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Original Research

The determinants for top ranker of Korean Greco-Roman wrestlers

Hong Sun Song[1], Kyoung Choen Cha[2,*], Buong O Chun[3]

[1]Department of Sports Science, Korea Institute of Sport Science, 01794 Seoul, Republic of Korea
[2]Department of Business Administration, Dong-A University, 49236 Busan, Republic of Korea
[3]Graduate School of Physical Education, Myongji University, 17058 Yongin, Republic of Korea

***Correspondence:** kccha@dau.ac.kr (Kyoung Choen Cha)

Abstract

Background and objective: This study investigates the physical factors that determine the top ranker players based on the Greco-Roman wrestlers in the national athletic team of South Korea. Additionally, the study developed a prediction model using physical factors. For this analysis, the data of 163 players in the last 20 years (1999–2018) available on the Athletic Competition Performance Assessment Computer System were used. A top ranker was defined as an athlete who had won a medal in a world championship or the Olympic Games.

Methods: The logit model was used as the model and the estimations were performed using maximum likelihood estimation (MLE) with E-views9.5 (Lightstone Corp., Tokyo, Japan). The estimation results demonstrated that the probability of becoming a top ranker increased with the following: increase in the length of the career compared to age, increase in the distance of standing long jumps, decrease in response time to light, and increase in bench press weight.

Results: The analysis of the model's estimation results showed that superior results were produced when the standing long jumps, response time to light, and bench press weight were normalized using the weight class based on McFadden R^2, Akaike Information Criterion (AIC), and Schwarz information criterion (SBIC) as compared to when they were normalized using the height and body weight.

Conclusion: The estimation model established in this study for the significant physical strength factors shown in the South Korean top rankers is expected to be used as important data for predicting and fostering world-class South Korean Greco-Roman wrestlers.

Keywords

Greco-roman; Wrestler; Top ranked; Physical fitness; Physiology

1. Introduction

Wrestling is one of the oldest combat sports that dates back to 708 BC in the ancient Greek Olympic Games [1–3]. Greco-Roman (acknowledged as the classic style) and freestyle are the two internationally recognized forms of competitive wrestling. The Greco-Roman wrestlers were permitted to attack using their upper bodies. However, holds below the waist were forbidden. Freestyle wrestlers are allowed to use their upper and lower bodies during competitions [4].

Establishing a clear understanding of the physique and physiological characteristics that contribute to successful wrestling competition is one of the biggest issues for coaches and researchers [5, 6].

Wrestlers' physiological demands are complex, requiring athletes to have highly developed capacities of anaerobic power, maximal aerobic capacity, maximal strength, power, and muscular endurance [7, 8]. During the match, the anaerobic system contributes to sustained short quick bursts of maximal power activities, whereas the aerobic system contributes to the wrestler's endurance throughout the duration of the match and accelerates the recovery process [9, 10].

Several studies have investigate the physique and physical fitness profiles of wrestlers at various levels to investigate the physical and physiological differences that could contribute to the success of wrestlers [7, 11–16]. According to a previous study, wrestlers have a physique of strong shoulder girdles and arms with a long upper body, short lower extremities, and a low lower limb/trunk ratio [17]. It has been reported that an athlete with long arms and a relatively long upper body compared to lower body with 35% long arms, 35% height/weight ratio, and 30% height/lower limb ratio is favorable for athletic performance [18]. All these physique conditions are beneficial in a wrestling match since they lower the center of mass making it difficult for the opponent to break the balance [19]. With respect to physical fitness in wrestling, the following have been reported: high anaerobic power and aerobic capacity, strong muscular strength and muscular endurance, high power, and flexibility of normal range, etc. [5, 7, 20–23]. The physical fitness of athletes shows a difference depending on the level of the competition. In general, elite wrestlers have higher maximum strength, power, anaerobic power, muscle endurance, and flexibility than amateur wrestlers [7, 8, 12, 24–27]. These previous studies have contributed significantly to the planning of training programs and track progress to predict elite wrestlers and the success of the wrestlers.

It can be said that the wrestlers of South Korea are at an inferior state of physical fitness compared to those of Russia, Iran, and European countries [8, 28, 29]. South Korean wrestlers, who are at a disadvantage compared to the Western athletes in terms of strength, power, andphysique tend to depend relatively more on endurance training [8]. The wrestling coaching staff of the national athletic team conducted physical fitness training to effectively respond to the rules of the game. In the meantime, the coaching staff determined that maximal strength, power, and muscle endurance were the physical factors that were relatively lacking in South Korean athletes compared to competing opponents [8, 30]. The coaching staff conducted physical training on a full scale by focusing on and strengthening these physical fitness factors. In fact, this was an inevitable choice for South Korean athletes to compete with Western athletes who had relatively better physiques, maximal strength, power, etc., in addition to considering the changes in competition rules [30–32].

South Korean wrestlers have been attending a significant number of physical training sessions to overcome this problem. Based on these efforts, the Greco-Roman wrestling has continually produced medalists in the Olympics and world championships. In the case of South Korea, which fosters wrestling as a major sport, it is indispensable to develop programs for predicting and training potential medalists to win medals in Greco-Roman wrestling. Many researchers have focused work on describing physical differences between elite and amateur wrestlers [16, 25, 27]. However, to the best of our knowledge, the factors that determine top-level performance amongst elite wrestlers have not been reported. Understanding the factors that determine such top-level elite performance, we will be able to provide the foundation for scientific training methods to win medals at the Olympics and World Championships.Therefore, this study aimed to investigate the physical factors that determine the top rankers among South Korean Greco-Roman wrestlers and develop a prediction model using these factors.

2. Methods

The analysis used the data from 74 South Korean Greco-Roman wrestlers whose physical fitness and anthropometric data were recorded along with the records of 163 Korean Greco-Roman wrestlers available on the Athletic Competition Performance Assessment Computer System (http://nkeft.sports.re.kr) for the last 20 years (1999–2018) [33]. Among them, nine individuals (duplicates were allowed for the same person) were the top rankers.

The study participants agreed to participate in our study after completely understanding its purpose and methods, in accordance with the ethical principles of the Declaration of Helsinki [34]. Fig. 1 shows the physical factors considered in this study.

2.1 Anthropometry and body composition measurements

The body composition, length, and circumference were measured as physical factors. For body composition, the weight, fat-free mass, and body fat were measured using a body composition analyzer (X-SCAN PLUS II, Jawon Med., Gyeongsan, Korea) after measuring the height using a height and weight measuring device (TBF 202, Tanita corporation, Tokyo, Japan) Body mass index (BMI) (kg/m^2) was calculated using height and weight. For the lengths and circumferences, a Martin anthropometric instrument was used to measure the neck circumference, length of upper extremities, length of lower extremities, circumference of the upper arm, thigh, calf, chest, and arm span (the distance between the middle fingers of both hands in a state of both arms stretched out to the sides).

2.2 Strength

2.2.1 Maximal isometric hand grip and back strength measurements

The hand-grip strength was measured using a grip dynamometer (TKK-1270, TAKEI, Tokyo, Japan). The measurement method was as follows: after standing naturally with both feet spread at shoulder width, the participant grabbed the handle of the grip dynamometer in such a way that the second joint of the index finger would be as perpendicular as possible and squeezed by exerting maximal strength. The measurement was performed twice using the dominant hand in 0.1 kg unit, and the maximal

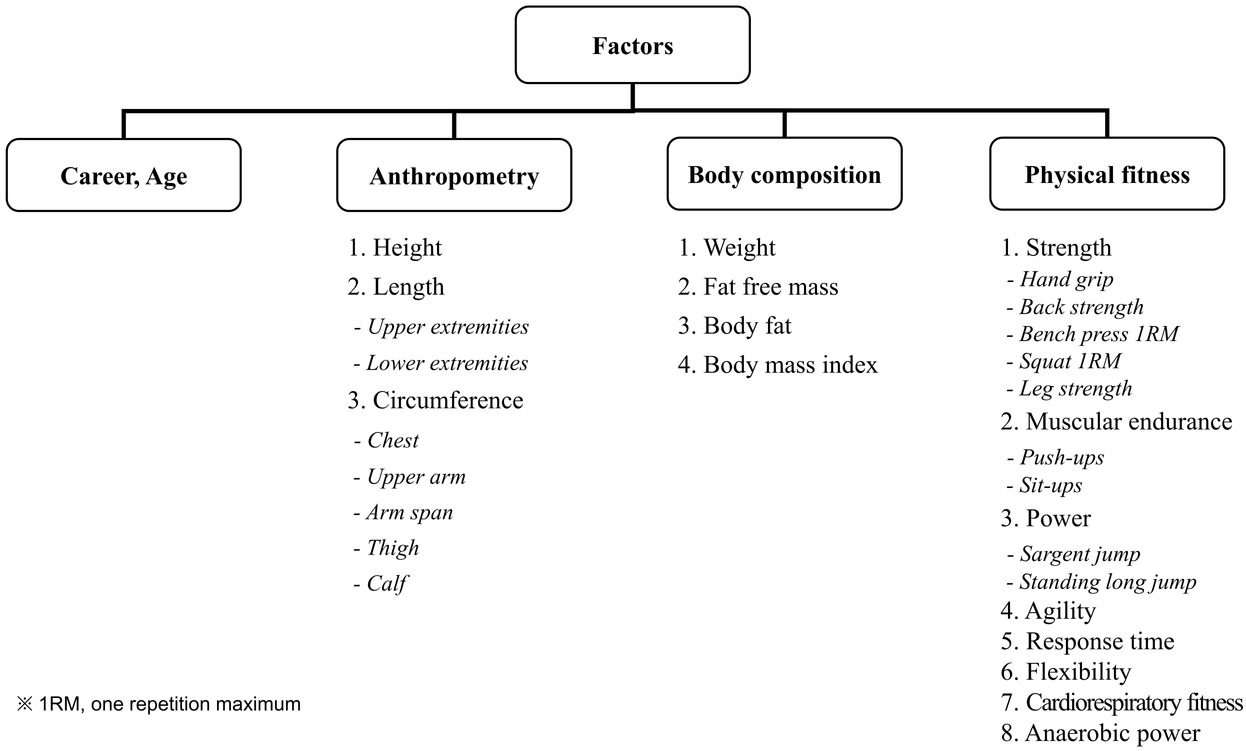

FIG. 1. Factors of the Top Ranker. This figure shows the physical factors considered in this study.

value among them was used as the measurement value. The back-muscle strength and hand-grip strength were measured for muscle strength. The back muscle strength was measured using a back muscle dynamometer (TKK-1270, TAKEI, Tokyo, Japan). The measurement method was as follows: a participant inclined the body approximately 30 degrees to the front and straightened the waist while standing with straightened knees and arms and holding handles so that the maximal strength could be exerted. The measurement was performed twice in 0.1 kg unit and the maximum value among them was used as the measurement value. Muscle strength was measured using a back muscle force system (TKK-5402, TAKEI, Tokyo, Japan). The subject was made to stand in a normal position with their back straight, after which they were asked to hold the knob on the equipment and pull it towards themselves while the machine moved forward and in the vertical direction. Subsequently, the maximum force in the vertical direction was measured. The measurements were made using the unit of 0.1 kg twice, and the maximum value was taken as the measurement value.

2.2.2 Muscular isotonic maximum strength measurements

For the maximal strengths, the ACE-2000 Multi-Function (ACE-2000 Multi-Function, Ariel Dynamics Inc., Trabuco Canyon, CA, USA) was used to measure the isotonic maximum strength (one repetition maximum, 1RM) when performing the bench press and squat movements. After sufficiently performing warm-up exercises, the participants practiced several times with weights that could easily be lifted. After the equipment was set up, the weight that could be lifted once with the maximal strength was measured in the unit of kg when the assistant provided the "start" signal.

2.2.3 Muscular isokinetic strength measurements

For the isokinetic leg strength, the muscle functions of the left and right legs were measured by performing the test at 60°/s using Humac Norm (Humac Norm CSMi, Stoughton, MA, USA). They were assessed after performing flexion and extension exercises thrice. After practicing two or three times, the participants rested. Subsequently, when the "start" sound was provided, they performed flexion and extension three times with maximal strength, and the peak torque (Nm) was calculated for each participant.

2.3 Muscular endurance mesurements

Push-ups, sit-ups, and half-squat jumps were performed to measure muscle endurance. For push-ups, the participants were instructed to grab the push-up bar at 30 cm height while keeping their arms perpendicular to the ground and the body in a straight line, with both feet placed together. Using a metronome, the participants performed the push-up once every two s for as long as they could go on. For sit-ups, the participants were asked to lie down while spreading their feet 30 cm wide, and bend and raise their knees in a perpendicular manner. The number of sit-ups performed in a minute was recorded;one sit-up was counted when both elbows touched the knees and returned to the original place. The number of half-squat jumps was recorded for two min, whereby a participant jumped by changing the foot and touching the hip on the mat when landing.

2.4 Power measurements

The sargent jump and standing long-jump were used to measure power. A sargent jump meter (TKK-1220, TAKEI, Tokyo, Japan) was used for the sargent jump. Each participant was instructed to jump as high as possible from a standstill position. The measurement was performed twice using the middle finger as the peak position, and the maximum value was used as the measurement value. Additionally, the sargent jump meter (TKK-1220, TAKEK, Tokyo, Japan) was used for standing long jumps. The participants were instructed to jump as far as possible from a standstill position. It was measured twice using the middle finger as the peak position, and the maximum value was used as the measurement value.

2.5 Agility measurements

A side-step was used to measure the agility. A side stepping test Count Meter, fabricated by the Sport Engineering Department, Korea Institute of Sport Science (KISS), was used to measure the side step. Each participant was instructed to take the most comfortable position to perform side-steps centering on the center line and perform side-steps when the "start" signal was given. The side-step was performed as quickly as possible for a period of 20 s. One cycle included the going to and returning from both sides.

2.6 Response time measurements

A whole-body response time measuring device (YB-1000, Yagami, Nagoya, Japan) was used to measure the whole-body response time. Each participant stood on the response board in a state of lightly bending the knees (120°–160°). The measurement was performed by instructing the participants to move out of the response board quickly as soon as they recognized a visual stimulation of the whole-body response time measuring device placed 2–3 m in the front. The measurement was performed twice in 0.001 s, and the fastest record was used as the measurement value.

2.7 Flexibility measurements

Sitting trunk flexion and backward flexion were performed to measure flexibility. Sitting trunk flexion was measured using the WL-35 (WL-35, YAMAGI, Nagoya, Japan). After sitting with the knees straight, each participant stretched both their arms and hands forward as much as possible, and the position at which the fingertip reached was measured. The measurement was taken twice in a unit of 0.1 cm and the best record was used as the measurement value. For backward flexion, a backward flex meter (TKK-1860, TAKEI, Tokyo, Japan) was used. The participant raised the upper body as much as possible in a lying down posture with the face down, while both ankles were held down by an assistant, and the height from the ground to the chin was measured and recorded.

2.8 Cardiorespiratory fitness measurements

The maximal oxygen consumption (VO_2max) and maximal heart rate were assessed using an automatic respiratory gas analyzer (Q4500, Quinton, Bothell, WA, USA) in the maximal graded exercise test for cardiorespiratory assessment. The measurement protocol used was the KISS protocol developed by the KISS (Korea institute of sport science) for elite athletes. The load was started initially at a speed of 80 m/s and a slope of 5%–6% and was increased by 20 m/min every two min until the test subject was all-out. The resting heart rate at rest was checked prior to the exercise and the heart rate during the exercise was measured in real time. VO_2max was determined using the peak value of measured oxygen consumption and was finally evaluated based on the predicted maximal heart rate and the respiratory exchange ratio (1.15). The analysis was performed by selecting a representative variable in the corresponding category because the correlations of the measurement variables of each category were relatively high.

Lung capacity was measured using a Chestgraph HI-101 (CHEST M.I. Inc., Tokyo, Japan). The athletes learned the measurement methods and practiced them several times. After inhaling as much air as possible while standing comfortably in the complete recovery state, each athlete placed their mouth on a mouthpiece and exhaled the air from inside the lung as much as possible. Based on this, the forced vital capacity (FVC, cc) and forced expiratory volume for 1 s (FEV1, cc) were measured.

2.9 Anaerobic power measurements

A wingate test using a stationary bicycle was performed for the anaerobic power. A bicycle ergonometer (Monark 828E, Monark Exercise AB, Vansbro, Sweden) was used. The participants performed a warm-up exercise for a duration of two min with light pedaling. As soon as the "start" signal was provided, the participants pedaled with full power for 30 s. The peak power (w/kg), mean power (w/kg), and power drop rate lrb (%) were used as the measurement values.

2.10 Statistical analysis

This study used data from 163 individuals (duplicate records of the same individual were allowed) who had physical measurement records among the national team athletes of South Korea from 1999 to 2018. Among them, 74 individuals had records of all the physical factors used in the final analysis. Therefore, 74 Greco-Roman male wrestlers participated in this study. The participants were assigned to two groups according to their competitive level: top-elite (n = 9) and sub-elite (n = 65). The criteria to be placed in the top-elite group wrestlers: (i) they should have won at least one medal during an international tournament in the International Federation of Associated Wrestling Styles tournaments the Olympic and/or World Championships. Sub-elite wrestlers were the finalists at their respective national championships in the last season, although they had not taken part in any international

TABLE 1. Descriptive statistics of factors. This table shows the descriptive statistics of the dataset (n = 74).

	Career (yr)	Age (yr)	Height (cm)	Weight (kg)	Standing long-jump (cm)	Response time from Light (1/1000 s)	Benchpress (kg)
Mean	11.338	24.255	170.145	75.455	239.358	0.296	118.393
Median	11.000	24.500	168.500	73.750	240.000	0.297	119.500
Maximum	16.000	29.501	189.700	116.400	281.000	0.376	172.000
Minimum	4.000	16.471	157.100	55.900	185.000	0.228	71.000
Std. Dev.	2.971	2.794	8.337	13.249	16.115	0.032	22.568
Skewness	−0.237	−0.545	0.366	0.853	−0.407	0.197	0.240
Kurtosis	2.151	2.848	2.522	3.466	4.458	2.602	2.270

TABLE 2. Subjects' characteristics of Top elite and elite Greco-Roman wrestlers. This table shows the characteristics of Top elite (n = 9) and elite (n = 65) Greco-Roman wrestler.

	Top elite (n = 9)	Elite (n = 65)
	M ± SD (95% CI)	M ± SD (95% CI)
Career (yr)	13.89 ± 2.03 (12.33–15.45)	10.98 ± 2.92 (10.26–11.71)
Age (yr)	26.20 ± 2.00 (24.67–27.74)	23.98 ± 2.79 (23.98–23.29)
Height (cm)	164.83 ± 5.17 (160.05–169.61)	171.08 ± 8.6 (168.82–173.34)
Weight (kg)	66.06 ± 7.58 (59.05–73.07)	77.12 ± 13.99 (73.45–80.8)
Standing long-jump (cm)	243.33 ± 6.60 (238.26–248.40)	238.81 ± 16.98 (234.60–243.01)
Response time from Light (1/1000 s)	0.267 ± 0.018 (0.253–0.281)	0.300 ± 0.032 (0.292–0.308)
Benchpress (kg)	117.28 ± 23.69 (99.07–135.49)	118.55 ± 22.60 (112.95–124.15)

M, mean; SD, standard deviation; CI, confidence interval.

competition. Table 1 shows the descriptive statistics of the dataset (n = 74). Table 2 also compares the characteristics of top-elite (n = 9) and sub-elite (n = 65). Pearson's correlation analysis was conducted to examine the variables related to the top rankers. Descriptive statistics were conducted for the variables that showed relevance. The maximum likelihood estimation (MLE) method was used to estimate the logit model; additionally, E-views9.5 was used as the statistical software. All statistically significant differences were set at $p < 0.05$. A normalized variable "Career", unrelated to the physique of the individual person, was set using a relative value compared to the age. In contrast, because the athlete records of various weight classes were gathered in the dataset, the standing long-jump, response time, and benchpress, which were variables related to the personal physique status, needed to be normalized. Therefore, this study performed the analysis by normalizing the standing long-jump, response time, and bench press with the height, body weight, and competing weight class.

3. Results

Model estimation results: Table 3 shows the correlation between the variables. The variable "Top Ranker" is a dummy variable that a player was ranked at the top 1, 2, or 3 at the competition of the year as "1", otherwise "0". The p-value of the Pearson t-test for correlation is shown as *, **, and *** under the critical values of 0.1, 0.05, and 0.01, respectively.

The Logit model for the discriminant of Top Ranker is seen in Eqn. 1 below.

$$\text{TopRanker}_{\,i} = \frac{e^{\text{Utility}_{\,i}}}{1+e^{\text{Utility}_{\,i}}}$$

where

$$\text{Utility}_{\,\text{i}} = \begin{pmatrix} \alpha \\ +\beta_1 \cdot \text{ Career}_{\,\text{i}}/\text{Age}_{\text{i}} \\ +\beta_2 \cdot \text{ Standing long-jump}_{\,\text{i}} \\ +\beta_3 \cdot \text{ Resposetime}_{\,\text{i}} \\ +\beta_4 \cdot \text{ Benchpress}_{\,\text{i}} \end{pmatrix} \quad (1)$$

The maximum likelihood estimation (MLE) method was used to estimate the logit model; additionally, E-views9.5 was used as a statistical software. The results are summarized in Table 4. The values in brackets in the following table are p-values.

The estimation results showed that the probability of becoming a top ranker was high when an athlete had records of a long career compared to the age, long distance of standing long-jump, fast response time, and heavy weight of bench press. We compared the fitted values of the whole model, McFadden R^2, Akaike Information Criterion (AIC), and Schwarz information criterion (SBIC), and the significance (p-value) of the estimation coefficient of the three models. Among the three models, the results obtained by normalizing the standing long-jump, response time, and benchpress with the competing weight class were better.

4. Discussion

The goal of this study was to investigate the physical factors that discriminated the top rank athletes among the South Korean Greco-Roman wrestlers who had participated in the

TABLE 3. Correlation of variables. This table shows the correlation between the variables. The variable "Top Ranker" is a dummy variable that a player was ranked at the top 1, 2, or 3 at the competition of the year as "1", otherwise "0".

	X1	X2	X3	X4	X5	X6	X7	X8
Top Ranker (X1)	1.000							
Career (X2)	0.322***	1.000						
Age (X3)	0.261**	0.898***	1.000					
Height (X4)	−0.257**	−0.315	−0.244**	1.000				
Weight (X5)	−0.275	−0.134	−0.051	0.863***	1.000			
Standing long-jump (X6)	0.092	−0.082	−0.064	0.244**	0.046	1.000		
Response time_Light (X7)	−0.337***	0.021	0.019	0.175	0.242**	−0.065	1.000	
Benchpress (X8)	−0.019	0.115	0.169	0.398***	0.605***	−0.014	0.023	1.000

*** $p < 0.01$; *** $p < 0.001$.

TABLE 4. Logit model estimation results. The maximum likelihood estimation (MLE) method was used to estimate the logit model; additionally, E-views9.5 was used as a statistical software. The values in brackets in the following table are *p*-values.

Independent variables/Model	Model-height	Model-weight	Model-weight class
Constant	−17.602 (0.115)	−36.735 (0.010)	−63.016 (0.017)
$Career_i$ / Age_i	20.711 (0.037)	24.170 (0.043)	38.288 (0.041)
$\frac{\text{Standing long-jump}_i}{\text{Height}_i}$	9.288 (0.093)		
$\frac{\text{Responsetime}_i}{\text{Height}_i}$	−5950.070 (0.037)		
$\frac{\text{Benchpress}_i}{\text{Height}_i}$	2.717 (0.475)		
$\frac{\text{Standing long-jump}_i}{\text{Weight}_i}$		7.422 (0.018)	
$\frac{\text{Responsetime}_i}{\text{Weight}_i}$		−3902.941 (0.022)	
$\frac{\text{Benchpress}_i}{\text{Weight}_i}$		7.122 (0.038)	
$\frac{\text{Standing long-jump}_i}{\text{WeightClass}_i}$			11.310 (0.017)
$\frac{\text{Responsetime}_i}{\text{WeightClass}_i}$			−5670.657 (0.020)
$\frac{\text{Benchpress}_i}{\text{WeightClass}_i}$			11.754 (0.025)
McFadden R^2	0.353	0.531	0.629
AIC	0.614	0.483	0.410
SBIC	0.770	0.638	0.566

AIC, Akaike Information Criterion; SBIC, Schwarz information criterion.

World Championships and the Olympics, and to develop and verify an estimation model. The probability of becoming a top ranker was high when an athlete had records of a long career compared to the age, longer standing long jump distance, fast response time to light, and a heavier weight of bench press. The estimation model applying the physical fitness variables shown significantly in the top rankers of South Korea can be used as important data for predicting and fostering world-class Greco-Roman wrestlers.

The study results are discussed as follows: In the results of comparing the athletes who participated in international competitions, it was shown that athletic career compared to the age was an important parameter for determining a top ranker. In other words, an athlete with a long athletic career compared to the age had a higher possibility of becoming a top ranker than an athlete with a short career. García Pallarés *et al.* [12] compared male elite and amateur wrestlers and showed that the athletes were 8%–12% older and had 25%–37% more training experiences than the amateur athletes, thereby supporting the results of this study. It seems that the wrestling match management ability, skill performing ability, and level of dealing with various wrestling match situations are perfected by many years of training and experience of wrestling matches [25, 35, 36]. This implies that the skills, strategy, and wrestling match experiences as well as physical factors are very important to top-rank wrestlers. The career compared to age is an important parameter for predicting the level of a top elite and must be considered when predicting top-rank wrestlers and fostering athletes. Additionally, this result implies that an early introduction of wrestling to young athletes can be an important factor for becoming top-ranked wrestlers.

Wrestling matches have the characteristic of repeatedly performing explosive offense and defense to powerfully lift up the opponent or to escape quickly from the defense position on the mat floor. Such a wrestling match pattern requires a high level of power from the athletes [7, 22, 25]. Previous studies have reported that power is related to the explosive movement needed to dominate the opponent, and is an important factor for predicting a successful wrestler. In this study, the top rankers and world-class athletes that were not top rankers were also compared, and the results showed that power was an important parameter in determining the top rankers. The power (standing long-jump) of South Korean athletes, who participated in international competitions varied between 185 and 281 cm. The higher the top rank, the higher is the power. This result was consistent with the results of previous studies comparing the power between the elite and non-elite athletes [12, 27, 35]. García Pallarés *et al.* [12] demonstrated that the elite wrestlers showed 7.6%–16.6% higher muscular power (standing high jump) compared to an amateur group, thereby supporting the results of this study. Furthermore, Nikooie *et al.* [27] reported that successful wrestlers showed higher power than non-successful wrestlers, supporting the results of this study. Power seems to be an important physical factor for discriminating not only elite and non-elite athletes, but also top elite athletes and elite athletes. Moreover, this result implies that training programs should be continuously developed and performed to improve power in the field so that elite athletes can attain the level of top rankers.

The response time was defined as the time interval between the start of an unexpected stimulation and the start of the response. In a wrestling match, a wrestler performs complex motions, such as grabbing and feinting that lasts from several hundred milliseconds to several seconds, and a very short single motion of less than 100 ms [37, 38]. In such a situation, anticipating a certain circumstance or movement (mistake) of the opponent and taking a quick response is important because a wrestler can quickly defend against the attack of the opponent and take an attacking opportunity [39]. In this study, the comparison results of the top rankers and world-class athletes who were not top rankers showed that the response time was an important parameter for determining top rankers. The response times of the South Korean athletes, who had participated in international competitions varied in the range of 228–376 ms. The higher the top rank, the faster the response time. This result seemed to be similar to the results of several previous studies reporting that the response time was faster for excellent athletes than non-excellent athletes, although direct comparison was impossible because of the difference in the measurement tools [37–39] stated that in the results of measuring the response time before the wrestling match and after finishing each round for 20 Greco-Roman wrestlers, the response times of finalists were significantly faster, and the finalists exhibited more skills and strategic actions. Furthermore, the response time in the last round showed strong correlations with an athlete's moving time, skills, and strategic action (r = –0.58, $p < 0.01$), leading to the conclusion that response time was an important factor in determining the result of a wrestling match. As such, the response time is an important factor for determining the top rankers and seems to be a factor that must be considered when predicting the top rankers and fostering athletes. Furthermore, based on the study confirming that an improvement of response time is possible with continuous training, it is thought that the response time training should be added to the training programs of elite athletes.

Wrestlers need a high level of maximal muscular strength when lifting or attempting a technique of lifting an opponent up in a match [5, 6, 40, 41]. According to previous studies, high maximal strength level of the upper extremities and lower extremities of a wrestler is a prerequisite that must be possessed for excellent wrestling performance [6–8]. In this study, the results of comparison of the top rankers and world-class athletes that did not show that upper body strength (bench press 1RM) is an important parameter determining the top rankers. The maximal upper body strength (bench press) of South Korean athletes who participated in international competitions varied in the range of 71–172 kg. Morán-Navarro *et al.* [42] showed that elite wrestlers had 20% higher maximal bench press strength than amateur wrestlers, thereby supporting the results of this study. Zi-Hong *et al.* [36] reported that among Chinese elite female wrestlers, successful wrestlers had higher maximal strength compared to non-successful wrestlers. Furthermore, with respect to the isometric strength, Roemmich and Frappier [14] stated that excellent wrestlers had a higher absolute grip strength and relative grip strength than non-excellent wrestlers, thereby supporting the results of this study. Demirkan *et al.* [11]. reported a considerably large difference in back strength between selected and non-selected athletes was observed, thereby supporting the results of this study. Previous studies have shown that the maximal upper body strength is not only a factor that discriminates elites and amateurs among Greco-Roman wrestlers, but also a factor that can discriminate the world-class top rankers and elites. In particular, Greco-Roman wrestling is a sport that allows only upper-body attacks and as grabbing each other is performed frequently with strong force, it can be said that the upper body strength is relatively important. Considering that the ability of the wrestler to lift the opponent up and resist attacks is important for the wrestling performance, a high level of muscular strength seems to be important to attain excellent wrestling performance results [43]. Furthermore, since maximal strength of the upper extremities is a prerequisite for the development of various physical strengths, it seems to be a factor that must be developed for the athletes. As such, the upper body strength is an important parameter for predicting top-rank Greco-Roman wrestlers and is a factor that must be considered when predicting top-rank wrestlers and fostering athletes.

5. Conclusions

In conclusion, the athletic career (age-to-career ratio), power, maximal strength, and response time are the determinants of predicting world-class top rankers of Greco-Roman wrestling. The estimation model established in this study for the significant physical factors shown in the South Korean top rankers can be used as important data for predicting and fostering world-class Greco-Roman wrestling athletes in South Korea. Furthermore, the results of this study may be applicable to elite wrestlers (Greco-Roman) in various countries in Asia and the world. However, the limitation of this study is that the information regarding the mental strength and physical condition of the participants on the day of competition and information regarding the opponents were not considered. Therefore, systematic measurements of the qualitative variables, such as concentration power, should be incorporated in future studies. In addition, the national team was a special group, so there were not many cases included. A precise analysis through normality tests should be conducted in future studies by adding more cases.

Abbreviations

AIC, Akaike Information Criterion; BMI, Body mass index; FEV1, Forced expiratory volume for 1 second; FILA, International Federation of Associated Wrestling Styles; FVC, Force vital capacity; KISS, Korea institute of sport science; MLE, Maximum likelihood estimation; SBIC, Schwarz-Bayesian information criterion; VO_2max, Maximal oxygen consumption; 1RM, One repetition-maximum.

Author contributions

Conceptualization: KCC and HSS; methodology: KCC; software: KCC and HSS; validation: KCC; formal analysis: KCC; investigation: BOC; resources: BOC; data curation: KCC; writing—original draft preparation: HSS and BOC; writing—review and editing: HSS and BOC; visualization: KCC; supervision: HSS and KCC; project administration: HSS. All authors have read and agreed to the published version of the manuscript.

Ethics approval and consent to participate

All participants who agreed to participate in our study received a detailed explanation of its purpose and methods, in accordance with the ethical principles of the Declaration of Helsinki. All participants signed an informed consent form before measurements.

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Conflict of interest

The authors declare no conflict of interest.

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