A Study on the Physiological Profiles and Performance Characteristics of Modern Pentathletes

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Abstract Modern pentathlon is characterized by the possible direct effects on performance of physical characteristics, fitness level, and record management and therefore, obtaining information about the fitness level and records can be an important factor in improving performance among athletes. To examine the specificity of anthropometrics, physiology, and performance among modern pentathlon athletes, it is necessary to examine and analyze many factors for performance and few researchers have measured or analyzed modern pentathletes. This study aimed to analyze anthropometric data of elite modern pentathlon athletes through a literature review and determine the physical characteristics for better performance, examine cardiorespiratory functions directly connected with the performance in sport shooting-running. The literature review found that maximal heart rate (HR_{max}) ranged from 184.10 bpm to 197.89 bpm, maximal voluntary ventilation (VE_{max}) from 151.7 L/min to 163.05 L/min, and maximal oxygen uptake (VO_{2max}) from 54.4 ml/kg/min to 75.97 ml/kg/min. For the anaerobic threshold (AT) level, oxygen uptake (VO₂) ranged from 53.72 ml/kg/min (82.6% VO_{2max}) to 63.65 ml/kg/min (84.4% VO_{2max}), heart rate from 169 bpm to 182 bpm, and blood lactate concentration from 10.64 mM to 17.20 mM. Therefore, it is also necessary to develop an effective interval training method for improving anaerobic threshold, cardiorespiratory endurance, and lactate tolerance. Further research is needed to identify effective training for improving cardiorespiratory endurance, the AT level, and lactate tolerance rather than the physical characteristics.

Keywords Modern Pentathlete, Body Composition, Cardiorespiratory Function, Laser-Run

1. Introduction

Modern pentathlon consists of five events, namely epee, swimming (freestyle 200 m), equestrian jumping, and a new combined event (five sessions of shooting 10 m * pistol shooting + four repetitions of running 800 m), with the records in the five events added up to determine the winner [6, 23, 33, 41]. Specifically, control, power, concentration, adjustment, and coordination are important for equestrian jumping; agility, power, endurance, responsiveness, and determination are important for epee; power, flexibility, and cardiorespiratory endurance are important for swimming; and fitness factors such as judgment, speed, general endurance, concentration, composure, cardiorespiratory fitness, and muscular endurance are important for the new combined event (laser-run) [23, 35].

Modern pentathlon is characterized by the possible direct effects on performance of physical characteristics, fitness level, and record management and by ranking based on converted scores for the fitness level and records in each event; therefore, obtaining information about the fitness level and records can be an important factor in improving performance among athletes [30]. It is necessary to collect detailed data regarding the determinants of performance comprehensively and

systematically [38].

While some studies have been conducted on modern pentathlon by determining the effects of training methods on swimming and running performance [20, 29] and the effects of bio-feedback training on heart beat in pistol shooting, there are still limitations in determining the association between events and performance [41]. In modern pentathlon, a laser-run (new combined event) has similar characteristics to biathlon, an event of winter sports, and the sum of scores for the two events of track and pistol shooting rather than the records in both events play a crucial role in ranking [41]. A few studies on multi-sport events, including biathlon and triathlon, confirm that the order in performing these events ultimately exerts a great impact on performance; and this implies the need to differentiate and characterize the events, while taking the personal characteristics of athletes into account [32, 41].

In most sports, a successful condition for athletes depends on their physical capabilities; the higher the level of training experiences and performance they have, the lower the level of physical capabilities they may show in the same event and training. However, little research has been conducted on the properties of body composition in modern pentathlon athletes as well as on the references for the system of energy supply. The performance in modern pentathlon can depend on the laser-run, even with five events. Moreover, useful indicators to determine performance in the recent laser-run are heart beat control to meet the level of speed with the variation in instantaneous exercise intensity and muscle strength and cardiorespiratory endurance, which are principal factors for performance. [32, 41]. The highest score in the laser-run depends on whether the athlete made the best use of his/her VO_2max capabilities [33]. Still, little research has been conducted on the cardiorespiratory fitness or energy metabolic demands of modern pentathlon athletes.

This study aimed to analyze anthropometric data of elite modern pentathlon athletes through a literature review and determine the physical characteristics for better performance, examine cardiorespiratory functions

directly connected with the performance in sport shooting-running (laser-run) based on pistol shooting scores and track records, and investigate the characteristics of the performance in the laser-run, which determines modern pentathlon performance.

2. Materials and Methods

2.1. Physique and Body Composition of Modern Pentathlon Athletes

To examine the specificity of anthropometrics, physiology, and performance among modern pentathlon athletes, it is necessary to examine and analyze many factors for performance and few researchers have measured or analyzed these variables.

The results of the literature review of the characteristics of physique and body composition of male and female elite modern pentathlon athletes are summarized in Table 1. For the physical characteristics of modern pentathletes, weight ranged from 68.85 kg to 70.32 kg for male adults [21, 40-41] and was approximately 61 kg for female adults [35]. Height ranged from 169 cm to 178 cm for male adults [21, 33, 35, 40-41] and from 161 cm to 168 cm for female adults [33, 35]. The body mass index (BMI) ranged from 20.38 to 22.80 for male adults [33-35, 41] and from 20.19 to 24.30 for female adults [6, 33, 35]. The body fat percentage (%body fat) ranged from 10.77% to 15.5% for male adults [21, 33, 35] and from 16.0% to 28.4% for female adults [33, 35]. Research on the anthropometrics of male collegiate modern pentathlon athletes found that muscle mass, LBM, body fat, and BMI—33.8 (± 5.1) kg, 59.5 (± 8.2) kg, 13.4 (± 5.3) %, and 21.8 (± 0.9), respectively—were at similar levels to those in this study. A recent study showed that age, weight, height, and BMI were 21.7 (± 3.1) years, 75.9 (± 9.5) kg, 182.6 (± 6.1) cm, and 22.7 (± 2.3) kg/m^2 , respectively, for Polish (Warsaw in Poland) elite male modern pentathlon athletes [15], demonstrating that they were at significantly higher levels of height and weight and at similar levels of BMI compared with the findings of the literature review.

Table 1. Main characteristics of modern pentathlon athletes according to gender

Variables	Male		Female		Reference
	Pubescent	Post-pubescent	Pubescent	Post-pubescent	
Body weight (kg)	- 58.52(±8.69)	- 68.85(±1.91) 66.70(±4.8) 70.32(±3.42)	- 52.60(±6.69)	61.00(±5.3) -	Loureiro et al. [35], Kim et al. [21], Yoon et al. [41], Yoon et al. [40]
Height (cm)	- 163.40(±10.3) -	- 175.90(±7.4) 169.00(±7.0) 176.0(±4.02) 176.0(±5.2) 178.95(2.33)	- 155.50(±10.7) -	168.1(±5.4) 162.60(±3.5) 161.00(±6.0)	Coutinho et al. [33], Loureiro et al. [35], Kim et al. [21], Yoon et al. [41], Yoon et al. [40]
BMI (kg/m ²)	- 21.68(±3.2)	- 20.38(±1.66) 22.80(±1.9) 22.18(±0.9) 22.18(±0.59)	- 20.10(±2.6)	21.60(±1.4) 20.19(±1.44) 24.30(±2.4)	Loureiro et al. [35], Coutinho et al. [33], Yoon et al. [40], Lim et al. [29]
Body fat (%)	- 20.40(±8.3) -	- 15.50(±6.4) 14.24(±1.97) 10.77(±0.65)	- 23.80(±6.8) -	16.00(±2.4) 28.40(±1.2) 23.66(±7.33)	Coutinho et al. [33], Loureiro et al. [35], Kim et al. [21]

Table 2. Summary of anthropometric data in different sports event besides MP*

Items	Age	Height (cm)	Weight (kg)	BMI (kg/m ²)	Body fat (%)	LBM	Reference
Biathlon pentathletes	21.4±2.1 19.6±1.5	181.1±4.7 184.7±3.2	76.5±4.8 73.1±4.1	23.5±1.3 -	- 8.8±0.7		Luchsinger et al. [36], Cech et al. [39]
Fencing	21.5±2.6 22.3±4.5 23.3±2.8	175.2±6.1 181.0±5.0 180.8±5.4	71.1±15.0 76.6±9.3 79.0±7.42	23.5±4.5 23.4 24.2±2.1	13.9±5.9 - 15.7±2.7		Ghloum & Hajji [18], Gutierrez-Davila et al. [12], Sterkowicz-Przybycień [17]
Shooters (female)	23.1±1.8 31.2±11.2	175.3±4.7 164.0±0.6	78.5±7.6 66.6±12.2	22.2±3.7 24.6±4.3	- -		Molla et al. [37], Mon-López et al. [7]
Jockeys (female)	24.0±3.1 28.7±10.1	172.0±5.2 163.4±7.1	63.2±4.7 55.1±5.9	- 20.6±1.6	11.3±2.2 13.9±3.5		Wilson et al. [11], Hitchens et al. [14]
Swimming	18.6±0.7	178.1±3.1	73.9±4.3	-	15.4±2.5		Erica J et al. [9]
Elite MP athletes	21.7±3.1	182.6±6.1	75.9±9.5	22.7±2.3			Hoffmann et al. [15]
Healthy non-obese subjects	44.4±17.9 51.7±15.0	180.1±7.2 166.8±6.5	79.2±10.2 64.4±8.3	24.4±2.7 23.2±2.9	22.9±6.4 33.5±6.7	61.2±6.9 42.6±3.9	Armbruster et al. [2]
Elite European pro soccer players	24±3.7	180.5±5.1	76.7±5.3			67.2±5.3	Owen et al. [1]
K-Pro female ballet dancer	25.9±2.8	163.6±4.2	49.4±4.4	18.4±1.0	19.7±3.0	36.9±3.3	Kim et al. [24]

*MP: modern pentathlon athletes

The modern pentathlon was compared with other events (Table 2). There was a report that %fat mass was usually not more than 10% (ranging from 4% to 9%) and ranged from 8% to 16% during an off-season period for world wrestling champions [43]; the literature review found that it was slightly higher for elite male modern pentathlon athletes, ranging from 10.77% to 15.50%, which was at a similar level to the off-season level for elite wrestlers. For the physical conditions of European professional soccer players [1], age, height, weight, and

LBM were 24 (±3.7) years, 180.45 (±5.12) cm, 76.66 (±5.34) kg, and 67.21 (±5.31) kg, respectively, which were generally superior to the respective figures for modern pentathletes. For Korean professional female ballet dancers [24], age, height, weight, BMI, %body fat, and LBM were 25.9 (±2.8) years, 163.6 (±4.2) cm, 49.4 (±4.4) kg, 18.4 (±1.0) kg/m², 19.7 (±3.0)%, and 36.9 (±3.3) kg, respectively, which were all inferior to those of female modern pentathletes except for height. Finally, for ordinary German people [2], age, height, weight, BMI,

LBM, and %body fat of German men and women were 44.4 (± 17.9) y and 51.7 (± 15.0) years, 180.1 (± 7.2) cm and 166.8 (± 6.5) cm, 24.4 (± 2.7) kg/m² and 23.2 (± 2.9) kg/m², 61.2 (± 6.9) kg and 42.6 (± 3.9) kg, and 22.9 (± 6.4)% and 33.5 (± 6.7)%, respectively, which are higher than those of modern pentathletes in every category. Ultimately, %body fat, BMI, and LBM rather than height and weight are expected to be useful as predictors in that they seem to be more positively correlated with performance for modern pentathletes. This is consistent with the finding that body mass and lean body mass were lowest among endurance and team sport players [45].

3. Cardiorespiratory Functions of Modern Pentathlon Athletes

(1) Cardiopulmonary fitness in modern pentathlon athletes

The results of the literature review of the characteristics of cardiorespiratory fitness of male and female elite modern pentathlon athletes are summarized in Table 3. For the cardiopulmonary fitness of male elite modern pentathletes, maximal heart rate (HR_{max}) ranged from 184.10 bpm to 197.89 bpm [40-41], maximal voluntary ventilation (VEmax) ranged from 151.7 L/min to 163.05 L/min [40], and maximal oxygen uptake (VO₂max) ranged from 54.4 ml/kg/min to 75.97 ml/kg/min [19, 40-41]. For the anaerobic threshold (AT) level, oxygen uptake (VO₂) ranged from 53.72 ml/kg/min (82.6%VO₂max) to 63.65 ml/kg/min (84.4%VO₂max) [41], heart rate ranged from 169 bpm to 182 bpm [41], and blood lactate concentration (BL_{max}) ranged from 10.64 mM to 17.20 mM [19]. The Graded Exercise Test (GXT) in modern pentathletes showed that exercise duration ranged from 20:30 to 22:33 [19, 41].

The modern pentathlon was compared with other events: VO₂max was 60.8 (± 9.5) ml/kg/min for endurance athletes, 61.4 (± 4.4) ml/kg/min for kayakers, and 61.8

(± 4.0) ml/kg/min for caoecists [4]. For sprint and power, it was 52.1 (± 7.7) ml/kg/min for men and 46.1 (± 7.2) ml/kg/min for women [27]. For combat sports, it was 55.6 (± 9.5) ml/kg/min for men and 46.4 (± 5.2) ml/kg/min for women [27]. For junior judo athletes, it was 53 to 66 ml/kg/min, which is similar to that of junior boxers [27]. Wrestlers reported an average level of 53 to 56 ml/kg/min and Korean representative wrestlers reported HR_{max}, VEmax, VO₂max, AT (% of VO₂max), BL_{max}, and exercise duration of 197.5 (± 8.8) bpm, 141.56 (± 21.99) L/min, 60.24 (± 5.13) ml/kg/min, 8.34 (± 1.71) mM, 76.55 (± 2.92)%, and 14.43 (± 1.57) min, respectively [43]. Male badminton players showed a VO₂max range of 50-70 ml/kg/min [10, 26], and young male and female racquet players recorded 54.9 (± 6.7) ml/kg/min and 44.0 (± 4.8) ml/kg/min, respectively [45].

Winning a match in team sports (basketball, field hockey, soccer, etc.) requires better fitness [44]. That is, soccer players reported 56 to 59 ml/kg/min [3], volleyball players reported 46.9 to 51.1 ml/kg/min [8], and basketball players reported 51.3 (± 5.7) ml/kg/min in Greece and Belgium [16, 45]. For endurance players, in particular AT has been used as a determinant of VO₂max utilization and long-term mobility [10], which is called the blood lactate-based threshold and is an important key variable that determines the submaximal lactate level (VLT) [4]; they reported a usual level of 80 to 85 ml/kg/min [45]. To summarize the findings of the literature review, modern pentathletes had %VO₂max at AT ranging from 70.21 to 84.4%, which is very similar to that of endurance athletes [45].

The combined event (laser-run) in modern pentathlon is similar to biathlon and the harmony between track (800m*4) and pistol shooting (5 *4) plays a crucial role in determining performance [22]. In the laser-run, instantaneous variation in exercise intensity occurs from the very dynamic movements of running followed by static movements of pistol shooting, where heart rate control based on the increase or decrease in speed and accurate shooting motions become important determinants of performance [22, 38].

Table 3. Summary of cardiopulmonary functions of modern pentathletes in previous studies

Reference/Variable	HR _{max} (bpm)	VEmax (L/min)	VO ₂ max (ml/kg/min)	%VO ₂ max on AT	VO ₂ on AT	HR on AT	BL _{max} (mM)	Exerciseduration (min:sec)
Kim KJ [19]			69.68 (± 4.12)	70.21 (± 4.90)			9.34* (± 0.10) 10.64# (± 1.35)	20:33 (± 2.53)
Yoon JR et al. [41]	189.00 (± 6.77)		75.97 (± 4.92)	84.4	63.65 (± 4.12)	169		22:30
Yoon JR et al. [40]※	184.10 (± 10.9)	151.7 (± 15.8)	54.4 (± 4.4)					
Kim HS et al. [21]							17.20+ (± 1.19)	

*after swimming, #after running, +whole blood, ※after new combined event

@junior athletes; a: ml/kg/min

Table 4. HR, VE, VO₂ during the four running phases in the new combined event*

Variables/Runs	1 (800m)	2 (1,600m)	3 (2,400m)	4 (3,200m)
HR(bpm)	165.9(±11.5)	173.8(±9.8)	180.0(±10.3)	184.1(±10.9)
VE(L/min)	120.7(±24.3)	135.5(±15.3)	139.5(±17.1)	151.7(±15.8)
VO ₂ (ml/kg/min)	45.3(±4.5)	55.4(±4.3)	53.8(±3.4)	54.4(±4.4)

*J.R.Yoon et al. (2017), Analysis of physiological parameters for new combined event in modern pentathletes [41].

(2) Cardiorespiratory functions of modern pentathletes in previous studies

Previous research of elite modern pentathletes [41] showed variation in 800 m running time, the heart rate (HR) in each section, ventilation equivalent (VE), and VO₂ during the laser-run (Table 4). This research found that HR and VE reflected exercise intensity, which became higher in Sections 3 and 4 than in Sections 1 and 2, and VO₂ was higher in Sections 4, 3, and 2 than in Section 1. There was a need to keep the VO₂ level close to that of maximal oxygen uptake when a slight delay occurs in the shift from track to pistol shooting in the laser-run [31]. This inter-section variation demonstrates the need to control the heart rate stably in pursuit of accurate shooting because the laser-run is characterized by a higher heart rate with fast running at the early stage, making shooting difficult, as found in previous research [5, 28]. In short, competition with world-class athletes requires consideration of the importance of interval training to improve endurance and lactate tolerance.

(3) Performance characteristics of modern pentathlon athletes

In modern pentathlon, running scores were separated from pistol shooting scores in the new combined event (laser-run); and a comparison of the total scores, running (800 m*4) time, running speed, total shooting time, hit rate, and transition time is provided in Table 5. LeMeur et al. [31] showed that the top, middle, and bottom groups had running times of 551 s, 549 s, and 564 s, respectively,

and running speed of 18.2 km/h, 18.2 km/h, and 17.7 km/h, respectively, with no significant difference. In contrast, total shooting time and hit rate showed significant differences because running speed and transition to pistol shooting were not remarkably differentiated among the groups. This indicates that total pistol shooting time is a primary differentiation factor for exercise performance capabilities: the top group had a shorter total shooting time of 23 s compared with the middle group and of 31 s compared with the bottom group during laser-run performance. At the same time, in general the top group showed a better hit rate compared with their competitors in the field, which might affect total shooting time [22].

Kim et al. [22] found no significant difference between high- and low-level athletes in total running time, running time in each section, and running speed in the entire laser-run. Any significant inter-group difference demonstrates a meaningful implication in determining performance for high- and low-level athletes. Han et al. [13] found no significant difference between the top 25% group and the bottom 25% group in running records, but they showed that converted laser-run scores had significant differences. Therefore, obtaining correct data concerning the records of each event can be an important factor for athlete management. Comprehensive and systematic measurement and analysis of the records of athletes is expected to provide important data for setting training goals and in planning a training level for each event.

Table 5. Performance during the CE* and shooting sessions for the top, middle, and bottom third of competitors in the CE*

Variables	Total CE performance(s)	Running performance		Shooting performance			References
		Total running time(s)	Running speed (km/hr)	Total shooting time(s)	Total shooting accuracy (%)	Delay per attempt (s)	
Top third	695 (±10)	551 (±11)	18.2 (±0.4)	86 (±16)	79 (±13)	4.5 (±0.4)	LeMeur Y et al. [32]
Middle third	714 (±7)	549 (±20)	18.2 (±0.6)	109 (±19)	68 (±12)	5.0 (±0.7)	
Bottom third	741 (±25)	564 (±11)	17.7 (±0.3)	117 (±23)	64 (±10)	5.0 (±0.4)	
High-level	-	676.4 (±7.38)	17.73 (±0.6)	77.5 (±1.87)	71.3 (±11.4)	1.28 (±0.1)	Kim YS et al. Lim CH et al. Yoon JR et al. [22, 34, 41]
Low-level		706.7 (±8.6)	17.05 (±0.8)	135.1 (±1.92)	78.5 (±17.7)	1.30 (±0.2)	
Top 25%	-	683.53 (±36.42)					Han DR et al. [13]
Bottom 25%		700.40 (±183.69)					
#shooting in CE				3.35(male) 3.62(female)			Park JC et al. [38]

*CE: Combined event (laser-run), (41) #: shooting time/number of shooting

4. Conclusions

There are performance determinants for each event so that athletes can attain the best performance in every sport. The most important principle of training to improve these performance factors is the principle of specificity. To determine the specificity of modern pentathletes, efforts to analyze the factors for performance and measure and analyze the variables cannot be overemphasized. This study aimed to analyze the anthropometric, exercise-physiological, and performance characteristics of elite modern pentathletes; and the findings of a literature review can be summarized as follows.

The anthropometric data for elite modern pentathlon athletes are characterized by medium sight length, muscular skeleton, relatively low %body fat, and muscular physique.

For exercise-physiological characteristics, because instantaneous heart rate control following rapid running is used as a useful determinant of performance in the recently revised combined event (laser-run), good cardiorespiratory endurance and anaerobic capabilities are essential factors, along with high lactate tolerance.

Almost no research has been conducted on whether the determinants of performance in modern pentathlon are generated from running records in the recently revised laser-run or from the shortened shooting time. Considering that high-level athletes showed statistically better results than low-level athletes in each of total performance time for a laser-run, total running time, transition time, running time in each section, and running speed, as found in the comparison of comprehensive and systematic records from correct data, these results can be

used as important data and useful indexes for setting a training goal and in planning a training level for each event.

For the future direction of research for the development of world-class athletes, it is necessary to improve running records and devise various training methods for optimal conditions in transition to pistol shooting on arrival at a pistol shooting site because the recently revised laser-run depends on the running speed and the quick motions and hit rate of pistol shooting.

It is also necessary to develop an effective interval training method for improving anaerobic threshold, cardiorespiratory endurance, and lactate tolerance with the aim of having a competitive edge over world-class athletes.

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