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ORIGINAL ARTICLE

A Comparison of Optimal Training Load for Maximal Power Output in Upper and Lower Body Exercises According to Different Sports

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ABSTRACT
Aim: The purpose of this study was to compare optimal training load which maximizes power output in both lower and upper body exercises for athletes competing in different sports.
Methods: To achieve this, a total of sixty athletes from different sports (football, handball, arm-wrestling, volleyball, wrestling, and martial arts) volunteered for the study. To determine the lower and upper body strength characteristics, bench press (BP) and full squat (SQFull) exercises were performed in the research. To determine the mean propulsive power (MPP), the participants executed bench throw (BT) and loaded-squat jump (SJLoad) exercises using an external load corresponding to 30% and 40% of their body weight respectively for the upper body the lower body (10% increments until reaching the maximal power value) via an isoinertial velocity transducer (T-Force dynamic measurement system). One-way analysis of variance, test of significance between two means, and correlation analysis were used in the study.
Results: The results showed there was a statistically significant difference according to different sports in terms of maximal power value and optimal training load for the MPP parameter in both SJLoad and BT exercises.
Conclusion: Consequently, it can be claimed that the optimal load value for maximal power output in exercises include shows dissimilarity according to different sports, and individuals need to perform their training by using the load value capable of maximizing their power output.
Keywords: Power, optimal load, exercise

INTRODUCTION

Power which is determined by muscle contraction rate and strength is one of the main determining factors of dynamic athletic performance and training-induced effects[1]. In many sports, there are movements like throws, jumps, change-of-directs, and surprising movements that require power production in a short period of time. Power is a significant performance indicative in such explosive and rapid movements. Therefore, to perform many physical movements and to maintain them or to achieve success in different sports, power is accepted to be an important parameter[2, 3]. Power defined as the amount of work with respect to time (power = work / time) usually depends on the ability to produce maximal power output, and the ability to produce power at a specific load is a factor usually affecting performance since in many sports, successful performance is generally linked with how much power to produce against the objects (a ball, the ground or equipment)[3, 4]. It is often necessary to produce maximal power output in sports in which aperiodic motions such as throws, jumps, leaps, kicks, quick chance-of-directions, rapid increase or decrease in velocity are performed to reach maximal performance. This is why ability to produce high levels of power is essential for sport performance[5].

The highest power output that is required in measurements at various loads is defined as maximal power output (P_{max})[2], and it is considered as the most significant mechanical quantity for determining the performances of athletes competing in sports require strength or power[4]. It has been found that there is a great increase in the dynamic athletic performance of the athletes who perform their training using loads that maximize their mechanical strength. Similarly, training performed with loads ensuring maximal power output is found to be the best stimulator to achieve more improvement in power[6]. Baker[2] analysed maximal power output of an athlete in depth and stated that P_{max} reflected the athlete's level of fitness. Thus, optimal load for maximal power output in lower and upper body exercises has extensively been researched by many sports scientists since it is claimed that when training programs are designed in order to improve maximal power output, it is necessary to complete the training with optimal load to maximize the power output. In the literature, the optimal load for maximal power output has widely been the subject of many discussions. While the optimal training load for maximal power output was initially found by using light loads such as 30% of maximal isometric strength or maximal muscle contraction velocity, in later studies in which multi-joint dynamic muscle movements are performed in isoinertial conditions (a constant external load), it was found out that the relative load producing P_{max} varied (20-80% of 1RM) [7].

Taking the studies in the literature and their results into consideration, it has been seen that training load that maximizes power output is a significant element, and it varies in both lower and upper body for various reasons. This is why optimal training load for maximal power output in both lower and upper body exercises for athletes competing in different sport disciplines are studied in this research. It is thought that the results of the study will benefit conditioning coaches, sports scientists, and athletes who are in search for loads to maximize muscle strength which is considered as a significant parameter for successful performance in many different sports.

MATERIAL AND METHODS

Participants: A total of sixty athletes who are actively competing in different sports (handball, volleyball, football, arm-wrestling, kickboxing, and wrestling) volunteered for the study. The physical characteristics of the participants are presented in Table 1. The participants were informed about the aim of the study, test procedures, the potential risks and possible benefits of the study and signed the written voluntary participation consent document.

Table 1: The Physical Characteristics of the Participants

Sports	n	Age (year)	Height (cm)	Weight (kg)
		mean±sd	mean ±sd	mean ±sd
Handball	10	21.90±2.33	181.00±5.51	80.70±14.20
Volleyball	10	21.70±4.27	180.10±4.55	76.75±6.77
Football	10	20.40±1.64	180.70±4.90	76.90±9.87
Arm-wresting	10	20.40±2.17	179.72±5.71	70.70±5.86
Kickboxing	10	20.70±5.43	185.80±6.77	82.70±9.62
Wrestling	10	20.40±2.22	179.10±6.13	81.50±10.22

An Experimental Approach To The Problem: The participants of the study were athletes who were actively doing sports and had completed power training programs in the past. Measurements of the subjects were completed in two consecutive days with participants having adequate resting time. The physical characteristics of the participants were measured on the first day with one-repetition maximum (1RM) tests by performing full squat (SQ_{Full}) for the lower body and bench press (BP) for the upper body. On the second day, an external load corresponding to 30% and 40% of participants' body weight was used to determine the mean propulsive power (MPP) in concentric phase by respectively performing bench throw (BT) for the upper body and loaded squat-jump (SJ_{Load}) for the lower body power output. All measurements were performed on a Smith machine (Esjim IT7001, Eskisehir, Turkey). To determine the power parameter while performing BT and SJ_{Load}, a linear velocity transducer (T-Force Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) was utilized.

Before the application of the test procedures targeting both upper and lower body, the participants completed a 20-minute warm-up procedure including 10 minutes of general (upper and lower body stretching exercises after a moderate warm-up run) and 10 minutes of specific (BP, BT, SQ_{Full}, SJ_{Load}) exercises. They also completed a practise session to enable them to get used to the test procedures in Gümüşhane University fitness centre. This study was approved by the Scientific Research and Publication Ethics Committee of Gümüşhane University (E-95674917-044-73550) and was prepared in accordance with the Declaration of Helsinki.

Procedures:

Measurement of Height and Body Weight : In order to measure the height and body weight of the participants, a Seca 769 electronic column scale (Seca Corporation, Hamburg, Germany) was used respectively with the precision of 0.001m and 0.01kg. So as not to affect the body weights of the participants, they only wore shorts and a T-shirt, and their body weights were measured in kilograms (kg). In addition, their height was measured in centimetres (cm) in a position where their body weight was evenly distributed on both feet.

Determining the Optimal Power in Bench Throw and Loaded Squat-Jump: Using an external load corresponding to 30% of the participants' body weight for upper body and 40% of their body weight for lower body to determine the power parameters in bench throw (BT) and loaded squat-jump (SJ_{Load}) in concentric phase, the participants performed the movements as three repetitions at the maximal velocity. Until reaching the maximal power in both BT and SJ_{Load}, the loads were increased by 10%. The participants were asked to perform BT in a controlled way until the bar touched their chest and then throw the bar as fast and as high as possible with the start command[8]. While performing SJ_{Load}, they were asked to flex their knees, beginning from a static position, until their thighs were parallel to the ground and to keep the bar in contact with their shoulders[9]. Furthermore, as the power value would be determined considering the ability to move the body weight as well as the external load and the acceleration of the total mass (the external load and the body weight), the movement was repeated when it was partly or not correctly performed[6].

1RM Measurements in Bench Press and Full Squat: The procedure designed by Beachle et al.[10] was used to determine one-repetition maximal (1RM) strength value of the participants in bench press (BP) and full squat (SQ_{Full}) exercises. The procedure is explained in detail below:

1. The participants performed a general warm-up for both exercises, and they also warmed up using loads with which they could repeat the exercise 5 to 10 times.
2. They were allowed to rest for a minute.
3. The warm-up loads which allowed participants 3-5 repetitions were determined by adding 14 to 18 kg for SQ_{Full} and 7-9 kg for BP to the loads used in the first step of the procedure.
4. The participants were given two minutes of recovery time.
5. 14 to 18 kg for SQ_{Full} and 7-9 kg for BP were added to the loads in the third step of the procedure, and the near-maximal loads which could allow 2-3 repetitions were determined.
6. The participants were given three minutes of recovery time.
7. After adding a load between 14 and 18 kg for SQ_{Full} and a load between 7 and 9 kg for BP to the loads in the fifth step, and one-repetition maximum (1RM) attempts were performed.
8. The participants were given three minutes of recovery time.
9. The loads of the individuals who were successful at lifting the loads in the seventh step were increased at the same rate. The loads of the individuals who failed at1RM attempts decreased by 7 to 9 kg for SQ_{Full} and 3 to 5 kg for BP exercises.
10. The participants were given three minutes of recovery time.
11. Until the 1RM tests in SQ_{Full} and BP were completed with the appropriate technique, the loads are increased or decreased, and the 1RM values were obtained within the five attempts.

Statistical analysis: The data obtained was analysed using Statistical Package for Social Sciences (SPSS) for Windows 26.0. In the statistical analysis of the data, categorical measurements were summarized as numbers and percentages, and numerical measurements were summarized as mean and standard deviation. For the normally distributed data from parametric tests, one-way analysis of variance was used to compare the mean scores of more than two groups, and test of significance and correlation analysis were used to compare the means of the two groups. The statistical significance was found to be 0.05.

RESULTS

Table 2 shows the comparison load values for optimal power output in loaded squat-jump and bench throw exercise with different sports. Table 3 demonstrates the comparison of one-repetition maximum strength values of the participants in bench press and full squat exercises according to different sports, and Table 4 demonstrates the correlation between mean propulsive power in loaded squat-jump and bench throw and one-repetition maximum strength values.

Table 2: The Comparison of the Mean Propulsive Power and Load Value in Loaded Squat-Jump and Bench Throw According to Different Sports

Exercise	Sports	Mean Propulsive Power (w)	Load value for Mean Propulsive Power (kg)
Loaded-Squat Jump	Handball (n = 10)[a]	715.74±128.63	76.00±8.43
	Volleyball (n = 10)[b]	771.23±168.04	75.00±5.27
	Football (n = 10)[c]	733.13±117.50	75.00±11.78
	Arm-Wrestling (n = 10)[d]	441.63±157.48	52.00±4.21
	Kickboxing (n = 10)[e]	770.26±140.75	80.00±6.66
	Wrestling (n = 10)[f]	787.49±151.64	75.00±11.78
		a>d, b>d, c>d, f>d	a>d, b>d, c>d, f>d
	KW	8.149	13.858
	p	0.0001	0.0001
Bench Throw	Handball (n = 10)[a]	422.85±82.04	75.00±5.27
	Volleyball (n = 10)[b]	396.59±54.96	57.00±13.37
	Football (n = 10)[c]	358.51±78.02	57.00±9.48
	Arm-Wrestling (n = 10)[d]	399.15±93.72	69.00±9.94
	Kickboxing(n = 10)[e]	417.41±53.31	77.00±9.48
	Wrestling (n = 10)[f]	424.54±66.42	71.00±7.37
			a>b, a>c, e>b
	KW	1.167	8.474
	p	0.337	0.0001

Post-hoc analysis: Bonferroni correction Mann-WhitneyU test, p=0.008

When the Table 2 is examined, it can be seen that there is a statistically significant difference in terms of the maximal power value and load value producing that power for the MPP parameter in SJ_{Load} (p=0.0001) according to different sports. In the analysis to find out which different sports had significant difference, it was discovered that the branch was arm-wresting, and compared to other branches of sport, in SJ_{Load} of arm-wrestlers, the mean power and the load producing mean power values were much lower. Furthermore, there was no statistical significance among the other different sports. For the MPP parameter in BT, there was no significant difference in terms of optimal power value across the branches of sport (p=0.337), while there was statistical significance in the load

value for mean propulsive power according to different sports (p=0.0001). In the post-hoc tests to find our which different sports showed statistical significance, it was found out that the athletes in handball, kickboxing and wrestling groups when compared to the athletes from the other sports, had higher training load for optimal power value, and there was no statistical significance according to different sports.

Table 3: The Comparison of One-Repetition Maximum Strength Values of the Participants in terms of Bench Press and Full Squat According to Different Sports

Sports	Bench Press 1RM (kg)	Full Squat 1RM (kg)
Handball (n = 10)[a]	102.00±9.77	113.50±11.43
Volleyball (n = 10)[b]	79.00±13.70	114.75±21.68
Football (n = 10)[c]	69.50±13.42	111.50±9.44
Arm-Wrestling (n = 10)[d]	86.75±15.23	83.25±14.43
Kickboxing (n = 10)[e]	91.75±7.82	107.75±8.53
Wrestling (n = 10)[f]	107.75±9.67	128.00±15.17
	a>c, a>b, f>b, e>c, f>c	a>d, c>d, e>d, f>d
KW	14.281	10.800
p	0.0001	0.0001

Post-hoc analysis: Bonferroni correction Mann-Whitney U test, p=0.008

Table 3 shows that there was no statistical significance in terms of 1RM values in BP and SQ_{Full} exercises among the different sports (p=0.0001). The post-hoc analysis to find out which different sports presented statistical significance demonstrated that arm-wrestlers showed statistical difference in SQ_{Full} exercises, and compared to other different sports, 1RM values of arm-wrestlers were much lower, and there was no statistical significance accordind to different sports. In addition, it was seen that the athletes competing in the sports handball and wrestling had higher 1RM values than the ones playing football and volleyball; the kickboxers had higher 1RM values than footballers considering BP exercises. In addition, there was no significant difference according to different sports.

Table 4: The Correlation Between Mean Propulsive Power in Loaded Squat-Jump and Bench Throw and One-Repetition Maximum Strength Values

	Bench Press 1RM			Full Squat 1RM	
BT_{MPP}	r	p	SJ_{MPP}	r	p
	0.295	0.02		0.686	0.0001

When the Table 4 is analysed, it is possible to observe that there was correlation in the positive direction between the MPP values and 1RM values in both bench throw (r=0.295; p=0.02) and loaded squat-jump (r=0.686; p=0.0001); the correlation with bench throw was weak and with loaded squat-jump, it was moderate, and there was statistically significant difference.

DISCUSSION

This study is a study that compares the optimal training load that contributes to the formation of maximal power efficiency in exercises performed for the lower and upper parts of the body, according to different sports (football, handball, volleyball, arm wrestling, kickboxing, wrestling). The reason why bench press (BP) and bench throw (BT) exercises targeting the upper body were used is both are multi-joint exercises and are widely used in the enhancement of upper body performance[11]. BP is one of the widely used exercises for both training upper body muscles (chest, arms, and shoulders) and their evaluations[12], and in order to evaluate the upper body muscle strength, 1RM strength test is often applied in BP exercises. Moreover, as there is a braking phase which affects power output as a result of the pressure in BT exercises, this exercise is used to determine the power value in propulsive phase[13]. Since both exercises are two of the most commonly used ones to improve lower body muscle power and strength, loaded squat-jump (SJ_{Load}) and full squat (SQ_{Full}) which target lower body were also included in the study[14].

In the study, there was a statistically significant difference between the different sports in terms of the maximal power output and optimal training load value producing maximal power output taking the mean propulsive power (MPP) parameter in SJ_{Load} and BT exercises into consideration. The optimal load values for maximal power output in SJ_{Load} exercise were found to be 75% of the body weight in football, volleyball, and wrestling; 76% of the body weight in handball; 80% of the body weight in kickboxing; 52% of the body weight in arm-wrestling. Therefore, the maximal power value of the arm-wrestlers appeared at a lower load. Additionally, the optimal load value for maximal power output in BT exercise was revealed to be 57% of the body weight in football and volleyball; 75% of the body weight in handball; 71% of the body weight in wrestling; 77% of the body weight in kickboxing; 69% of the body weight in arm-wrestling. This shows that the maximal power values of the athletes competing in the volleyball and football were produced at a lower load. The MPP values of the participants in SJ_{Load} exercises were found to be 715.74 (± 128.63 W) for handball players, 771.23 (±168.04 W) for volleyball players, 733.13 (±117.50 W) for football players, 441.63 (±157.48 W) for arm-wrestlers, 770.26 (±140.75 W) for kickboxers, and 787.49 (±151.64 W) for wrestlers. Additionally, the MPP values of the participants for BT exercises were 422.85 (±82.04 W) for handball players, 396.59 (±54.96 W) for volleyball players, 358.51 (±78.02 W) for footballers, (±93.72 W) for arm-wrestlers, 417.41 (±53.31 W) for kickboxers, and 424.54 (±66.42W) for wrestlers.

In a study by Loturco et al.[15] to determine the optimal power load in squat-jump exercises of the elite athletes competing in individual and team sports, it was discovered that the optimal training load value producing maximal power output of a group of male sportsmen (80.6±10.6 kg) consisting of rugby and American football players was higher than female athletes (60.4±9.9 kg), footballers (54.3±9.2 kg), endurance runners (41.6±7.7 kg), martial artists (54.4±11.1 kg) and tennis players (54.2±8.6 kg). In the same study, MPP values of participants in the squat-jump were 1117.7 (± 129.3 W) for male athletes, 778.6 (± 124 W) for female athletes, 997.2 (± 142.9 W) for rugby and American football players, 705.5 (± 113.5 W) for footballers, 543.0 (± 111.1 W) for endurance runners, 704.0 (± 120.2 W) for martial artists, and 659.3 (± 115.4 W) for tennis players.

In research including various exercise techniques targeting upper and lower body, optimal training load for maximum power output was investigated. Zink et al.[16] discovered the peak power in squat exercise increased at loads ranging from 20-40% of 1RM, decreased at loads 40-80% of 1RM and showed a second increase at 90% of the 1RM. Furthermore, Pearson et al.[17] stated that the mean power value increased between 10 and 50% of 1RM in BP exercises, increased between 10 and 80% of 1RM in bench pull exercises and gradually decreased. In their research Izquierdo et al.[18, 19] discovered handball players and middle-distance runners produced maximal power output in squats at 60% of 1RM, while weightlifters and cyclists reached it at 45%. Similarly, in studies with sprinters[20] and semi-professional footballers[21], the athletes reached maximal power output at below 60% of 1RM. Cormie et al.[6] reached the maximal power output in squat exercises at 56% of 1RM. When studies done on the upper body exercises are examined, it is found that Mayhew et al.[22] concluded that the maximal power output produced reached between 40 and 50% of 1RM in BP exercises with different loads. Furthermore, Baker et al.[1] in their study with rugby players found that the maximal power output at the loads between 47 and 63% of 1RM in BP exercises generally had similar results.

In their study Sanchez-Medina et al.[23] expressed training load for maximal power output in BP and prone bench pull exercises varied in terms of the parameters mean power (MP), the mean propulsive power (MPP), and peak power (PP). They also found that when MP was used, the power output peaked at the loads 56% of 1RM in BP and 70% of 1RM in PBP. In addition, it was discovered there was no statistical significance in terms of the power output produced at the loads between 40 and 70% of 1RM in BP and between 50 and 90% of 1RM in PBP. When MPP was used, the power output reached at the loads between 20 and 60% of 1RM in BP, between 20 and 70% of 1RM in PBP showed no meaningful difference, and maximal power output was achieved at the loads 37% of 1RM in BP and 46% of 1RM in PBP. When PP was used, there was no statistical difference between the loads 20 and 65% of 1RM in BP and 20-75% of 1RM in PBP, and maximal power output was produced at the loads 37% of 1RM in BP and 41% of 1RM in PBP.

In the literature, it is observed that the training load for maximal power output in the exercises targeting the lower and upper body has intensively been investigated, and the results obtained differed. In the studies, it has been presented that these variations generally have resulted from things such as movement mechanics, gender, age, methodology (peak or mean power measurements, including or excluding body mass when calculating lower body power output, how the movement was performed), fibre types, muscle-tendon morphology, individual differences (inexperienced or trained), muscular fatigue, targeted muscle group, and type of training (upper or lower body, single-joint or multi-joint, explosive or traditional), and there are parameters affecting optimal training load for maximal power output[2, 3, 4, 6, 8, 15, 20, 23].

Can et al.[24] compared MPP and PP values in loaded squat-jump and bench throw exercises in athletes across various sport disciplines in their study. They determined that MPP in SJ_{Load} was higher in handball, volleyball players, and martial artists than in arm-wrestlers, and PP in

SJ_{Load} was higher in volleyball and handball players than arm-wrestlers and martial arts. The MPP in BT was much higher in volleyball and handball players than arm-wrestlers, and PP in the same exercise was higher in volleyball players than arm-wrestlers; it was higher in handball players than both arm-wrestlers and martial artists. They claimed the reason why arm-wrestlers had the lowest values in terms of MPP and PP values in both exercises could be that rather than propulsive moves, pulling moves in the upper body were more dominant in the sport, and generally their training programs did not include lower body exercises.

CONCLUSION

In this study, it was discovered that the optimal load for maximal power output in the exercises targeting both lower and upper body varied according to different sports. In conclusion, it can be claimed that in order to get high-level outputs in training programs, the optimal load value of individuals for producing maximal power output should be taken into consideration.

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