International Journal of Human Movement and Sports Sciences 12(6): 919-929, 2024 http://www.hrpub.org
DOI: 10.13189/saj.2024.120604

Effects of Short-Term Plyometric Training on High-Intensity Movement-Related Variables in Elite Female Field Hockey Players Using Global Positioning System

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Received August 6, 2024; Revised September 20, 2024; Accepted October 25, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Kihyuk Lee, Minkyung Choi , "Effects of Short-Term Plyometric Training on High-Intensity Movement-Related Variables in Elite Female Field Hockey Players Using Global Positioning System," International Journal of Human Movement and Sports Sciences, Vol. 12, No. 6, pp. 919 - 929, 2024. DOI: 10.13189/saj.2024.120604.*

(b): *Kihyuk Lee, Minkyung Choi (2024). Effects of Short-Term Plyometric Training on High-Intensity Movement-Related Variables in Elite Female Field Hockey Players Using Global Positioning System. International Journal of Human Movement and Sports Sciences, 12(6), 919 - 929. DOI: 10.13189/saj.2024.120604.*

Abstract The implementation of revised rules in modern field hockey has emphasized the importance of high-intensity movements such as short sprints, accelerations, and decelerations. This study aimed to analyze the effects of short-term plyometric training on high-intensity movement-related variables in elite female field hockey players. For this study, 20 collegiate female field hockey players were divided into two groups of 10: the Continuous Training Group (CTG) and the Plyometric Training Group (PTG). Each group underwent their respective training protocols for 60 minutes, three times a week, over a six-week period. To analyze the impact of these programs on high-intensity movement-related variables, simulated matches were conducted before and after the training period to measure high-intensity movement-related variables and athletic performance. The effectiveness of the programs was assessed using two-way repeated measures ANOVA. The results showed significant improvements in high-intensity movement-related variables for the PTG group compared to the CTG group in maximum velocity, sprint distance, and the number of acceleration bouts, with significant group × time interactions (all, $p < 0.05$). In terms of athletic performance, significant improvements were found in the 10m sprint, 20m sprint, and arrowhead agility test, with significant group × time interactions (all, $p < 0.05$). This study concludes that plyometric training is more effective than continuous and agility training in improving high-intensity movement-related variables and athletic performance in elite female field hockey players.

Keywords Field Hockey, GPS, Plyometric Training, Performance, Female Athlete

1. Introduction

Field hockey is a team sport characterized by its fast speed and high intensity movements. To perform the technical and tactical elements involving handling the ball with a stick, excellent physical condition is required [1, 2]. The International Hockey Federation (FIH) has introduced changes to the rules of field hockey, such as removing offside [3], allowing self-passing [4], implementing unlimited player substitutions [3], and changing the game format to four 15-minute quarters [5] to speed up the flow of the game and increase scoring opportunities. Consequently, in modern field hockey, the ability to perform multiple positions has become important, and to meet these demands, the endurance, speed, power, and recovery ability of players are emphasized [5-7].

McGuinness et al. [8] monitored the movements of elite female field hockey players at the international level and reported that players covered an average distance of approximately 4.9 km, with 44% of their movements being of moderate intensity and 12% being of high intensity. Another previous study reported that players covered an average distance of approximately 5.3 km during a game, with high-intensity movements accounting for about 19% [9]. As such, in international level field hockey games, high-intensity movements such as high-intensity running, sprinting, acceleration, and deceleration are reported to be crucial factors influencing the outcome of the game [10].

Plyometric training utilizes various jumping movements such as jumps, hops, and skips to rapidly transit from eccentric contraction to concentric contraction (Stretch-Shortening Cycle). This training method contributes to improving athletes' strength, agility, and reducing power manifestation time [11]. It is also reported to help prevent injuries that may occur during sudden performances such as changing directions [12]. Additionally, plyometric training is reported to improve athletes' neuromuscular function and performance [13-14].

Plyometric training is a training method related to high-intensity movements and is actively researched across various sports [15, 16]. For example, a 4-week plyometric training program conducted twice a week for elite female soccer players resulted in improved jump performance and agility [17]. Similarly, a 6-week plyometric training program led to significant improvements in 20m sprint times and agility T-test results for male soccer players [18]. Research involving 6 weeks of plyometric training for adolescent male and female basketball players also showed that the plyometric group improved in jump height, 20m sprint times, and direction changeability compared to the control group [19]. Furthermore, a study on elite squash players reported significant improvements in 5-0-5 agility test, vertical jump, and 10m sprint performance as a result of plyometric training [20].

In the context of field hockey-specific training research, various studies have been conducted both domestically and internationally. Examples of domestic research include a functional movement comparison and analysis study applying a 12-week corrective exercise program [21], a study on the balance and functional ability of hockey players through the application of PNF training [22], and a study applying 12 weeks of aerobic combined training [23]. Additionally, international research has investigated the effects of high-intensity interval training over 6, 8, and 12 weeks [24-26], as well as warm-up programs utilizing plyo boxes [27]. Overall, there is a greater volume of training research for field hockey players conducted internationally compared to domestically.

Especially with the changes in field hockey game rules, there is a growing demand for anaerobic capacity that enables rapid attacking flows through high-intensity movements [8, 9]. Consequently, physical elements such as repeated sprints, single sprints, agility, direction change, and power have been emphasized [10]. However, current practices often focus on improving strength and muscular power through weight training.

Therefore, this study aims to compare and analyze the effects of plyometric training on high-intensity movements-related variables and performance in elite female field hockey players, and to provide training strategies tailored to the specific characteristics of the field hockey sport.

2. Materials and Methods

Participants

This study was conducted with 20 elite female field hockey players from a university in Seoul, registered with the Korea Hockey Association. After thoroughly explaining the purpose of the study to the participants and obtaining their voluntary consent to participate, the research was carried out. The study was conducted in accordance with the Declaration of Helsinki. There were no mid-study dropouts during the program, and the general characteristics of the study participants are shown in Table 1.

Table 1. Physical characteristics of subjects

Group	Age (yrs)	Height (cm)	Weight (kg)	BMI (%)	Career (yrs)
CTG (N=10)	21.20 ±1.03	166.40 ±4.06	57.90 ±4.86	21.08 ±1.23	8.70 ±1.63
PTG (N=10)	21.80 ±1.06	164.40 ±2.71	57.20 ±2.89	21.56 ±1.05	9.60 ±1.95

BMI: Body Mass Index, CTG: Continuous Training Group, PTG: Plyometric Training Group

Measurement Tools and Variables

This study analyzed the effects of short-term plyometric training on high-intensity movements in elite female field hockey players by examining relevant data from testing and game conditions. Detailed information on measurement tools and methods is provided below.

Analysis of High-Intensity Movement Variables Using GPS

The data for this study were collected and analyzed by conducting practice games both before and after the implementation of the program. The researcher recorded the serial numbers of all GPS devices (Oh-Coach Ultimate X4, Seoul, Korea) and collected information on the players' basic demographics and positions. The GPS equipment was prepared outdoors 30 minutes before the start of the practice game, with the devices turned on. GPS vests were fitted closely to the players' chests. Prior to warm-up, players confirmed that the GPS was correctly positioned between the 2nd and 6th thoracic vertebrae on their back. To ensure accurate movement analysis, the start and end times of each quarter were recorded. Immediately after the game, all data variables were collected using a dedicated GPS analysis program [28]. The game conditions data were set according to McGuinness et al. [8] and included high-intensity movement-related variables such as distance traveled (>16 km/h), sprint distance (>20 km/h), number of accelerations and decelerations, and number of sprints.

10m & 20m Sprint Tests

To measure high-intensity movement performance, 10m and 20m sprints were conducted. The players started from behind the starting line and, upon the signal from the tester, sprinted at full speed to a cone placed 10 meters ahead. Similarly, for the 20m sprint, players sprinted at full speed to a cone placed 20 meters ahead (Figure 1). Each player completed the test twice, and the best time from the two trials was used for analysis.

Arrowhead Agility Test

To assess agility as part of high-intensity movement performance, the arrowhead agility test was administered. Players started behind the starting line and began the test upon the tester's signal. Each player sprinted from the starting line to point A as quickly as possible, then navigated through zones C and B, and crossed the finish line (see Figure 2). Measurements were taken twice in each direction (left and right), and the best time in seconds for each direction was recorded and used for analysis.

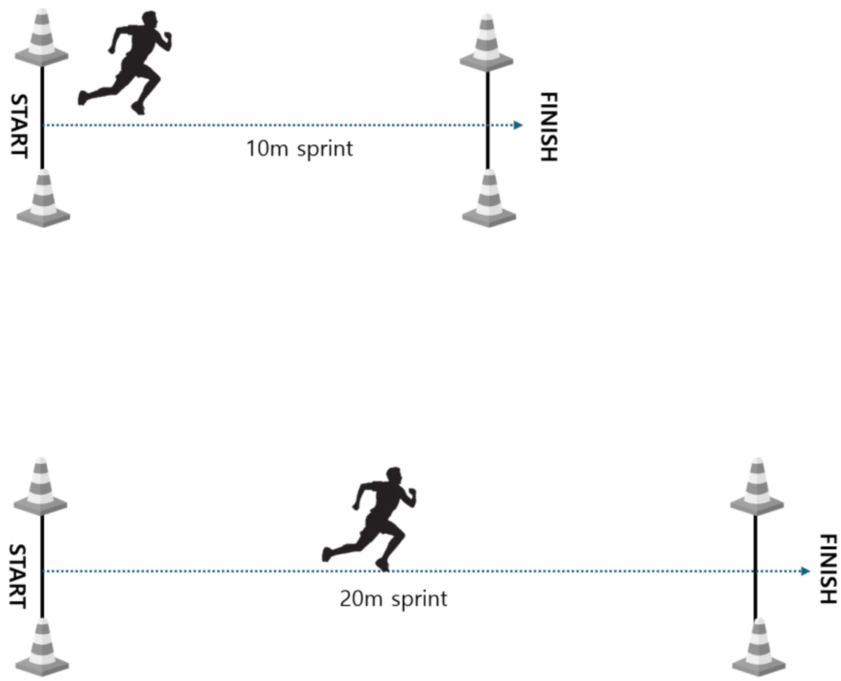

Figure 1. 10m & 20m Sprint Tests

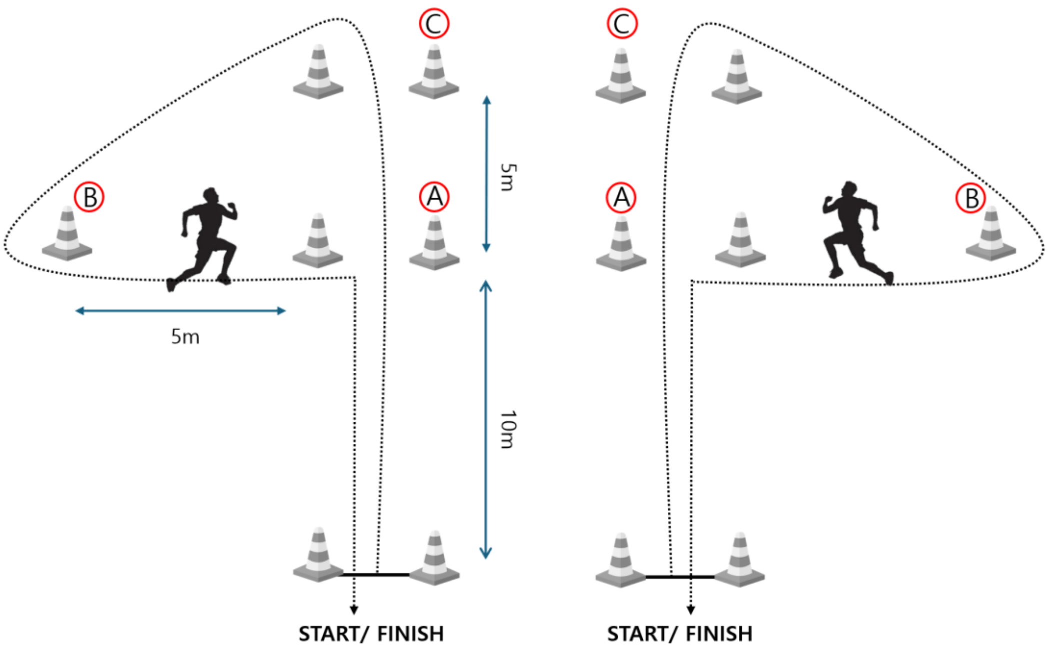

Figure 2. Arrowhead Agility Test

Table 2. Continuous Training Program

Week	Program	Intensity		Notes
		rep	set	
1-3	Continuous running	10min	1	Rest between set: 2min
	Side shuffles and sprint	4	2	
	Back pedals and sprint	4	2	
	180 °turns and sprint	4	2	
	High knee and sprint	4	2	
4-6	Continuous running	10min	1	Rest between set: 2min
	Sprint to 45 °	4	2	
	90 °turns and sprint	4	2	
	Diagonal square sprint	4	2	
	Zig-zag sprint	4	2	

Table 3. Plyometric Training Program

Week	Program	Intensity		Notes
		rep	set	
1-3	Squat jump	10	3	Rest between set: 2min hurdle height : 40cm
	Hurdle jump	10	3	
	Counter movement jump	10	3	
	Skater jump	12	3	
	Vertical depth jump	10	3	
4-6	Banded squat jump	10	3	Rest between set: 2min hurdle height : 40cm box height : 50cm
	Single leg lateral hurdle hop to box jump	12	3	
	Box jump, drop, broad jump	10	3	
	Skater to hurdle hop	10	3	
	Depth jump to hurdle hop	10	3	

Training Programs

For this study, 20 elite female field hockey players were divided into two groups of 10 each. One group followed a 6-week training program consisting of continuous and agility training (Continuous Training Group: CTG) three times a week for 60 minutes each session. The other group performed plyometric training (Plyometric Training Group: PTG) under the same schedule. Both groups conducted warm-up, main training, and cool-down sessions for the same duration. The training programs for each group are detailed in Tables 2 and 3.

Statistical Analysis

All data obtained from the study were analyzed using the Windows SPSS/PC 25.0 statistical software. Descriptive statistics, including mean and standard deviation, were provided. To test for normality of the data, the Shapiro-Wilk test was conducted to confirm that all values followed a normal distribution. Differences in high-intensity movement-related variables due to the training programs were analyzed using a two-way repeated measures ANOVA. The significance level for all tests was set at $\alpha < .05$. The effect size (eta-squared) for the two-way ANOVA interpreted 0.01, 0.06, and 0.14 as small, medium, and large, respectively.

3. Results

Effect of Plyometric Training on High-Intensity Movements

Changes in high-intensity movement variables following 6 weeks of plyometric training are shown in Table 4. The PTG demonstrated improvements over the CTG in maximum velocity, sprint distance, and number of accelerations. Significant results were found for time (all, $p < 0.001$) and the interaction between group and time (all, $p < 0.05$). In contrast, for sprint bouts and deceleration bouts, significant results were observed for time (all, $p < 0.001$), but no significant interaction effects were found.

Effect of Plyometric Training on High-Intensity Movement-Related Performance

Changes in high-intensity movement-related performance variables following 6 weeks of plyometric training are shown in Table 5. The PTG showed improvements over the CTG in 10m sprint, 20m sprint, and arrowhead agility. Significant results were found for time (all, $p < 0.001$) and the interaction between group and time (all, $p < 0.05$).

Table 4. Changes in High-Intensity Movement Variables Using GPS

	Group	Time			*F*	*P*	*ES*
		pre	post				
maximum velocity (km/h)	CTG	25.03±2.12	25.94±1.43	G	2.267	0.150	0.112
				T	35.358	0.000***	0.663
	PTG	23.39±1.45	25.47±1.55	G x T	5.440	0.031*	0.232
sprint distance (meter)	CTG	53.56±22.77	70.37±24.19	G	0.271	0.609	0.015
				T	68.214	0.000***	0.791
	PTG	42.73±17.34	71.77±19.75	G x T	4.845	0.041*	0.212
sprint (bouts)	CTG	4.55±1.90	5.84±2.23	G	0.125	0.728	0.007
				T	44.940	0.000***	0.714
	PTG	3.77±1.87	5.96±2.56	G x T	3.023	0.099	0.144
acceleration (bouts)	CTG	8.84±3.14	11.67±3.17	G	0.003	0.959	0.000
				T	157.567	0.000***	0.897
	PTG	8.07±2.93	12.30±2.68	G x T	6.136	0.023*	0.254
deceleration (bouts)	CTG	5.88±1.69	7.69±1.86	G	0.514	0.482	0.028
				T	41.952	0.000***	0.700
	PTG	6.24±2.06	8.51±2.22	G x T	0.529	0.476	0.029

CTG: Continuous Training Group, PTG: Plyometric Training Group, G: Group, T: Time, G x T: Group x Time, ES: Effect Size, Values are means ± SD, *p<.05, **p<.01, ***p<.001

Table 5. Changes in Exercise Performance Related to High-Intensity Movement

Factor	Group	Time			*F*	*P*	*ES*
		pre	post				
10m sprint (sec)	CTG	2.59±0.37	2.49±0.43	G	0.288	0.598	0.016
				T	209.098	0.000***	0.921
	PTG	2.59±0.32	2.46±0.68	G x T	5.759	0.027*	0.242
20m sprint (sec)	CTG	4.33±0.15	4.09±0.10	G	0.002	0.965	0.000
				T	296.104	0.000***	0.943
	PTG	4.37±0.11	4.05±0.09	G x T	6.934	0.017*	0.278
arrowhead agility (sec)	CTG	9.32±0.18	9.01±0.21	G	0.134	0.719	0.007
				T	507.341	0.000***	0.966
	PTG	9.39±0.22	9.01±0.18	G x T	4.588	0.046*	0.203

CTG: Continuous Training Group, PTG: Plyometric Training Group, G: Group, T: Time, G x T: Group x Time, ES: Effect Size, Values are means ± SD, *p<.05, **p<.01, ***p<.001

4. Discussion

This study aimed to investigate the effects of 6 weeks of continuous running and agility training versus plyometric training on high-intensity movements and performance in elite female field hockey players using GPS. The analysis and comparison of the measured data provide insights into how each training method influences changes in high-intensity movements and performance. The results were discussed in terms of the impact of each training method on these variables.

The field hockey is a team sport characterized by intermittent high-intensity running, which accounts for approximately 12-26% of the game [8, 29]. Maintaining consistent performance in high-intensity running throughout the season is essential in team sports [8] and can be indicative of success [30]. The results of this study indicate that the Plyometric Training Group (PTG) showed significant improvements in sprint distance and maximum velocity compared to the Continuous Training Group (CTG). Plyometric training is known to be effective in enhancing maximal strength and explosive power by utilizing the Stretch-Shortening Cycle (SSC) through rapid eccentric contractions and brief braking phases [31]. This type of training particularly benefits high-intensity movement skills performed at fast speeds, such as jumping, sprinting, and direction changes [32]. A previous study on rugby players that applied plyometric training reported significant improvements in maximum velocity compared to a control group [33]. Additionally, Branquinho et al. [34] observed significant improvements in the Yo-Yo Intermittent Recovery Test Level 2 (YYIR 2) following plyometric training. The YYIR test is closely related to high-intensity running performed in team sports such as soccer and field hockey [35, 36], and athletes with well-developed intermittent running abilities can perform more high-intensity movements effectively during games.

Acceleration ability is a critical physical characteristic for elite field hockey players, as it is a key component of repeated sprinting capability [37]. In the field hockey, repeated sprints occur frequently during a match, with up to 17 instances reported within a game and recovery times of less than 20 seconds [38]. Additionally, the ability to accelerate quickly and decelerate efficiently for direction changes is crucial for overtaking opponents and creating decisive moments [39, 40]. The results of this study show that plyometric training led to significant improvements in acceleration bouts compared to the control group, with a notable interaction effect. However, deceleration bouts only showed significant effects related to the timing of the measurements. Gamlath and Thotawaththa [20] reported approximately a 16% improvement in short-distance acceleration tests among elite squash players following plyometric training. Similarly, Ciocca et al. [41] found that plyometric training was effective in enhancing deceleration abilities in soccer players. These findings are associated with increases in maximal strength and rate of force development (RFD) [42, 43], with plyometric and resistance training commonly used to improve these attributes [44].

Acceleration and deceleration abilities are related to maximum speed, sprint distance, and direction change skills during a game in team sports [45, 46]. These performance attributes are crucial for regaining possession after losing it, as they involve a range of technical skills [47]. Therefore, improvements in short-distance acceleration through plyometric training are expected to lead to effective enhancements in high-intensity movement performance, including maximum speed and direction changes.

In the field hockey, sprints typically cover distances of 10 to 20 meters [38], accounting for approximately 1.4% to 2.1% of the total distance traveled [48], with an average duration of 2.6 to 4 seconds [49]. The application of plyometric training resulted in significant improvements in the 10m and 20m sprint tests. A study applying plyometric training to male and female basketball players over 6 weeks found that the plyometric group showed greater improvements in sprint performance compared to the control group, with particularly notable effects observed in females [19]. Similarly, a 12-week study involving volleyball players reported trends consistent with those found in this research [50]. The effectiveness of plyometric training in reducing sprint times is attributed to its ability to enhance neuromuscular adaptations through vertical and horizontal jumps, thereby decreasing ground contact time during sprints [51, 52]. Therefore, plyometric training can effectively improve sprinting ability in the field hockey players.

In the field hockey, fast sprints and efficient direction changes are crucial components that encompass all aspects of performance, including acceleration, deceleration, and decision-making [53, 54]. This study demonstrated that a 6-week plyometric training program was more effective than continuous running and agility training, with significant improvements observed. A study involving elite college basketball players that applied plyometric training for 8 weeks found significant differences in T-tests [55], and another study reported positive effects on sprinting, lower body strength, and agility [56]. The results of this study, along with previous research, suggest that plyometric training positively affects agility in elite athletes. This is attributed to increases in muscle length, strength, flexibility, muscle mass, and hypertrophy, which enhance sprinting and agility speeds [57, 58]. Additionally, plyometric training impacts muscle spindles, Golgi tendon organs, and tendons, contributing to improved performance [59]. Plyometric training programs are generally recommended to include 800 to 3,240 jumps over 6 to 12 weeks [60], with rest periods between sets ranging from 30 to 120 seconds for optimal recovery [61, 62]. While the short-term plyometric training program used in this study improved high-intensity movement performance in female college field hockey players, there is still a lack of research on various forms of plyometric training tailored for elite field hockey players. Therefore, further research comparing and analyzing different plyometric training durations and structures to enhance the performance of elite field hockey players is warranted.

5. Conclusions

Short-term plyometric training for female elite field hockey players has been shown to be effective in improving high-intensity movement-related variables and performance compared to continuous running and agility training. Plyometric training is expected to be a promising method for enhancing high-intensity movements in field hockey players.

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