photos/video recordings/voice recordings related to me be used in any form of publication or presentation (if applicable)

* Delete where necessary

Signature ……..…………………… Signature…………………………
(Respondent) (Witness)

Date………………. Name……………………………

I/C No. ……………………

I confirm that I have explained to the respondent the nature and purpose of the above-mentioned research.

Date…..………………………… Signature ……..…………………………….
(Researcher)

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Appendix D

Intervention Information

Table 1 : Description of the Core Strength Training Programme (Experimental Group)

Weeks	Duration & Freq.	Types of Exercises	Sets	Intensity & Repetition	Recovery	Improvement Suggestions
1st-3th	3 time/week 1 hour	Swiss Ball Side Crunches	3	Body Weight*10 Freq.	60s	
		Swiss Ball Rotational Crunches	3		60s	
		Supine Leg Swings	3		60s	
		Quadruped Alternate Arm and Leg Raise	3		60s	
		Hanging Knee Raise	3		60s	
		Overhead Squat	3	65%1RM×15 Freq.	60s	
		Barbell Hip Lift	3		60s	
		Plank	3	Body weight*90s	60s	
		Quadruped	3	Body weight*90s	60s	
4th-6th	3 time/week 1 hour	Rope High/Low Chop Exercise	3	Body Weight*15 Freq.	80s	
		Rope Low/High Chop Exercise	3		80s	
		Weighted Russian Twists	3		80s	
		Seated Medicine Ball Chest Press	3		80s	
		Reverse Underhand Medicine Ball Toss	3		80s	
		Overhead Medicine Ball Slam	3		80s	
		Barbell Hip Thrust	3	70%1RM*15 Freq.	80s	
		Weighted Lift	3		80s	
		Kneeling Cable Crunch	3		80s	
		Side Elbow Plank	3	Body weight*120s	80s	
		Opposite Arm	3	Body	80s	

		and Leg Support		weight*120s	
7th-9th	3 time/week 1 hour	Barbell Diagonal Chop	3	Body Weight*20 Freq.	100s
		Dumbbell Side Bend	3		100s
		Rotational Wall Ball Toss	3		100s
		Reverse Swiss Ball Core and Back Training	3		100s
		Rope Kneeling Rotational Crunch	3		100s
		Barbell Hip Thrust	3	75%1RM*15 Freq.	100s
		Weighted Lift	3		100s
		Kneeling Cable Crunch	3		100s
		Sit-ups	3	10KG*20 Freq.	100s
		Oblique Side Twist	3	8KG*15 Freq.	100s
		Landmine Rotation	3	15KG*20 Freq	100s
10th-12th	3 time/week 1 hour	Barbell Roll-out	3	Body Weight*25 Freq.	120s
		Lateral Leg Lifts	3		120s
		Swiss Ball Rotational Back Extension	3		120s
		Rotational Medicine Ball Slam	3		120s
		Landmine Rotation	3	20KG×30 Freq.	120s
		Barbell Hyper	3	20KG×30 Freq.	120s
		Weighted Sit-Ups	3	15KG×20 Freq.	120s
		Abdominal Leg Swing	3	Height:150cm*15 Freq.	120s
		Barbell Hip Thrust	3	80%1RM×15 Freq.	120s
		Weighted Lift	3		120s
		Kneeling Cable Crunch	3		120s

Table 2 : Description of the Standard Training Programme (Control Group)

Weeks	Duration & Freq.	Types of Exercises	Sets	Intensity & Repetition	Recovery	Improvement Suggestions
1st-3rd	3 time/week 1 hour	Armlet Extension	3	Body Weight*10 Freq.	60s	
		Chin-up (physical exercise)	3		60s	
		Weighted Sit-ups	3		60s	
		Weighted Back	3		60s	
		Abdominal Lifts	3		60s	
		Bench Press	3	65%1RM×15 Freq.	60s	
		Squats	3		60s	
		Back Hooks	3	15KG×20 Freq.	60s	
		Seated Abduction	3	15KG×20 Freq	60s	
4-6th	3 time/week 1 hour	Armlet Extension	3	Body Weight*15 Freq.	80s	
		Chin-up (physical exercise)	3		80s	
		Weighted Sit-ups	3		80s	
		Weighted Back	3		80s	
		Abdominal Lifts	3		80s	
		Bench Press	3	70%1RM×15 Freq.	80s	
		Squats	3		80s	
		Back Hooks	3	20KG×20 Freq.	80s	
		Seated Abduction	3	20KG×20 Freq	80s	
7-9th	3 time/week 1 hour	Armlet Extension	3	Body Weight*20 Freq.	100s	
		Chin-up (physical exercise)	3		100s	
		Weighted Sit-ups	3		100s	
		Weighted Back	3		100s	
		Abdominal Lifts	3		100s	
		Bench Press	3	75%1RM×15 Freq.	100s	
		Squats	3		100s	
		Back Hooks	3	25KG×20 Freq.	100s	
		Seated Abduction	3	25KG×20 Freq	100s	

10-12th	3 time/week 1 hour	Armlet Extension	3	Body Weight*25 Freq.	120s
		Chin-up (physical exercise)	3		120s
		Weighted Sit-ups	3		120s
		Weighted Back	3		120s
		Abdominal Lifts	3		120s
		Bench Press	3	80%1RM×15 Freq.	120s
		Squats	3		120s
		Back Hooks	3	30KG×20 Freq.	120s
		Seated Abduction	3	30KG×20 Freq	120s

Appendix E

Registration of Trial Protocol

ClinicalTrials.gov PRS
Protocol Registration and Results System

ClinicalTrials.gov Protocol Registration and Results System (PRS) Receipt
Release Date: March 7, 2024

ClinicalTrials.gov ID: NCT06297889

Study Identification

Unique Protocol ID: Ma Hucheng

Brief Title: Effect of Core Strength Training on the Physical Fitness and Skills of Youth Field Hockey Players in China

Official Title: Effects of Core Strength Training on Physical Fitness and Field Hockey Skills Performance Among Youth Male Field Hockey Players in Gansu, China

Secondary IDs:

Study Status

Record Verification: March 2024

Overall Status: Recruiting

Study Start: February 15, 2024 [Actual]

Primary Completion: June 1, 2024 [Anticipated]

Study Completion: June 15, 2024 [Anticipated]

Sponsor/Collaborators

Sponsor: Universiti Putra Malaysia

Responsible Party: Principal Investigator
Investigator: MA HUCHENG [mhucheng]
Official Title: Principal Investigator
Affiliation: Universiti Putra Malaysia

Collaborators:

Oversight

U.S. FDA-regulated Drug: No

U.S. FDA-regulated Device: No

U.S. FDA IND/IDE: No

Human Subjects Review: Board Status: Approved
Approval Number: 2023006
Board Name: Sichuan Nursing Vocational College Ethics Committee
Board Affiliation: Sichuan Nursing Vocational College
Phone: 8618030431596
Email:
Address:

- Page 1 of 6 -

Appendix F

Validation of Experts for Intervention Programme

Dear Experts (Prof/Dr),

My name is Ma Hucheng. I am a PhD student from Universiti Putra Malaysia. I am in the process of writing my dissertation titled: Effects of Core Strength Training on Physical Fitness and Skills Performance Among Youth Male Field Hockey Players in Gansu, China. As an expert in the field of exercise training, I would like to invite you to give me some comments of my functional training intervention. All the information you have filled in will only be used for this study and will not be used for any other purpose. All the information you have filled in sprint be kept confidential. Therefore, please rest assured and fill in in detail. Your assistance has made an important contribution to this study. Thank you for your assistance and cooperation.

Universiti Putra Malaysia
Supervisor committee: Prof. Dr. Soh Kim Geok
Dr. Shamsulariffin Samsudin

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1. **Basic Information**

Name: Title: Specialized field:

2. **Questionnaire Information**

This questionnaire adopts a 5-point Likert scale, with 1-5 representing increasing support (1=strongly disagree; 2=Disagree; 3=Not necessarily; 4=agree; 5=strongly agree). Please score the functional training intervention. If there are other content, you can add them and indicate the name. After reading the questionnaire, please rate the following aspects and tick "√" on the corresponding rating scale.

Table 1 : Evaluation of the Effectiveness of Intervention Programme

Type	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Improvement suggestions
Overall evaluation of the program						
Duration						
Frequency						
Intensity						
Basic content						
Sets						
Recovery						
Risk						

3. Training intervention information

This study consists of two groups, namely the control group and the core strength training group. According to the literature, to compare whether core strength training is more effective than a control group, regular traditional training exercises are performed in players. The sample is Chinese male youth hockey players participating in the U18 group who do not perform core strength training.

According to the literature review, the training frequency of this experiment was arranged to be 3 times/week, the total training duration was 12 weeks, and each the training time was changed over 3 weeks. The 12-week training session lasted 1 hour. Training intensity ranges from 65% to 80% (NSCA). Teach all core strength training movement techniques prior to intervention.

This study was divided into an experimental group and a control group. The experimental group performed core strength training, while the control group performed standard training. The sample was Chinese male youth field hockey players (15-17 years old). participating in the U18 group. According to the literature review, the training frequency of this experiment was arranged to be 3 times/week, the training length was 12 weeks, and each training time was 60 minutes. The core strength training program was adapted from the ice hockey training program outlined in the book "Developing the Core (NSCA Sports Performance)" by Jeffrey M. Willardson (Willardson, 2013).

Table 2 : Core Strength Training Duration, Frequency, Intensity, Time, Rest

Duration (12weeks)	Frequency	Intensity	Time	Rest	Improvement suggestions
1-3 weeks	3times/week	65% 1RM	60min	60-90s	
4-6 weeks	3times/week	70% 1RM	60min	60-90s	
7-9 weeks	3times/week	75% 1RM	60min	90-100s	
10-12weeks	3times/week	80% 1RM	60min	1-2min	

The core strength training load and intensity design of this study is based on four training phases. The first phase is the basic training phase (3 weeks), the second phase is the intermediate training phase (3 weeks), and the third phase is the advanced training phase (3 weeks) and the strengthening and consolidation phase (3 weeks). (Willardson, 2013; Liu, 2022; Hirono et al., 2022) In addition, the core strength training program has been approved by the author and publisher.

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Appendix G

Validation of Experts for Instrument Contents

Dear Experts (Prof/Dr),

My name is Ma Hucheng from Putra University Malaysia. My research title is "Effects of Core Strength Training on Physical Fitness and Field Hockey Skills Performance Among Youth Male Field Hockey Players in Gansu, China." You have a wealth of theoretical knowledge and practical experiences. I invite you to give me some comments about my study. All the information you have filled in will only be used for this study and not for any other purpose. This content does not need to be signed, and all the information you have filled in will be kept confidential. Therefore, please rest assured and fill in the details.

Thank you for your assistance and cooperation.

Universiti Putra Malaysia
Supervisor committee: Prof. Dr. Soh Kim Geok
Dr. Shamsulariffin Samsudin

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1.Expert's information

Name: Title: Specialized field:

2. Questionnaire Information

This questionnaire adopts a 5-point Likert scale, with 1-5 representing increasing support (1=strongly disagree; 2=Disagree; 3=Not necessarily; 4=agree; 5=strongly agree). Please score the functional training intervention. If there are other content, you can add them and indicate the name. After reading the questionnaire, please rate the following aspects and tick "√" on the corresponding rating scale.

Table 1 : Evaluation of the Effectiveness of Instruments Programme

Type	Sub-type	Measurements Method	Relevance 4	3	2	1	Comments
Physical fitness	Strength	Push-up Sit-up Back squat					
	Power	Left gravity ball Right gravity ball Standing long jump					
	Speed	25-yards sprint test 50-yards sprint test					
	Endurance	300-yards switchback run test					
	Agility	Left arrow run test Right arrow run test					
	Flexibility	Sit and reach test					
Skills	Passing	Forehand pass test Backhand pass test					
	Pulling	One-meter pull test					
	Dribbling	Slalom dribble test					
	Shooting	Shooting accuracy test					

3. Instruments Information

The dependent variables for this study are physical fitness and field hockey skills. Data were collected using the physical fitness and field hockey skills program recommended by the CHA (sub-variables are shown in Table 1). First, the selected physical fitness components that will be collected are strength, power, speed, endurance, agility, and flexibility. Second, the selected field hockey skills that will be collected are dribbling, pulling, passing, and shooting accuracy.

Appendix H

Information of Experts for Content Validity

Table 1 : Information of Experts for Content Validity Intervention and Instruments

Number	Name	Title	Area for research
1	Luo Shengyao	Associate. Professor	Sports training core training
2	Li Long	Associate. Professor	Core strength training
3	Wei Wei	Senior Coach	Exercise Training
4	Qin Chengxiu	Senior Coach	Exercise Training
5	He Changning	Intermediate Coach	Exercise Training
6	Yang peichun	Intermediate Coach	Exercise Training

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Appendix I

Variables Test Detail

Programme 1: Physical Fitness Test Protocol
The physical fitness variables test protocol followed according to previous literature on field hockey for physical fitness test procedures as below.

1. Strength

The strength of field hockey players is mainly tested through upper limb strength tests, waist and abdomen strength tests, and lower limb strength tests.

(1) Push-up test

Aim: To determine the muscular endurance of the triceps, pectoral and deltoid muscles.

Instruments: Stopwatch, whistle, score sheet, and pen

Procedure:

1. The player assumes the prone position on the floor with the hands directly underneath the shoulders, legs extended and together, and toes tucked under, so they are in contact with the floor, (push up position).

2. The player then pushes with the arms until they are fully extended.

3. The player then lowers the body until the chin or chest touches the floor. At this point, the line from the head to the toes should be straight.

4. All this movement should be performed only by the rams and shoulders.

Scoring: The score is the number of push-ups, while maintaining correct form, completed in one minute

(2) Sit-ups test

Aim: To assess the muscle endurance of the rectus abdominis, external obliques and iliopsoas.

Instruments: Stopwatch, whistle, score sheet and pen.

Procedure:

1. The athlete lies on his back with his knees bent, feet flat on the ground and hands crossed over his chest.

2.An assistant or partner gently holds the athlete's feet to maintain stability.

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3.At the command "start", the athlete rolls up his upper body through the abdomen until the elbows touch the knees, then slowly returns to the starting position with the shoulders and head completely touching the ground.

4. The movement should be smooth and continuous, and the body should remain under control throughout the process without relying on momentum or other parts of the body.

Scoring: The number of sit-ups completed in one minute while maintaining the correct posture is scored.

(3) Back Squat

Aim: To assess the muscular endurance and strength of the lower extremity muscles (quadriceps, gluteus maximus, and hamstrings).

Instruments: A barbell, weight plates, and a power rack.

Procedure:

Using a grip that is slightly wider than shoulder width places the bar behind the shoulders approximately 2 inches (5 cm) below the top of the trapezius muscle and lift the bar off of the rack. Participants initiated the movement in a fully extended position with the feet shoulder-width apart and the barbell held across the back at the level of the acromion ("high-bar position"). From this position, they were required to descend in a continuous motion before reaching 90° of knee flexion, hold this position for ~2 s, and then return to the initial position as fast as possible. The squat depth was individually controlled using an elastic cord positioned under participants' hips (McBride et al., 2010). Briefly, the 1RM testing protocol consisted of performing 3–5 repetitions at ~50–80% of participants' self-perceived 1RM, followed by 2–5 single attempts to determine the 1RM strength. Three minutes of rest was given between sets and 1 RM attempts (Pérez-Castilla et al., 2021).

Scoring:

$$\text{Bench press/back squat Weight ratio} = \frac{\text{Weight pushed (kg)}}{\text{Body weight (kg)}}$$

Used Calculator to see the strength level: https://strengthlevel.com/

2. Power

Field hockey player power test can be divided into upper body power test and lower body power test.

(1) Throwing a gravity ball

Aim: To measure the ability of the upper body to exert force at high speed.

Instruments: 2kg medicine ball, measuring tape or wheel, tape measure

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Procedure:

In this test, the participant stands beside a marked line, holding a 2 kg medicine ball with both hands. The feet should be positioned parallel to the line. The participant rotates their torso backward while bending the knees slightly, then quickly pushes off the ground, rotating their body forward to throw the ball with maximum force. It is crucial that the feet remain behind the marked line during the throw. The distance from the landing point of the ball to the marked line is measured to assess performance. Each athlete performs three throws on both the left and right sides, with the best result recorded. Greater distances indicate better explosive power (Yan, 2013).

Scoring: The score was calculated by measuring the distance from the front of the baseline to the powder-marked point where the ball landed. There are three tries allowed. The best of the three throws is chosen and recorded.

Figure 1 : Course of the Gravity Ball Test (Yan, 2013)

(2) Standing long jump

Aim: In much the same way as the vertical jump/hop tests measure a player's leg power in jumping vertically, this series of tests provide for the assessment of explosive force application in a horizontal (and to a lesser extent, vertical) direction. The hop test similarly provides the evaluation of any discrepancy between the right and left leg operating independently in this fashion.

Procedure:

1. Player stands with toes of both feet touching the back of the baseline (or any line).

2. From this position players jump as far forward as possible.

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3. Players may swing arms backwards and forward to provide momentum to assist with coordination and length of jump. The measurement is taken from the back of the baseline to the heel of the player's foot that is nearest to the baseline.

4. Players should endeavour to 'stick' their landing. The forward momentum is allowed to carry them forward so one (or both) hand/s touches the ground in front of them. Upon landing, if the player steps forward or for that matter steps backwards or touches the ground with his hand behind his feet, the jump should be deemed invalid.

Scoring: Players complete a minimum of three trials but may continue if still improving. The best of the trials is recorded. This procedure can also be repeated with right and left hops.

3. Speed

Field hockey player speed testing can be divided into 25-yards sprint and 50-yard speed run tests.

(1) 25-yards sprint

Aim: The 25-yard sprint test was selected to evaluate players' acceleration and initial forward speed, which are critical components of performance in field hockey. In accordance with field hockey regulations, the 25-yard line represents a strategically significant zone on the field, commonly involved in both offensive and defensive actions. Within this area, players are often required to perform short, high-intensity sprints to press opponents, intercept passes, or rapidly reposition in response to game dynamics. Therefore, this test serves as a valid and context-specific measure of a player's ability to execute explosive movements over short distances, reflecting the real-time physical demands of match play. The inclusion of the 25-yard sprint test aligns with the China Hockey Association's official physical fitness assessment standards, ensuring both practical relevance and standardized validity for evaluating the speed performance of youth hockey players.

Instruments: Field hockey rink, Speed Smart infrared speed measuring device, log book and notebook

Procedure:

The speed test begins from the baseline of one end of the hockey field. Speed Smart infrared timing equipment is set up at both the starting point and the 25-yards sprint mark. The athlete positions themselves 10 cm behind the infrared device at the start line. When ready, the athlete sprints straight forward at maximum speed. The infrared timing system automatically records the time when the athlete crosses the 25-yards sprint mark. This setup ensures accurate measurement of the 25-yards sprint time.

Scoring: Participants perform three maximal attempts and the best result is recorded.

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(1) 50-yards sprint

Aim: To evaluate forward sprinting capacity and speed endurance, this study employed the 50-yard sprint test, which corresponds to approximately half the length of a standard field hockey pitch (91.4 meters or 100 yards). This test was selected to reflect the physical demands placed on athletes during fast-paced counterattacks, defensive recovery runs, and long-distance sprinting transitions, which are common in modern field hockey match play. The ability to maintain high sprinting velocity over extended distances is essential for players to exploit open space, cover the width of the field, and respond rapidly to tactical changes, particularly in high-tempo competitive environments. The inclusion of the 50-yard sprint test aligns with the China Hockey Association's official physical fitness assessment standards, ensuring both practical relevance and standardized validity for evaluating the speed performance of youth hockey players.

Instruments: Field hockey rink, Speed Smart infrared speed measuring device, log book and notebook

Procedure:

The speed test begins from the baseline of one end of the hockey field. Speed Smart infrared timing equipment is set up at both the starting point and the 50-yard mark. The athlete positions themselves 10 cm behind the infrared device at the start line. When ready, the athlete sprints straight forward at maximum speed. The infrared timing system automatically records the time when the athlete crosses the 50-yard mark. This setup ensures accurate measurement of the 50-yards sprint time.

Scoring: Participants perform three maximal attempts and the best result is recorded.

Figure 2 : Course of the Speed Test (Yan, 2013)

4. Endurance (300 Yard test)

Aim: The aerobic capacity test is designed specifically for field hockey players, as their movement patterns involve frequent stopping, starting, and changing directions. It allows for efficient group testing, providing relevant insights into players' endurance and overall cardiovascular fitness under match-like conditions.

Instruments: Field hockey rink, stopwatch, number book, marker bucket, log book and notebook

Procedure: There are two markers on the hockey field 25 yards apart. After hearing the command to start the test, the athlete runs 6 times within 25 yards. When the athlete reaches each end, he must touch the marker with his foot and then quickly turn and run to the other side. The total distance traveled is 300 yards. The total distance traveled is 300 yards. Use a stopwatch to time each athlete twice, rest for 5 minutes or more between tests.

Scoring: Each athlete is tested three times and the best result is recorded. The shorter the time, the better the athlete's aerobic capacity.

Figure 3: Course of the Endurance Test (Yan, 2013)

5. Agility (Left and right arrows run test)

Aim: The left-right arrow run test is an important test indicator for field hockey players to evaluate their ability to change direction and accelerate frequently during a game. The test simulates the movement patterns in a game scenario and helps to fully understand the agility and reaction speed of the athlete. It can be performed in a team or collective environment, providing performance data of the athlete in an actual game situation, thereby evaluating their physical fitness level and athletic performance.

Instruments: Field hockey rink, stopwatch, flagpole, marker barrel, log book and notebook

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Procedure:

A. Turning right agility test

After hearing the command, run quickly from A to point B, then run quickly to point C bypassing point B to the right; run quickly to point E bypassing point C to the right; run fully to point A bypassing point E to the right, and be timed for the time when you pass point A.

B. Turning left agility test

After hearing the command, run quickly from A to point B, run quickly to point C bypassing point B to the left; run quickly to point E bypassing point D to the left; run to point A bypassing point E to the left with all the strength, and time is taken when the athlete passes point A.

Scoring: Each athlete will be tested 3 times in each direction, and the best value is recorded, and the athlete who has the shorter time is the better in terms of agility.

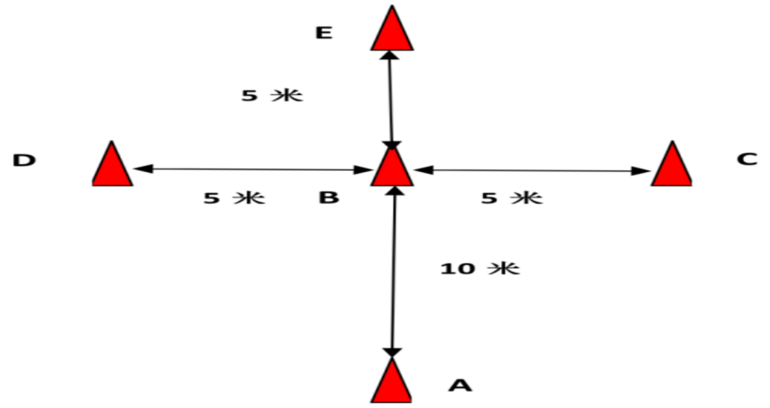

Figure 4 : Course of the Agility Test
(Yan, 2013)

6. Flexibility (Sit and Reach Test)

Aim: To measure a player's lower back and hamstring flexibility

Instruments: Sit and reach test tool

Procedure:

1. Allow the players to warm-up by running.

2. The starting position is sitting on the floor with shoes removed, feet flat against the table, and legs straight.

3. The player should reach forward and push their fingers along the table as far as possible without lifting their knees.

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4. The distance from the finger tips to the edge of the table represents the score for that person

Scoring: Players should complete three trials but may continue if they are still improving. The players' greatest distance travelled was recorded to the closest 0.5 cm.

Programme 2: Field Hockey Skills Test Protocol

1. Dribbling Skills (SDT)

Aim: The dribbling test is designed for field hockey players to assess their ability and skills to control the ball in a game. This test simulates real-life situations in a game and examines the player's flexibility, speed and technical execution in different directions. By evaluating the player's performance during dribbling, we can gain insight into their coordination, reaction ability and tactical awareness, providing data support for the development of personalized training programs. This test can be conducted in a team environment to reflect the player's performance level in actual games.

Instruments: Standard hockey balls (eight to ten); hockey field (half court); white tape (for marking); cones (five); stopwatch (three); measuring tape (at least 50 meters); pens, pencils; score sheet and video camera.

Procedure: The field hockey dribble test consists of twelve cones placed in a zigzag pattern (Figure 4). The start and finish lines (A and B) were marked by two cones. The test starts with the subject standing with both feet behind the A line; then, after a 5-second countdown with an auditory signal, the subject runs around the 12 cones with a hockey stick in hand and finally crosses the B line. Resumption of the walk is timed to allow the subject to return to the A line 1020 seconds before the start of the next section. The protocol for the dribbling portion is the same as the sprinting portion, except that the subject is now dribbling a hockey puck. If the subject loses control of the ball, i.e., if the subject is more than approximately 2 metres from the cone, the test is repeated. Timing data was measured using a stopwatch. The pirouette sprint time, the pirouette dribble time, and the difference in pirouette time between the dribble and the sprint (pirouette time Δ) were recorded and were accurate to within 0.01seconds (Lemmink,2004).

Scoring: Each athlete is tested three times and the best result is recorded. The shorter the time, the better the athlete's dribbling skills.

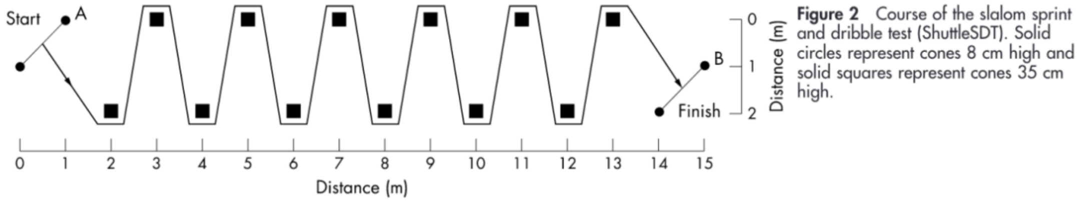

Figure 5 : Course of the Slalom Dribble Test (Lemmink et al., 2004)

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2. Pulling Skills (SDT)

Aim: The One-Meter Pull Test is a fundamental skill assessment used in field hockey to evaluate a player's ball control and agility over short distances. This test simulates the pulling motion commonly performed when confronting an opponent during gameplay and is designed to assess the athlete's ability to execute quick directional changes and maintain precise ball control under pressure.

During the test, specific observations are recorded, including:

(1) Ball control and stability – the player's ability to maintain possession while performing rapid pull movements.
(2) Directional change speed – the quickness and efficiency in shifting the ball laterally.
(3) Technical consistency – the smoothness and accuracy of execution throughout the trial.

Instruments: Standard hockey balls (eight to ten); hockey field (half-court); cones (two); stopwatch (three); pens, pencils; scoresheet, and video camera.

Procedure:

Two parallel short lines 1m apart, players can stand front and back or left and right into a dribbling position between the two lines, and put the ball on the right side of the line, the start of the clock, quickly pull the ball between the two lines and over the line, to the left, to the right, each for a time, counting the number of times completed within 1 minute (China Hockey Association,2007).

Scoring: Each athlete will be tested three times, and the best result will be recorded. The more times, the better the athlete's one-meter skills.

Figure 6 : Course of the One-meter pull Test (Yan, 2013)

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3. Passing Skills (SDT)

Aim: The Field hockey Passing Skills Test is designed to assess a player's ability to make accurate passes during a game. Passing is a fundamental and critical skill in hockey that not only affects a team's offensive efficiency, but also plays an important role in defense. Through this test, players make multiple passes in simulated game situations to examine their accuracy, strength, and timing. Mastering this skill is essential to improving teamwork and tactical execution.

Instruments: Standard hockey balls (eight to ten); hockey field (half-court); cones (two); stopwatch (three); pens, pencils; scoresheet, and video camera.

Procedure:

Partner with a teammate, using a 15-yard (13.8-meter) long area. Stand 7 yards (6.4 meters) from your partner. Starting in a sideways position (left side of body facing partner), place the ball in the control area and push pass the ball to your partner's stick. Your partner immediately pushes the ball back to your stick after receiving the ball. Complete 15 accurate forehand passes. Next, place the ball to your left and make a backhand pass to your partner's stick. Complete 15 accurate backhand passes to your partner. Next, 15 yards (13.8 meters) from your partner, complete 15 accurate forehand passes. Finally, complete 15 accurate backhand passes. Passing errors include making a bounce pass due to an improper stick angle, making an inaccurate push pass (the receiver must move the stick more than 12 inches (30.5 cm) away from the initial target), tapping the ball instead of bringing the stick close to the ball and pushing the pass, or passing the ball slowly. One point is awarded for each completed pass without errors (Anders & Myers, 2008).

Scoring: Each athlete will be tested on their passing skills three times, each consisting of 15 passes. In each test, one point will be awarded for each successful pass, with a maximum score of 15. The athlete's best score will be recorded. The higher the score for successful passes, the better the athlete's passing skills. This test is designed to systematically evaluate the athlete's ability in passing.

Figure 6 : Course of the Passing Skills Test (Yan, 2013)

4. Shooting Skill (Shooting Accuracy Test)

Aim: The Field hockey Shooting Skills Test is designed to assess a player's ability to effectively shoot during a game. Shooting is a core skill in hockey that directly affects a team's scoring opportunities and the outcome of the game. Through this test, players shoot multiple times in simulated game situations to test their accuracy, power, and reaction speed. Mastering this skill is crucial to improving a team's offensive threat and overall performance.

Instruments: Standard hockey balls (eight to ten); hockey field (half court); white tape (for marking); cones (five); measuring tape (at least 50 meters); pens, pencils; score sheet and video camera.

Procedure:

This test was carried out within the goal area. Each player had eight shots executed from five different positions, previously established, in the direction of the goal; four shots were hit from positions 1 to 4, two were pushed from positions 2 and 3, and two flick shots were taken from position 5. Each shot made was given 1 point, and failed shots were given 0, ranging from 0 to 8 points. No speed or strength was required by the participants (Keogh et al. 2003).

Shooting accuracy valuate by placing a hockey ball at five positions in the goal scoring area ("D"). Players perform a series of four hits (Shots 1–4), two pushes (Shots 5–6), and two flicks (Shots 7– 8) (Figure 1, a and b). A flick is similar to a pushing action. However, in executing a flick, the player angles the stick in relation to the ball so that the ball undergoes both horizontal and vertical displacement. The result of each shot was recorded, with each accurate shot being awarded 1 point and each inaccurate shot 0 points. An accurate shot defines as one that hit into the target zone. If the shot hit the post, it would deem accurate only if it rebounded into the goal. A score out of 8 was record for each athlete, with each player's performance then express as the percentage of accurate shots. As only shooting accuracy assess in this test, no special pushing, hitting, or flicking speed was required. Thus, the accuracy component of goal scoring could be isolated from the power component, in accordance with the speed/accuracy tradeoff (Spirduso et al., 1993).

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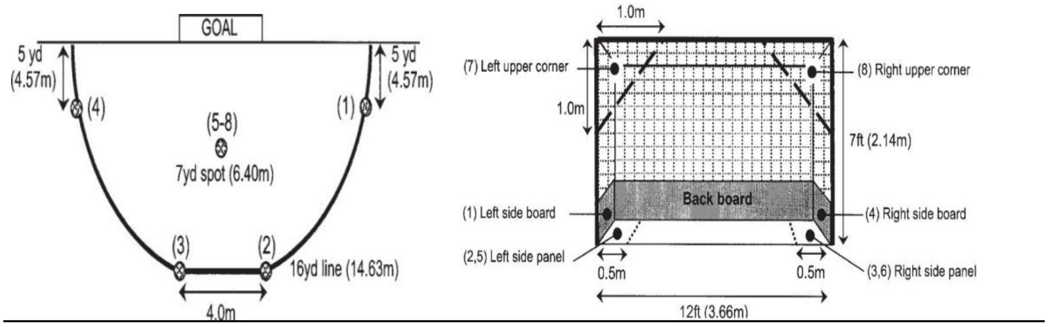

Figure 7 : (A) Top-view schematic of the shooting accuracy test. The 4 circles indicate the position from which the shots were taken. Numbers in parentheses indicate each of the 8 shots taken. Shots 1–4 = hits; Shots 5–6 = pushes; Shots 7–8 = flicks. (B) Frontal view of the goal used in the shooting accuracy test. Numbers in parentheses indicate the target zone of each shot taken.

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Appendix J

Data Collection Forms

Form 1: Physical Fitness Data Collection Form

Basic information of elite hockey players:

Name: **Training years:** **Date of birth:**

Height (cm): **Weight(kg):**

Test Content：

Variable	Components	Measurement Method	Score
Physical Fitness	Strength	Push-up	
		Sit-up	
		Back squat	
	Power	Left gravity ball	
		Right gravity ball	
		Standing long jump	
	Speed	25 yards	
		50 yards	
	Endurance	300 yards	
	Agility	Left arrow run test	
		Right arrow runs test	
	Flexibility	Sit and Reach Test	

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Data Collection Forms Form 2: Field Hockey Skills Data Collection Form
Basic information of elite hockey players:

Name: Training years: Date of birth:

Height (cm): Weight(kg):

Test Content：

Variables	**Skills**	**Measurement Methods**	**Score**	
Field Hockey Skills	Dribbling	Slalom Dribble Test		
	Pulling	One meter pull test		
	Passing	Forehand pass test		
		Backhand pass test		
	Shooting Accuracy	Shots	**Positions**	**Score**
		Shots 1–4	P1	
			P2	
			P3	
			P4	
		Push 5-6	P5	
			P6	
		Flick 7-8	P7	
			P8	
			Total Score	

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Appendix K

Normality Test for Variables at Baseline, Week-6, and Week-12

Table 1 : Normality Test for Basic Information Variables at Baseline, Week-6, and Week-12

Variables	Groups	Shapiro-Wilk		
		Statistic	df	p
Age (yr.)	CSTG	0.778	24	0.000
	CTG	0.796	24	0.000
Hight (cm)	CSTG	0.930	24	0.097
	CTG	0.947	24	0.237
Weight (kg)	CSTG	0.945	24	0.211
	CTG	0.914	24	0.043
Experience	CSTG	0.503	24	0.000
	CTG	0.542	24	0.000

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Table 2 : Normality Test for Physical Fitness Variables at Pretest

Variables	Groups	Shapiro-Wilk		
		Statistic	df	Sig.
Push-up	CSTG	0.953	24	0.320
	CTG	0.968	24	0.620
Sit-up	CSTG	0.926	24	0.080
	CTG	0.944	24	0.200
Back squat	CSTG	0.932	24	0.108
	CTG	0.908	24	0.033
Left gravity ball	CSTG	0.948	24	0.249
	CTG	0.958	24	0.396
Right gravity ball	CSTG	0.929	24	0.093
	CTG	0.942	24	0.181
Standing long jump	CSTG	0.960	24	0.473
	CTG	0.967	24	0.595
25 yards	CSTG	0.973	24	0.731
	CTG	0.928	24	0.088
50 yards	CSTG	0.960	24	0.438
	CTG	0.933	24	0.111
300 yards	CSTG	0.891	24	0.014
	CTG	0.954	24	0.327
Left arrow run test	CSTG	0.888	24	0.012
	CTG	0.954	24	0.330
Right arrow runs test	CSTG	0.976	24	0.821
	CTG	0.922	24	0.066
Sit and reach test	CSTG	0.953	24	0.321
	CTG	0.966	24	0.571

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

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Table 3 : Normality Test for Field Hockey Skills Variables at Pretest

Variables	Groups	Shapiro-Wilk		
		Statistic	**df**	**Sig.**
Slalom dribble test	CSTG	0.924	24	0.183
	CTG	0.964	24	0.523
One meter pull test	CSTG	0.973	24	0.741
	CTG	0.975	24	0.784
Forehand pass test	CSTG	0.914	24	0.042
	CTG	0.904	24	0.026
Backhand pass test	CSTG	0.881	24	0.009
	CTG	0.885	24	0.010
Shooting accuracy test	CSTG	0.873	24	0.006
	CTG	0.865	24	0.004

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

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Appendix L

Levene's Test of Equality of Error Variance at Pretest

Table 1 : Levene's Test of Equality of Error Variance at Pretest (Basic Information)

Variables	Levene statistic	df1	df2	P-value
Age (yr.)	0.015	1	46	0.903
Height (cm)	0.265	1	46	0.609
Weight (kg)	1.503	1	46	0.226
Experience	0.455	1	46	0.503

Table 2 : Levene's Test of Equality of Error Variances at Pretest (Physical Fitness)

Variables	Levene statistic	df1	df2	P-value
Push-up	0.030	1	46	0.864
Sit-up	1.070	1	46	0.306
Back squat	1.933	1	46	0.171
Left gravity ball	0.481	1	46	0.492
Right gravity ball	0.163	1	46	0.688
Standing long jump	0.091	1	46	0.765
25 yards	1.356	1	46	0.250
50 yards	1.202	1	46	0.279
300 yards	2.679	1	46	0.109
Left arrow run test	0.169	1	46	0.683
Right arrow runs test	0.061	1	46	0.806
Sit and reach test	0.511	1	46	0.478

Table 3 : Levene's Test of Equality of Error Variances at Pretest (Hockey Skills)

Variables	Levene statistic	df1	df2	P-value
Slalom dribble test	0.272	1	46	0.605
One-meter pull test	0.520	1	46	0.474
Forehand pass test	0.242	1	46	0.625
Backhand pass test	4.029	1	46	0.051
Shooting accuracy test	2.902	1	46	0.095

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Appendix M

Test-retest Reliability of Variables

Table 1 : Test-retest Reliability of Physical Fitness Instruments (n=16)

Variable	Measurement Method	Intra-class Correlation Coefficient	95% Confidence Interval	
			Lower Bound	Upper Bound
Strength	Push-up	0.914	0.695	0.978
	Sit-up	0.943	0.790	0.986
	Back squat	0.926	0.731	0.981
power	Left gravity ball	0.918	0.706	0.979
	Right gravity ball	0.921	0.714	0.980
	Standing long jump	0.959	0.845	0.990
Speed	25 yards	0.898	0.645	0.974
	50 yards	0.903	0.659	0.975
Endurance	300 yards	0.900	0.650	0.974
Agility	Left arrow run test	0.914	0.695	0.978
	Right arrow runs test	0.932	0.751	0.983
Flexibility	Sit and reach test	0.992	0.967	0.998

Table 2 : Test-retest Reliability of Hockey Skills Instruments (n=16)

Variable	Measurement Method	Intra-class Correlation Coefficient	95% Confidence Interval	
			Lower Bound	Upper Bound
Dribbling	Slalom dribble test	0.860	0.543	0.963
Pulling	One meter pull test	0.896	0.639	0.973
Passing	Forehand pass test	0.960	0.848	0.990
	Backhand pass test	0.975	0.902	0.994
Shooting	Shooting accuracy test	0.917	0.703	0.979

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Appendix N

Content Validity of Intervention and Instruments

Table 1 : Clarity Agreement of the Intervention Items

Type	Number in Agreement	Clarity	
		I-CVI	KAPPA
Overall evaluation of the programme	6	1.000	1.000
Duration	6	1.000	1.000
Frequency	6	1.000	1.000
Intensity	6	1.000	1.000
Time	6	1.000	1.000
Content of Warm- up	5	0.833	0.816
Basic content	6	1.000	1.000
Content of cool-down	6	1.000	1.000
Rest	5	0.833	0.816

Table 2 : Clarity Agreement of the Instruments Items

Variables	Measurement Method	Number in Agreement	Clarity	
			I-CVI	KAPPA
Strength	Push-up	5	0.833	0.816
	Sit-up	5	0.833	0.816
	Back squat	6	1.000	1.000
Power	Left gravity ball	6	1.000	1.000
	Right gravity ball	6	1.000	1.000
	Standing long jump	6	1.000	1.000
Speed	25-yards Sprint test	5	0.833	0.816
	50-yards Sprint test	6	1.000	1.000
Endurance	300-yards switchback test	5	0.833	0.816
Agility	Left arrow run test	6	1.000	1.000
	Right arrow runs test	6	1.000	1.000
Flexibility	Sit and reach test	6	1.000	1.000
Hockey Skills	Slalom Dribbling test	6	1.000	1.000
	One meter pull test	6	1.000	1.000
	Forehand pass test	5	0.833	0.816
	Backhand pass test	6	1.000	1.000
	Shooting Accuracy	5	0.833	0.816

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Appendix O

2nd Chapter

The PRISMA Table, Keywords and Characteristics of the Studies Examined

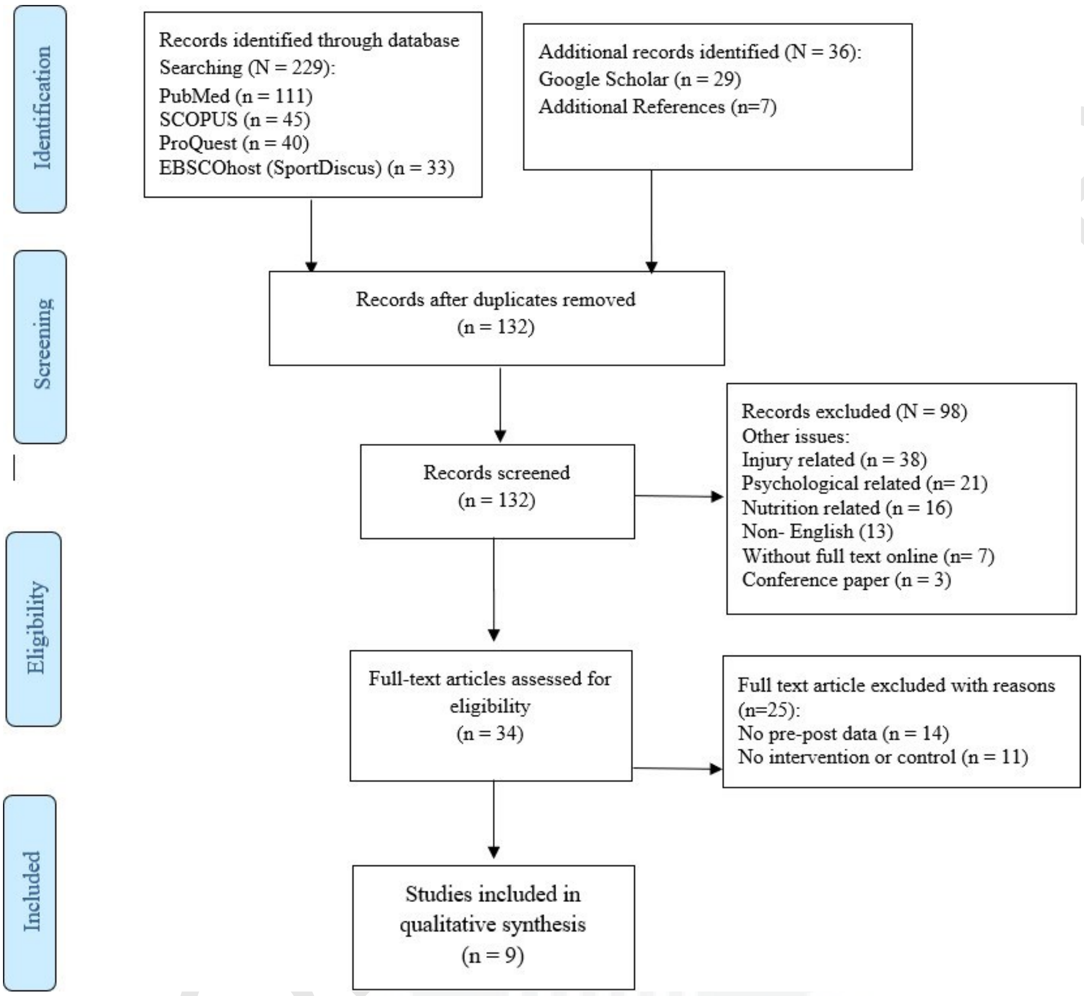

Figure 1 : PRISMA Flow Chart of the Study Selection Process

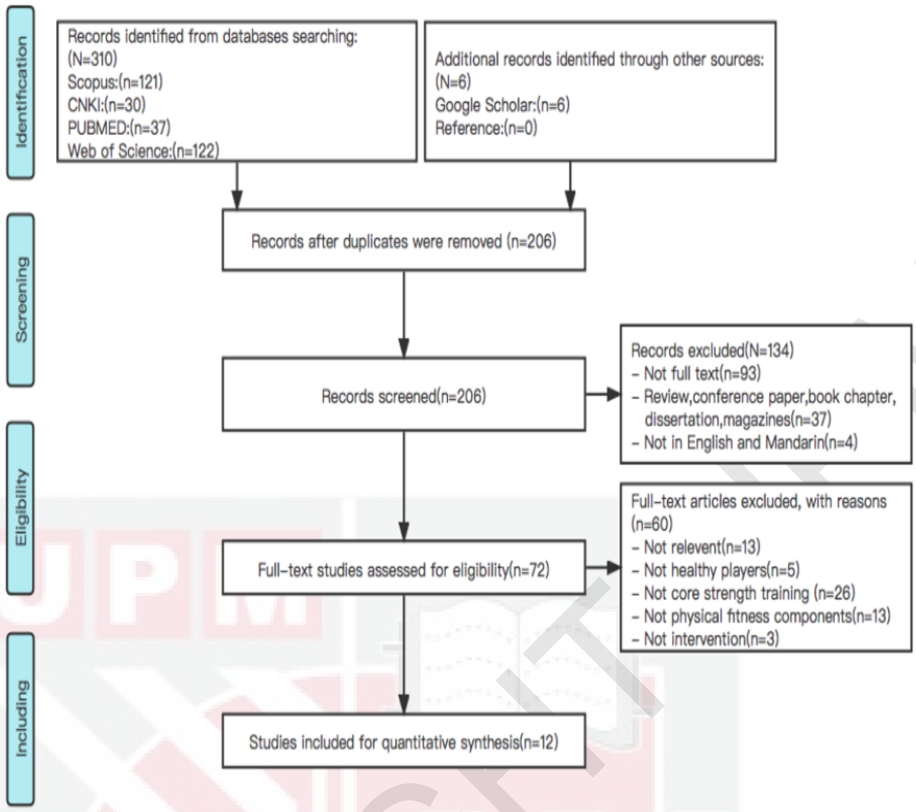

Figure 1 | PRISMA flow chart of the study selection process

Figure 2 : PRISMA Flow Chart of the Study Selection Process

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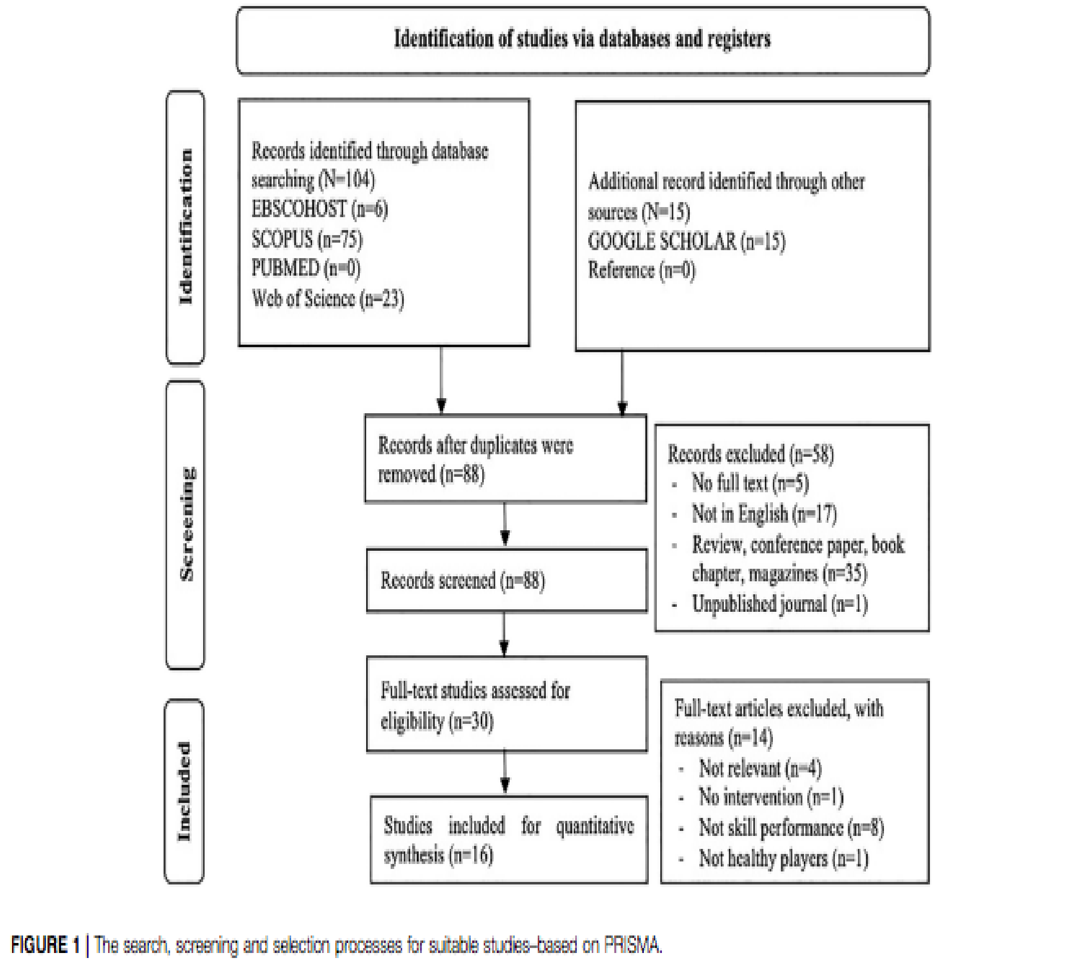

Figure 3 : PRISMA Flow Chart of the Study Selection Process

Table 1 : Predefined Combination of Keywords

Title	Keyword	Data Base
Effects of Exercise Training on Physical Fitness in Skills among Hockey Players. A Systematic Review	**“Hockey players” OR “hockey players performance” OR “male hockey players” OR “female hockey players” OR “Exercise” OR “exercises” OR “Exercise training” OR “Physical exercises” OR “Physical training” OR “Performance” OR “physical performance” OR “technical performance” OR “physiological responses” OR “speed” OR “agility” OR “muscular strength” OR “body composition” OR “endurance” OR “cardiorespiratory endurance” OR “cardiovascular endurance” OR “cardiovascular fitness” OR “jump” OR “jumping” OR “jumping performance” OR “leap” OR “drag flick” OR “drag-flick” OR “pushing speed” OR “shooting skill” OR “shooting accuracy” OR “shooting speed” OR “dribbling skill” OR “dribbling speed” OR “hockey skills” OR “hockey skill performance” OR “hockey techniques”**	**PubMed, SCOPUS, ProQuest, EBSCOhost (Sport Discus)**
Effect of Core Strength Training on Physical Fitness among Players in Sports: A Systematic Review	“core strength training” OR “core-muscle training” OR “core training” OR “core-Stability exercise” OR “core exercise” OR “trunk muscle training” OR “physical fitness” OR “physical endurance” OR “skill-related physical fitness” OR “health-related physical fitness” OR “strength” OR “speed” OR “power” OR “reactiontime” OR “agility” OR “balance” OR “coordination” OR “flexibility” OR “player*” OR “athlete*” OR “sportsman*” OR “sportswoman*” OR “sportsperson*”	**SCOUPS, PubMed, Web of Science, EBSCOhost, CNKI and Google Scholar**
Effect of Core Training on Skill Performance Among Athletes: A Systematic Review	**“Core Strength Training” OR “Core-Muscle Training " OR “Core training” OR “Core-Stability Exercise” OR “Core Exercise” OR “Skill” OR “Skill Performance” OR “Sport Skill Performance” OR “Sport Technology"**	**Ebscohost, SCOUPS, PubMed, Web of Science and Google Scholar**

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Table 2 : Characteristics of the Exercise Training Interventions used for the Field Hockey Players Performance in the Studies Included within this Review

References	Design	Participant Profile	Groups	Performance level	Type of exercises training	Interventions	Measure index	Main findings
Singh et al., (2018)	Pre-post test	M (11), F (6), (mean±SD) Age: 23±2.4 years, height 1.76±0.76 m, bodymass 73±8.5 kg,	TG 1 (8) TG2 (9)	Elite athletes	Plyometric training: Low-to-High drop jump plyometric protocol (EG1), High-to-low drop jump plyometric protocol (EG2)	Length: 6-week/ Freq.: 2 per week/ Time: NR Intensity: 70% HRmax	Speed (10m, 20m), Change of direction: (505 COD test)	Sprint 10m↑, 20m↑, 505 COD test↔,
Pavlů et al., (2021)	Pre-post test	M (30), TG, Age (years) 19-37 years,Body mass (kg) 84.90±7.14,Height (cm) 183.00±6.34,BMI (kg/m2) 25.35±1.66,CTG, Age (years) 25.40±5.14, Body mass (kg) 81.80±10.60, Height (cm)	TG (15) CTG (15)	Professional payers	Elastic band exercises: Elastic resistance exercises with PNF, Control group (CTG)	Length: 8-week/ Freq.: 1 day per week/ Time: NR Intensity: NR	Shooting speed (sports radar), shooting accuracy	Shooting speed↔, shooting accuracy↔,

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		182.33±5.87,BMI (kg/m2) 24.59±2.86						
Sener et al., (2021)	Randomised crossover design	M (10) (Age: 19.90 _ 1.29 years,body height: 175.78 _ 2.89 cm;body mass: 68.62 _ 7.52 kg; body fatpercentage: 10.10 _ 3.88%)	TG (10)	National level	Plyometric warm-up with different box heights (of maximum HR) (EG1)	Length: 6 days/ Freq.: NR week/ Time: 3hrs Intensity: 60–70% HRmax	Speed (10m, 30m sprint test), Agility (Illinois test)	10m↑, 30m sprint↑, Illinois test↑,
Quezada-Muñoz et al., (2021)	Pre-mid-post test	F (20) EG (Age 23.6 + 2.8 years, bipedal height 158.3 + 5.0 cm) CTG (Age 23.6 + 3.0 years, bipedal height 163.3 + 6.8 cm)	TG (10) CTG (6)	Professional payers	High-intensity interval training (EG1), Control group (CTG)	Length: 8 weeks/ Freq.: 16 session per week/ Time: 14 min Intensity: 85 %- 100 % HRmax	Body composition (Muscle mass and adipose mass), VO2max (Course-Navett), Jump performance (CMJ test), Pushing speed (10m, 20m stick to travel), Dribbling speed (IAR), Shooting accuracy	muscle mass↑, adipose mass, VO2max↑, CMJ test↑, Pushing speed↑, Dribbling speed↔, Shooting accuracy↑
Spencer et al., (2004)	Pre-post test	F (18) Mean + SD age: 27+3 years,	TG (18)	Elite female field-hockey	Hockey-specific training:	Length: 7 weeks/Freq.: NR per week/	Sprint (5 x 6-sec cycle test, 20m Shuttle	5 x 6-sec cycle test ↔, 20m Shuttle run

		(Mean +SD) body mass 60.8_+5.7 kg			repeated-sprint training (EG1)	Time:40-50mins Intensity: 70-95% HRmax	run test)	test↑
Kumar & Health, (2016)	Pre-post test	M (60) Age: 18-24 years. NR	LTG(20), STG(20), CTG (20)	University players	Land plyometric (EG1), Sand plyometric training (EG2), Control group (CTG)	Length: 8 weeks/Freq.: 3 per week/Time: 45 mins Intensity: NR	Speed (50m run test), Agility (T test), Cardiorespiratory endurance (12 mint run/walk)	50m run test↑, T test↑, Cardiorespiratory endurance↔
Sarika et al., (2019)	Pre-post test	M (56) Mean age (18.95±1.017) years, mean weight (59.02±5.629) kg, mean height (165.830± 6.190) cm., mean BMI (21.45±1.72) kg. /m2.	TG 1 (18), TG 2 (18), GG 3 (20)	College players	Swiss ball exercises (EG1), Plyometric training (EG2), Control group (CTG)	Length: 6 weeks/ Freq.: 3 per week/ Time: 20 mins	Speed (30m sprint test), Agility (Illinois test)	30m sprint test↑, Illinois test↑
Elumalai et al., (2020)	Pre-post test	M (40) Age: 14 to 16 years, NR	TG (20) CTG (20)	School players	High intensity interval training (EG1), Skill training group (CTG)	Length: 8 weeks/ Freq.: 2 per week/ Time: NR	Speed (30m sprint test), cardiovascular endurance (Multistage Shuttle Run (Bleep) test)	30m sprint test↑, cardiovascular endurance↔

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Taylor et al., (2022)	Pre-mid-post test	M (18) TG-1 (n=9; height 1.79 ± 0.07m, weight 75 ± 7.5 Kg, age 20.4 ± 1.0 years, BMI 23.5 kg.m2) TG-2 (n = 9; height 1.79 ± 0.04m, weight 76.2 ± 6.4 Kg, age 20.9 ± 1.0 years, BMI 23.7 kg.m2)	TG-1 (9) TG-2 (9)	Professional players	Sprint interval training: Uphill training (EG1), Flat training (EG2)	Length: 8 weeks/ Freq.: per week/ Time: 30 mins Intensity: 90%	Speed (10m, 30m sprint), squat jump (Opto jump system)	10m↔, 30m sprint↑, squat jump↑

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Table 3 : Characteristics of Core Strength Training Interventions for Athletic Performance in Studies Included in This Review

References	N	Performance level	Sex	Participant Profile	Groups	Physical fitness measured index	Frequency and duration	Main outcome
Kumar & Zemková, 2022	90	NR School-Aged players	M	EG: age:12.3±0.3 years Height (cm) 142.4±6.1 cm Weight (kg) 33.3±6.2 CG1: age:12.2 ± 0.3 years Height (cm) 141.8 ± 5.9 cm Weight (kg) 33.3 ± 6.2 CG2: age:12.2 ± 0.3 years Height (cm) 142.0 ± 6.0 cm Weight (kg) 33.1 ± 6.1	EG: Core strength training CG1: Weight training CG2: Control group	Abdominal strength; Flexibility; Endurance	Length: 12 weeks; Time: 60 min; Freq: 3 per week	Abdominal strength↑ Flexibility↑ Endurance↑
Liu, 2022	20	Tennis University players	NR	EG: age 18-24 CG: age 18-24	EG: Core strength training CG: Normal training	Speed of service; Forehand speed	Length: 14 weeks; Time: 30 min; Freq: 3 per week	Speed of service↑ Forehand speed↑
Yılmaz, 2022	16	Basketball Youth players	M	EG: age:13.29±1.96 years height: 159.38±12.89 cm	EG: Core strength training CG: Normal training	Sprint(20m); Vertical Jump; Agility	Length: 4 weeks; Time: 12 min; Freq: 2 per week	Sprint (20 m)↑ Vertical Jump↑ Agility↑

				body mass: 62.37±20.55 kg				
Mossa, 2022	26	Soccer Youth players	M	EG: age:14 years Height:168±3.62 cm Weight (kg) 56.92±5.5 CG: age:14 years Height 171±4.69 cm Weight (kg) 57.77 ± 4.82	EG: Core strength training CG: Routine training	Vertical jump, the Illinois agility test,10 m dash, t 40 m dash	Length: 12 weeks Time: NR Freq: 2 per week	Vertical jump ↑ The Illinois agility test↑ 10 m dash ↑ 40 m dash ↑
Li,2022	12	Basketball University players	M	EG: age:20.5±1.33 years height:176.8±2.68 cm body mass:69.4±4.55 kg CG: age:20.8±0.86 years height:175.6±2.65 cm body mass:71.5±3.23 kg	EG: Core strength training CG: Conventional training	run-up speed; dribble speed	Length: 12 weeks Time: 60 min Freq: 3 per week	Run-up speed↑ Dribble speed↑
Ozmen & Aydogmus,2015	20	Badminton Adolescent players	M/F	EG: age:10.9 ±0.3 years Height (cm) 139.4 ± 2.6 Weight (kg) 31.7 ±4.6 CG: age:10.8 ±0.4	EG: Core strength training CG: Traditional strength training	Balance test (SEBT); Agility test (IAT); Core Endurance test (SBT)	Length: 6 weeks Time: NR Freq: 2 per week	Balance test (SEBT)↑ Agility test (IAT)↔ Core Endurance test (SBT)↑

				years Height (cm) 141.7 ±2.6 Weight (kg) 36.2 ± 6.3				
Li,2022	24	Martial arts Professional players	NR	NA	EG: Core strength training CG: Normal training	Extensor power; Flexor power; Balance	Length: 12 weeks Time: NR Freq: NR	Extensor power↑ Flexor power↑ Balance↑
Yue, 2022	28	Sports dance professional players	F	EG: BMI (kg/cm) 19.8±5.6; CG: BMI (kg/cm) 19.2±4.8	EG: Core strength training CG: Conventional training	Physical stability; explosive power; muscle coordination	Length: 16 weeks Time: NR Freq: NR	Physical stability↑ Explosive power ↑ Muscle coordination↑
Hong, 2020	45	NR University players	M	EG: age 18-24 NA CG: age 18-24 NA	G1: Core strength training G2: Usual training G3: Traditional strength training	50m speed; 1000m speed; flexibility; strength	Length: 10 weeks Time: 90 min Freq: 3 per week	50m speed ↑ 1000m speed ↑ flexibility↑ strength↑
Yang et al., 2022	5	Javelin throwers Professional players	M	NA	EG: core strength training CG: Normal training	Speed	Length: 16 weeks Time: NR Freq: 2 per week	speed↑
Kabadayı,2022	29	Karate Professional players	M/F	EG: age:12.72 ±0.77 years Height (cm) 152.25 ± 10.18 Weight (kg) 43.18±9.40 CG: age:13 ±0.91	EG: Core strength training CG: Normal training	core endurance; agility; flexibility; Sprint(20m); jumping; kick performance	Length: 8 weeks Time: 30-35 min Freq: 3 per week	core endurance↑ agility↔ flexibility↔ Sprint(20m) ↔ jumping↔kick performance↑

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				years Height (cm) 152.92 ± 10.62 Weight (kg) 42.61±8.44				
Bauer & Muehlbauer, 2022	26	Handball Sub-elite players	M	EG: age:16.9 ±0.6 years Height (cm) 179.1 ± 6 Weight (kg) 81.9±12 BMI (kg/cm) 25.6±4.4 CG: age:17.2 ±0.8 years Height (cm) 183.6 ± 5.8 Weight (kg) 75.7±15.6 BMI (kg/cm) 22.3±3.7	EG: Core strength training CG: Usual training	Muscular endurance; body stability; Throwing velocity	Length: 6 weeks Time: 90 min Freq: 3 per week	Muscular endurance↑ body stability↑ Throwing velocity↑

Abbreviation--CST, Core strength training; WT, weight training; NTG, Normal training; UTG, Usual training; RT, Routine training; SEBT, star excursion balance test; IAT, Illinois Agility Test; SBT, side bridge test; Freq., frequency; mins, minutes; EG, experiment group; CG, control group; CG1, Weight training;CG2,Control group; M, Male; F, Female; BMI, Body mass index; m, Meter; kg, Kilogram; cm, Centimeter; mins, Minutes; wk, Week; N/A, Not available.

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BIODATA OF STUDENT

Ma Hucheng was born on January 13, 1996, in Lanzhou, Gansu Province, China. He attended Hualin Road No. 2 Primary School in Qilihe District, Lanzhou City (2002-2008) for his primary school and completed his junior high school at Lanzhou No. 60 Middle School (2008-2009). In 2009, he entered the Gansu Sports School, focusing on field hockey. He achieved excellent results in provincial and national competitions many times (2009-2012), laying a solid foundation for his sports foundation and cultivating a deep love for the sport. In 2012, he entered Xi'an Sports University to study sports training and obtained a bachelor's degree in education in 2016. After that, he studied sports education and training at Northwest Normal University. He received a master's degree in education in 2020, further enhancing his professional ability in sports training and physical education.

In September 2021, Ma Hucheng began to pursue a doctorate in sports education at Universiti Putra Malaysia, with research directions covering physical education, sports training and physical health. He has a solid academic background, having published three peer-reviewed articles in international journals and presented his research at national and international conferences. These educational experiences have provided him with valuable insights into improving athletic performance and have enabled him to make significant contributions in this field. His academic career has demonstrated a sustained commitment to the theory and practice of physical education and sports training.

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