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Review

Maximal Strength, Muscle Power, Rate of Force Development and Muscle Morphology in Ski Athletes, and Adaptations Following Resistance Training

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Abstract

The purpose of this narrative review was to describe the maximal strength, muscle power, rate of force development, and muscle morphology of athletes across different ski disciplines. Specifically, this review synthesizes evidence on upper- and lower-body maximal strength both dynamically and isometrically, muscle power through jumping performance and rate of force development, and muscle morphology in competitive skiers. Furthermore, it examines how these neuromuscular parameters adapt when resistance-training interventions are incorporated into athletes' routine training programs. Following a literature search, 30 studies met the inclusion criteria, 18 describing the ski athletes' characteristics mentioned above and 12 evaluating the effects of resistance-training interventions. Altogether, these studies involved 561 participants, with ages ranging between 14.6 ± 1.1 years and 35 years. Overall, the above characteristics of ski athletes appear to align with sport-specific demands, which vary across ski disciplines. The resistance-training protocols applied in this population are predominantly high-load resistance training and it appears that resistance training may benefit from increased emphasis in ski-specific preparation. However, training programs tailored to the specific demands of each discipline are recommended.

Keywords: winter sports; ski disciplines; muscle strength; muscle power; muscle morphology; RFD

1. Introduction

Neuromuscular performance encompasses several key physiological attributes including muscle strength, power and muscle morphology [1–3]. Maximal muscle strength represents the greatest amount of force or load that a muscle or a muscle group can produce during a single voluntary effort [4]. Muscle power reflects the ability to generate force rapidly and is therefore associated with explosive movements and high-velocity actions [5]. Muscle power is typically assessed dynamically through jumping performance or isometrically via the rate of force development. Muscle morphology comprises muscle architecture and muscle fiber-type distribution. Muscle architecture involves structural parameters such as muscle thickness, fascicle length, and pennation angle, which together influence the mechanical efficiency and force-generating potential of the muscle [6]. Finally, the distribution of Type I, Type IIa, and Type IIx muscle fibers, as well as their cross-sectional area, affect neuromuscular performance [1]. These parameters collectively shape the functional capabilities of the muscle, influencing strength, power, fatigue resistance, and overall athletic performance.

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Ski sports place substantial emphasis on aerobic capacity, with elite cross-country skiers typically demonstrating some of the highest VO_2max values recorded, even higher than 80 mL/kg/min [7,8]. Nevertheless, each skiing discipline also relies on distinct neuromuscular characteristics. On the one hand, ski jumping depends primarily on muscle power, which is crucial for optimizing take-off mechanics and maximizing jumping performance [9,10]. On the other hand, cross-country skiing and biathlon enhancements in neuromuscular components have been linked to improved ski economy, thereby contributing to better overall performance [11,12]. In addition, upper-body strength and power have been identified as critical contributors to performance in cross-country skiing, given the substantial involvement of the arms and trunk in poling and propulsion [13,14]. Finally, alpine skiing requires both muscle power and muscle strength, but with different emphases depending on the event. Slalom and giant slalom place greater demands on muscle power due to the high frequency of turns, whereas super giant slalom and downhill rely more heavily on muscle strength because of longer, more sustained turns [15]. Although previous studies have examined the muscular capacities of elite ski athletes and explored their associations with performance, these characteristics have not been characterized as clearly or comprehensively as the aerobic profile of skiers.

Resistance training induces a wide range of neuromuscular adaptations that can enhance performance across various sports, including skiing. These adaptations include increases in maximal strength, muscle power, maximal isometric contraction and rate of force development, as well as improvements in muscle architecture and fiber-type recruitment [1,16]. Previous studies have examined the integration of resistance training into standard aerobic and technical ski training programs, to induce improvements in general athletic performance. However, the specific impact of resistance training on the muscular capacity of ski athletes has not yet been clearly determined. A detailed understanding of these adaptations is essential to optimize training protocols and maximize performance in different ski disciplines.

The importance of muscular capacity in skiers highlights the need to clearly define the profile of these athletes. Therefore, the primary aim of the present review is to describe the maximal strength, muscle power, maximal isometric contraction, rate of force development and muscle morphology of ski athletes. The second aim is to examine how these parameters adapt following a structured resistance-training program in ski athletes. It was hypothesized that these characteristics will be described differently among the different ski disciplines. Also, ski athletes will possibly benefit from resistance-training protocols.

2. Results

A total of 30 studies were included in the present review, 12 of which included resistance-training intervention. Across all studies, 561 participants were enrolled, with 404 participating in cross-sectional designs and 157 in interventional studies. The sample consisted of 212 men, 192 women, 117 young males and 94 young females < 18 years old as well as 46 participants for whom gender was not reported. Participant ages ranged from 14.6 ± 1.1 years in the youngest cohort to 35 years in the oldest. Reported nationalities included Norwegian, Swedish, Danish, Finnish, Italian; however, nationality was not consistently provided across studies. The athletes represented a variety of skiing disciplines, including alpine skiing, ski jumping, Nordic combined, cross-country skiing, biathlon, and sprint skiing. All studies involved elite skiers competing at national or international level.

2.1. Maximal Strength

Maximal strength assessed using the one-repetition maximum (1RM) test is presented in Table 1. The 1RM test was performed in exercises such as squat, half-squat, pull-down, bench press, and clean (Table 1).

Table 1. Maximal strength (1RM) of ski athletes.

Study	**Participants' Characteristics**				**Maximal Strength**	
	N	**Gender**	**Level**	**Age (Years)**	**Exercise**	**1RM (kg)**
[17]	31	16 boys 15 girls	athletes with 3 and 5 years of experience competing in national events	boys: 14.6 ± 1.1, girls: 14.9 ± 1.0	squat	boys: 69 ± 13 girls: 49 ± 10
[18]	16	men	athletes of the Polish national ski jumping team	18–35	squat	112 ± 28
[14]	29	17 men 12 women	well-trained cross-country skiers from high schools for skiers in Southeastern Norway	22.1 ± 8.4	half-squat	120.8 ± 21.9
					pull-down	87.4 ± 16.5
[19]	16	men	elite sprint skiers from the Austrian and Norwegian national/international teams	26.4 ± 4.8	bench press	75 ± 10
					bench pull	68 ± 9
[20]	14	women	elite alpine skiers, members of the Swedish national alpine ski team	18–30	squat	111.5 ± 10.7
					bench press	65.5 ± 6.3
					cleans	80.2 ± 5.9

Squat strength of elite ski jumpers (112 kg) [18] was similar to elite alpine skiers with similar age (111.5 kg) [20]. Bench press strength seems higher in sprint skiers (75 kg) [19] compared to alpine skiers with similar age (65.5 kg) [20]. The highest value of lower-limb strength was reported in half-squat of well-trained cross-country skiers (120.8 kg) [14]. Finally, it should be mentioned that data are highly heterogeneous without normalization e.g., per body mass (kg/kg), which limits comparability across populations.

2.2. Muscle Power

Muscle power (Table 2) was evaluated through several jumping tests, including the squat jump (SJ), countermovement jump (CMJ), CMJ with arm swing (CMJas), repeated CMJs for 30 s (CMJ30), 10-fold standing long jump, bench jumps for 20 s, standing long jump, and triple jump. In addition, power output during the jump tests and during the 1RM assessments was calculated (Table 2). The main findings of Table 2 are presented in Section 2.6.

Table 2. Jumping performance of ski athletes.

Study	**Participants' Characteristics**				**Power Output**			
	N	**Gender**	**Level**	**Age (Years)**	**Jump Test**	**Jump Performance (cm)**	**Jump Power**	**Other Power Measurement**
[21]	47	20 men 17 women	members of the junior and European Cup alpine ski teams of the Austrian Ski Federation	women: 19.2 ± 2.3, men: 19.9 ± 1.9	SJ	women: 27.5 ± 3.1 men: 35.2 ± 3.4	presented in figure	
[17]	31	16 men 15 women	athletes who compete in national events, with 3–5 years of experience	boys: 14.6 ± 1.1 girls: 14.9 ± 1.0	CMJ	boys: 34.4 ± 7.7 girls: 29.8 ± 2.6	boys: 1495 ± 305 W or 25.5 ± 2.9 Wa/kg girls: 1266 ± 174 W or 23.5 ± 1.69 W/kg	CMJ30sec boys: 27.3 ± 5.0 cm girls: 22.6 ± 2.4 cm
[22]	334	--	207 ski jumpers and 127 Nordic combined athletes, trained athletes at various competitive levels	groups of participants from 15.7 ± 0.9 to 21.1 ± 2.8	CMJas	ski jumpers: from 44.42 ± 4.90 to 52.93 ± 5.99		
					CMJas	Nordic combined athletes: from 42.56 ± 5.58 to 49.45 ± 4.57		
[18]	16	men	athletes of the Polish national ski jumping team	18–35	SJ	54.37 ± 6		

Table 2. *Cont.*

Study	Participants' Characteristics				Power Output			
	N	Gender	Level	Age (Years)	Jump Test	Jump Performance (cm)	Jump Power	Other Power Measurement
[23]	24	12 men 12 women	elite and adolescent alpine ski racers and ski-cross athletes from the Canadian team	elite: 23.9 ± 3.0, adolescent: 17.8 ± 0.7	SJ	elite: 31.7 ± 4.2, adolescent: 29.4 ± 4.8	elite: 22.57 ± 2.80 W/kg, adolescent: 20.20 ± 3.36 W/kg	
					CMJ	elite: 35.8 ± 4.7, adolescent: 34.2 ± 6.8	elite: 28.46 ± 2.42 W/kg, adolescent: 27.24 ± 5.25 W/kg	
[14]	29	17 men 12 women	well-trained cross-country skiers from high schools for skiers in Southeastern Norway	22.1 ± 8.4	SJ	28.0 ± 5.1		
					CMJ	31.5 ± 5.5		
					CMJas	35.9 ± 5.5		
[20]	14	women	elite alpine skiers of the Swedish national alpine ski team	18–30	SJ	34.3 ± 4		
					CMJ	36.2 ± 3.9		
[19]	16	men	elite sprint skiers from the Austrian and Norwegian national/ international teams	26.4 ± 4.8	SJ	33 ± 8		Power during bench press 1RM test: 234 ± 94 W
								Power during bench pull 1RM test: 491 ± 80 W
[24]	12	women	elite alpine skiers of the Swedish national alpine ski team	18–31	CMJ	35.1 ± 5.1		

SJ: squat jump; CMJ: countermovement jump; CMJas: countermovement jumps with arm swing.

2.3. Maximal Isometric Contraction

Maximal isometric contraction (MIC) was measured in the squat, knee extension, and mid-thigh pull positions (Table 3). The rate of force development (RFD) was calculated based on the SJ force–time curve (Table 3).

Table 3. Maximal isometric contraction and rate of force development of ski athletes.

Study	Participants' Characteristics				Isometric Measurement		
	N	Gender	Level	Age (Years)	Position/Jump	MIC	RFDpeak
[25]	15	--	international alpine skiing racers	22.4 ± 2.5	squat	31.7 ± 7.8 N/kg	
[22]	334	--	207 ski jumpers and 127 Nordic combined athletes, trained athletes at various competitive levels	groups of participants from 15.7 ± 0.9 to 21.1 ± 2.8	knee extension on the right and left limbs	NC: from 10.03 ± 1.58 N/kg to 11.57 ± 1.01 N/kg; SJ: from 10.78 ± 1.40 N/kg to 12.76 ± 1.36 N/kg	
[18]	16	men	athletes of the Polish national ski jumping team	18–35	SJ		110.73 ± 13 N/s/kg
[26]	31	men	athletes of the French national alpine team	SL + GS: 23 ± 4, SG + DH: 25 ± 5	mid-thigh pull	SL + GS: 3286 ± 713 N, SG + DH: 2769 ± 459 N	
[19]	16	men	elite sprint skiers from the Austrian and Norwegian national/international teams	26.4 ± 4.8	squat	2961 ± 392 N	
					SJ		4353 ± 2408 N/s (both legs)

MIC: maximal isometric contraction; SJ: squat jump; RFD: rate of force development; NC: Nordic combined; SJ: ski jumpers; SL: slalom, GS: giant slalom; SG: super giant slalom; DH: downhill.

MIC was similar between ski jumpers and Nordic combined athletes [22]. However, the heterogeneity of data (position/jump, units) does not allow comparison of MIC or RFD among ski disciplines.

2.4. Muscle Morphology

Muscle morphology in ski athletes has been investigated in vastus lateralis, triceps brachii, biceps femoris long head, and abdominal wall muscles (Table 4). The examined morphological characteristics included muscle fiber-type distribution, muscle fiber cross-sectional area (CSA), the percentage contribution of each fiber type to total CSA (%CSA), as well as measures of muscle architecture and the anatomical CSA of individual muscles or muscle groups (Table 4).

Triceps brachii fiber-type cross-sectional area of cross-country skiers ranges between 4576–8978 μm^2 [27,28]. Vastus lateralis fiber-type cross-sectional area of cross-country skiers ranges between 5423–8970 μm^2 [28,29]. Vastus lateralis fiber-type composition of cross-country skiers ranges between 51–58% and 41–49% for type I and type II respectively [28,29]. Triceps brachii fiber-type composition of cross-country skiers ranges between 39–40% for type I and 60–61% for type II [28,29]. Nevertheless, fiber-type distribution and CSA data are not enough for comparisons among ski disciplines.

2.5. Changes in 1RM Following Resistance Training

Studies that incorporated resistance-training interventions included high-intensity strength training, and low-load resistance-training. Changes in 1RM strength were assessed in double poling, pull-down, half-squat, deep squat, triceps press, bench pull, and bench press exercises (Table 5).

1RM was increased after all resistance-training interventions reported in Table 5, even after low-load resistance training [30]. Upper body strength was mainly evaluated in cross-country skiers, reporting improvements from 9.9% in seated pull-down to 21.7% in triceps press after 8 weeks of strength training 3/week [31]. Lower body strength was increased similarly (12%) in cross-country [32] and Nordic combined [33] athletes after 12 weeks of heavy resistance training 2/week. Changes in lower-body maximal strength after resistance training have not been reported in alpine skiers, ski jumpers or sprinters.

2.6. Changes in Muscle Power Following Resistance Training

Improvements in muscle power were evaluated through performance in squat jumps, drop jumps, countermovement jumps, and the high-box test (Table 6).

CMJ performance of elite and adolescent alpine skiers (range 34.2–36.2 cm) [20,23,24] seems similar to cross-country skiers (range 31.5–34.2 cm) (Tables 2 and 6). Interestingly, junior competitive skiers reported higher CMJ performance than adult elite skiers (range 43.0–48.8 cm, Table 6), although lower values have been reported for young athletes (range 29.8–34.4 cm) [17]. SJ height is similar among alpine (range 27.5–34.3 cm) [20,21,23], cross-country (range 28.0–31.9 cm) [14] (Table 6) and sprint (33.0 cm) [19] elite skiers. Again, junior skiers performed higher values of SJ (47.7 cm) (Table 6) compared to adults. The highest jumping heights were performed from elite ski jumpers in SJ (54.4 cm) [18] and CMJas (52.3 cm) [22].

It should be mentioned that jumping performance was not always improved after strength resistance training [15,32,34]. The highest improvement was recorded in elite cross-country skiers, reporting 11.3% increase in SJ and also 8.2% increase in CMJ after 6 weeks of explosive-type strength training [35].

2.7. Changes in MIC Following Resistance Training

Changes in MIC were measured in leg extension, pull-down, leg press, knee extension, and knee flexion (Table 7). Only three training interventions assessed MIC, with data reported across eight different testing positions. Interestingly, MIC improved in the leg press (85° knee angle) and knee flexion (120° knee angle) only after a 6-week general strength training program performed 3/week in junior skiers [34]. In contrast, neither explosive nor heavy resistance training improved MIC in cross-country skiers [35,36], while no data on MIC was reported for other ski disciplines.

2.8. Changes in Muscle Morphology Following Resistance Training

Finally, muscle morphology adaptations following resistance training were examined in the vastus lateralis, triceps brachii, and quadriceps muscles (Table 8). Adaptations in muscle architecture have been assessed only in Nordic combined athletes [33]. Resistance training interventions focusing on upper-body exercises resulted in an increase in triceps brachii CSA, but not in vastus lateralis CSA, in competitive cross-country skiers [32,37]. Muscle morphology adaptations have not been reported in other ski disciplines.

Table 4. Muscle morphology and muscle fiber distribution of ski athletes.

Study	Participants' Characteristics				Muscle Morphology					
	N	Gender	Level	Age (Years)	Muscle	% Fibers	Fiber CSA (μm^2)	% CSA	Muscle Architecture	Anatomical CSA (cm^2)
[27]	10	men	skiers or candidates on the national ski team of Sweden and Denmark, systematically trained for 3–7 years	19.4 ± 2.8	vastus lateralis	Type I: 68.6 ± 8.2, Type IIa: 27.6 ± 6.9, Type IIx: 3.8 ± 2.6	Type I: 6065 ± 1179 Type IIa: 6255 ± 1108 Type IIx: 5518 ± 711	Type I: 68.0 ± 9.4 Type IIa: 28.6 ± 8.6 Type IIx: 3.4 ± 2.2		
					triceps brachii	Type I: 51.3 ± 13.2, Type IIa: 46.1 ± 13.2, Type IIx: 2.6 ± 3.2	Type I: 5678 ± 1182 Type IIa: 8978 ± 2204 Type IIx: 5554 ± 3969	Type I: 41.1 ± 14.7 Type IIa: 56.4 ± 15.1 Type IIx: 2.5 ± 3.1		
[28]	10	men	elite Norwegian cross-country skiers at national level (systematically trained for an average of 11 years)	22 ± 1	vastus lateralis	MHC-I: 58 ± 2, MHC-IIa: 41 ± 2, MH-IIx: 1.0 ± 0.4	Type I: 5423 ± 272 Type IIa: 6811 ± 297 Type IIx: 6590 ± 363 Type IIa/x: 5840 ± 518			
					triceps brachii	MHC-I: 40 ± 3, MHC-IIa: 60 ± 3, MHC-IIx: 0.4 ± 0.2	Type I: 5356 ± 200 Type IIa: 8105 ± 394, Type IIx: 6125 ± 960 Type IIa/x: 4576 ± 176			
[29]	8	men	cross-country skiers who competed in sprint and distance races at the national or international level	24 ± 4	vastus lateralis	MHC-I: 51 ± 12, MHC-II: 49 ± 12	MHC I: 8970 ± 1906, MHC II: 8211 ± 1382			
					triceps brachii	MHC-I: 39 ± 6, MHC-II: 61 ± 6	MHC I: 7619 ± 2566, MHC II: 8807 ± 2142			
[38]	95	33 girls 62 boys	competitive alpine skiers of the Swiss National Skiing Association	14.8 ± 0.6	biceps femoris long head				fascicle length: 9.2 ± 1.3 cm pennetion angle: 11.0 ± 2.3° muscle thickness: 1.9 ± 0.3 cm	8.2 ± 1.5
[39]	22	11 boys 11 girls	elite alpine skiers who compete at both national and international levels	women: 17.3 ± 1.35 men: 16.6 ± 0.5	abdominal wall muscles				muscle thickness women: from 3.47 ± 0.7 mm to 12.7 ± 1.46 mm, men: from 4.04 ± 0.9 mm to 16.4 ± 2.22 mm	
[40]	33	10 women 13 men	elite alpine skiers, members of a national ski squad	women: 21.5 ± 2.6, men: 23.0 ± 2.5	hamstrings					women: 44.19 ± 5.18 men: 54.10 ± 5.56
					quadriceps					women: 91.22 ± 11.52 men: 111.45 ± 20.95

CSA: Cross-sectional area; % CSA: Percentage muscle fiber cross-sectional area.

Table 5. Changes in maximal strength (1RM) after strength resistance training in ski athletes.

Study	Participants' Characteristics				Intervention			1RM			
	N	Gender	Level	Age (Years)	Type of Training	Duration	Frequency	Exercise	Pre (kg)	Post (kg)	*p*
[11]	8	women	cross-country skiers, competing at the regional level in Norway	17.8 ± 0.4	high-intensity strength training	9 weeks	3/week	double poling	24.8 ± 1.0	28.4 ± 1.2	<0.05
[36]	19	men	highly trained cross-country skiers	21.0 ± 1.6	high resistance-training	9 weeks	3/week	pull-down	43.8 ± 3.8	53.4 ± 3.4	<0.00
[32]	9	3 women 6 men	competitive cross-country skiers	21.2 ± 3.2	heavy strength training	12 weeks	2/week	seated pull-down	increase 19 ± 2%		<0.01
								half-squat	increase 12 ± 2%		<0.01
[33]	8	men	national or international level Norwegian Nordic combined athletes	19 ± 2	heavy strength training	12 weeks	2/week	deep squat	increase 12 ± 2%		<0.01
								seated pull-down	increase 23 ± 5%		<0.01
[31]	21	men	well-trained cross-country skiers	23 ± 4	strength training intervention	8 weeks	3/week	seated pull-down	96.8 ± 12.2	increase 9.9 ± 4.4%	<0.01
								triceps press	36.6 ± 4.6	increase 21.7 ± 10.8%	<0.01
[30]	15	not mentioned	cross-country skiers and biathletes	16 ± 2	low-load or high-load resistance training	10 weeks	2/week	bench pull	low load: 36.7 ± 7.4, high load: 48.8 ± 6.3	low load: 42.5 ± 8.7, high load: 55.8 ± 7.5	<0.00
								bench press	low-load: 32.9 ± 8.7, high load: 43.1 ± 7.2	low load: 35.8 ± 8.3, high load: 48.9 ± 8.9	<0.00

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Table 6. Changes in muscle power after strength resistance training in ski athletes.

	Participants' Characteristics				Intervention		Jump Performance (Height)				Jump Peak Power		
Study	N	Gender	Level	Age (Years)	Duration	Frequency	Test	Pre	Post	*p*	Pre	Post	*p*
[35]	7	men	Finnish cross-country skiers at a national level	19.8 ± 1.8	6 weeks	6–9/week	SJ	31.9 ± 2.8 cm	35.5 ± 3.0 cm	<0.01			
							CMJ	34.2 ± 2.6 cm	37.0 ± 2.8 cm	<0.01			
[41]	16	8 boys 8 girls	competitive skiers	12.9 ± 1.5	3 weeks	3/week	high-box test	number of repetitions: 49.8 ± 12.9	number of repetitions: 55.2 ± 17.4	<0.05			
[34]	7	girls	junior skiers from the Swiss winter-sport development school	15–20	6 weeks	3/week	CMJ	48.4 ± 6.1 cm	49.9 ± 7.1 cm	ns	53.9 ± 6.5 W/kg	54.7 ± 7.1	ns
							SJ	47.7 ± 7.1 cm	45.7 ± 6.6 cm	<0.05	56.5 ± 7.3 W/kg	54.9 ± 7.7	<0.05
							DJ	27.7 ± 7.9 cm	26.8 ± 5.9	ns	203 ± 21 W/kg	198 ± 10	ns
[42]	20	10 boys 10 girls	athletes competed in national Alpine skiing events with 3–5 years of experience	14.7 ± 1.04 years	2 years	3/week	CMJ	Increase (no data)		<0.05	Increase (no data)		<0.05
							CMJ (15″)				increase for boys only (no data)		<0.05
[32]	9	3 women 6 men	competitive cross-country skiers	21.2 ± 3.2	12 weeks	2/week	CMJ	increase 1.7 ± 2.4%		ns			
[33]	8	men	national or international level Norwegian Nordic combined athletes	19 ± 2	12 weeks	2/week	SJ	increase 8.8 ± 1.7%		<0.01			
[43]	12	men	Italian elite junior skiers	18 ± 1	8 weeks	2/week	CMJ	43.0 ± 9.3 cm	43.8 ± 10.6 cm	ns			
							DJ	35.4 ± 10.4 cm	35.7 ± 10.7 cm	ns			

SJ: squat jump; CMJ: countermovement jump; DJ: drop jump.

Table 7. Changes in maximal isometric contraction after strength resistance training in ski athletes.

Study	Participants' Characteristics				Intervention						
	N	Gender	Level	Age (Years)	Type of Training	Duration	Frequency	Position	Pre	Post	*p*
[35]	7	men	Finnish cross-country skiers at a national level	19.8 ± 1.8	explosive type strength training	6 weeks	6–9/week	knee extension	2626 ± 726 N	2518 ± 702 N	ns
[36]	19	men	highly trained cross-country skiers	21.0 ± 1.6	high resistance training	9 weeks	3/week	pull-down	no data	no data	no data
[34]	7	girls	junior skiers from the Swiss winter-sport development school	15–20	resistance training	6 weeks	3/week	leg press (85° knee angle)	1100 ± 279 N	1233 ± 226	<0.05
								leg press (100° knee angle)	1658 ± 279 N	1745 ± 341	ns
								knee extension (120° knee angle)	282 ± 37 N	277 ± 52	ns
								knee extension (135° knee angle)	221 ± 25 N	212 ± 55	ns
								knee flexion (120° knee angle)	146 ± 20 N	131 ± 19	<0.05
								knee flexion (135° knee angle)	150 ± 19 N	145 ± 11	ns

Table 8. Changes in muscle morphology after strength resistance training in ski athletes.

Study	Participants' Characteristics				Intervention			Muscle Morphology			
	N	Gender	Level	Age (Years)	Type of Training	Weeks	Frequency	Measurement	Pre	Post	*p*
[37]	6	men	competitive cross-country skiers with >6 years of competition in cross-country skiing	19 ± 1	general strength training	20 weeks	2/week	triceps brachii CSA Type I	5900 ± 503 μm^2	6567 ± 496 μm^2	<0.05
								triceps brachii CSA Type IIA	7567 ± 578 μm^2	9383 ± 779 μm^2	<0.05
								vastus lateralis CSA Type I	6100 ± 267 μm^2	6000 ± 403 μm^2	ns
								vastus lateralis CSA Type IIA	6800 ± 403 μm^2	6900 ± 365 μm^2	ns
[32]	9	3 women 6 men	competitive cross-country skiers	21.2 ± 3.2	heavy strength training	12 weeks	2/week	triceps brachii CSA	increase 5.5 ± 2.1%		<0.01
								quadriceps CSA	no data		ns
[33]	8	men	national or international level Norwegian Nordic combined athletes	19 ± 2	heavy strength training	12 weeks	2/week	vastus lateralis thickness	increase 7.4 ± 2.7%		<0.05
								vastus lateralis fascicle angle	22.1 ± 1.0°	22.8 ± 1.1°	ns
								vastus lateralis fascicle length	6.6 ± 0.4 cm	6.8 ± 0.3 cm	ns

CSA: Cross-sectional area.

3. Discussion

The purpose of the present review was to describe the existing findings on maximal upper- and lower-body strength, muscle power, maximal isometric contraction and rate of force development, as well as muscle morphology across different ski disciplines. In addition, we reported the documented changes in these neuromuscular parameters following the integration of resistance-training programs into regular sport-specific training routines.

The highest maximal-strength values were observed in the squat exercise among adult cross-country skiers, with a reported mean of 121 kg (17 men, 12 women, mean body mass 69 ± 9 kg, strength-to-body mass ratio 1.75 kg/kg) [14]. To better interpret the magnitude of this value, comparisons with other populations are informative. Physically active healthy women typically achieve approximately 100–133 kg in the 1RM half-squat test (strength-to-body-mass ratio 1.66–2.26 kg/kg) [44,45]. In contrast, elite female weightlifters in the −64 kg weight class have been shown to reach maximal squat values of up to 185 kg (strength-to-body mass ratio 2.89 kg/kg), whereas elite male weightlifters in the −72 kg weight class can reach approximately 243 kg (strength-to-body mass ratio 3.38 kg/kg) [46]. Although weightlifting training focuses on resistance training at a different level compared to skiing, these comparisons indicate that the highest lower-body maximal-strength value found in cross-country skiers is relatively low. This finding may emphasize that cross-country performance is strongly dependent on lower-body technique. Additionally, cross-country training predominantly focuses on aerobic endurance rather than maximal-strength development, which may partly explain these results. However, considering that 1RM squat performance is associated with key endurance-related outcomes, including time to exhaustion in double poling, VO_2max, and maximal aerobic speed in cross-country skiing [14], greater emphasis should likely be placed on improving maximal lower-body strength within ski-specific training programs. One previous study reported that 12 weeks of heavy strength training performed twice per week can induce approximately a 12% increase in squat performance [32]. Unfortunately, the maximal-strength characteristics of alpine skiers, sprint skiers, and ski jumpers remain poorly documented, highlighting the need for further research to define their maximal-strength profiles.

Upper-body strength is also a key factor for cross-country skiing performance. Pull-down performance also correlates with physiological and performance indicators in cross-country skiers [42]. The highest pull-down values reported in the literature come from well-trained cross-country skiers who demonstrated a mean seated pull-down performance of 97 kg (strength-to-body mass ratio 1.24 kg/kg, Table 1) [31]. Indeed, upper-body contribution plays a crucial role in double poling, even exceeding that of the lower body [47], which may explain the relatively high levels of upper-body strength observed in cross-country skiers. Moreover, resistance-training interventions targeting the upper body appear to be effective: an 8-week strength-training program produced approximately a 10% increase in pull-down strength (Table 5) [31].

Laboratory-based assessments of jumping performance were, as expected, higher in ski jumpers, who demonstrated mean values of 53 cm in the CMJas (Table 2) [22], and 54 cm in the SJ (Table 2) [18]. These values are considered exceptionally high, given that elite high jumpers typically achieve mean CMJ heights (without arm swing) of 43 cm in men and 33 cm in women [48]. Likewise, elite throwers reach CMJ performances of 32–33 cm [49]. Alpine skiers also appear to possess relatively strong jumping capabilities, exhibiting mean CMJ heights of 36 cm (Table 2) [23]. The combined demands for strength and power in ski jumping may explain the high performance observed in jumping tests. In addition, the contribution of equipment mass and snow friction during each jump likely increases the overall mechanical demands, thereby requiring greater muscle power output. These factors may contribute to enhanced neuromuscular adaptations in ski jumpers compared to non-ski power athletes. Among the resistance-training interventions included in the literature, the most effective improvement in jump performance was reported in cross-country skiers by Paavolainen et al. [35] (Table 6). Their program incorporated explosive-type strength training, consisting of various jump exercises performed with low external loads and high movement velocity alongside squat lifts, which resulted in approximately 18% increase in SJ performance and 8% increase in CMJ performance. Despite these findings, resistance-training interventions specifically targeting muscle power in jumping skiers and alpine skiers remain limited, and additional studies are needed to establish more clearly optimal training strategies for enhancing explosive performance in these populations.

MIC has been insufficiently investigated in ski athletes. The highest MIC values were observed in alpine skiers and sprint skiers, reaching moderate levels of approximately 3000 N in mid-thigh pull and squat positions (Table 3). For comparison, elite weightlifters can produce around 5000 N during isometric leg-press efforts [50], whereas physically active healthy women typically reach approximately 1800 N [45]. The moderate-to-high MIC values observed in alpine skiers may be explained by the substantial isometric demands placed on the outside limb during turning [15], while sprint skiers rely on powerful isometric contractions during the initial phase of the course [9,10]. RFD has been assessed exclusively during jumping tasks in the existing literature; however, no studies have examined RFD during isometric efforts in ski athletes. Future research should evaluate isometric RFD and determine its contribution to ski performance across different disciplines.

Vastus lateralis muscle fiber distribution has been examined in cross-country skiers (Table 4) [28] as well as in mixed groups of ski athletes from various disciplines, including sprint, long-distance, and alpine skiing (Table 4) [27,29]. Overall, findings show that type I muscle fibers predominate in the vastus lateralis of elite skiers, although the magnitude of this predominance varies—ranging from a small difference of about 2% [29] to a larger difference of approximately 35% [27] compared with type II fibers. Still, discipline-specific comparisons of vastus lateralis fiber composition are needed, given the distinct mechanical and metabolic demands across ski events. In the upper body, triceps brachii fiber distribution in high-level cross-country skiers appears to consist of roughly 60% type II and 40% type I fibers (Table 4). The proportion of type IIx muscle fibers in the vastus lateralis and triceps brachii ranges from 0.4% to 3.8%. It is well established that type IIx fibers can transition to type IIa fibers in response to exercise training [1]. Therefore, the neuromuscular demands of ski training may promote this fiber-type transformation, which could explain the relatively low proportion of type IIx fibers observed in ski athletes. The CSA of type I and type IIa fibers range between 5500 and 8000 μm^2, values that align with those reported in other athletic populations involved in endurance- or strength-dominant sports [51].

Muscle architecture has been sparsely investigated in ski athletes. Vastus lateralis fascicle length is approximately 8 cm long with pennation angle of 13° in non-athletic populations [52]. In contrast, Rønnestad et al. [40] reported shorter fascicle lengths (6.6 cm) and greater pennation angles (22°) in the vastus lateralis of international level Nordic combined athletes, suggesting that long-term ski training may be associated with increased pennation angle and reduced fascicle length. Notably, these architectural characteristics did not change following 12 weeks of heavy strength training in the same population [33]. Additional studies are therefore needed to further elucidate muscle architectural adaptations in ski athletes.

The present review outlines several key neuromuscular characteristics of ski athletes; however, important parameters such as muscle mass, electromyographic activity, and markers of muscle fatigue remain insufficiently documented in this literature. Furthermore, no quantitative statistical analyses, such as effect size calculations or assessments of gender-based differences, were conducted in this review. Therefore, the findings of the present review are primarily descriptive, lacking statistical comparisons across groups such as ski disciplines or age categories, which limit their interpretability. In addition, variability in participant characteristics among studies, particularly in terms of training experience and age, increases data heterogeneity. It should also be noted that the resistance-training protocols included across the examined studies varied substantially with respect to exercise selection, training loads, volume, and repetitions. Detailed descriptions of these protocols are not provided here, as such analysis fell outside the scope of the present work. Finally, the method used to obtain quantitative parameters has not been verified; therefore, some values may vary.

Several studies also examined the effects of the resistance-training interventions on performance-related outcomes. Performance was primarily assessed using VO_2max tests conducted on double poling ski ergometers or treadmills. However, evaluation of actual race performance has not been measured, although it is the most important outcome for competitive athletes. Future research should therefore examine whether improvements in neuromuscular characteristics following resistance-training interventions translate into enhanced competitive performance. In addition, key training details such as the time of year during which the program is implemented, the total duration of the intervention, and the primary training objective (e.g., maximal strength, power, or endurance) should be clearly specified.

4. Materials and Methods

A manual search procedure was performed in November 2025 through electronic databases, Pubmed and Google Scholar. No filters and limits were used during search. The key words used were: rate of force development, maximal strength, 1RM, power, muscle power, explosive, strength, muscle hypertrophy, muscle cross-sectional area, fiber type, muscle architecture, fascicle length, muscle thickness, fascicle angle, muscle morphology, ultrasonography, resistance training, strength training, together with the word “ski” separated with a comma.

The inclusion criteria of the studies were: (i) the participants were experienced ski athletes, (ii) the athletes were active taking part in races in the year of the measurements, (iii) age $\leq$ 35 years without specific gender or ethnicity, (iv) at least one test was evaluated in the study including maximal strength, muscle power, isometric strength, rate of force development, muscle architecture and muscle fiber type and cross-sectional area, (v) training intervention studies included only resistance training (of any type) with a duration of at least 3 weeks, (vi) data was presented as group means, (vii) peer-review original articles. The exclusion criteria were: (i) non-English publications, (ii) conference abstracts, (iii) narrative reviews, systematic reviews, and meta-analyses.

For each database, the first 20 studies were initially retrieved. Titles and abstracts were then screened to assess eligibility based on the inclusion criteria, and duplicate records were removed during this process. Subsequently, full-text articles were reviewed to determine final eligibility according to the predefined inclusion and exclusion criteria. The screening and selection process was conducted solely by the first author, and no automated tools were used.

5. Conclusions

In conclusion, despite the heterogeneity of the included studies, the neuromuscular characteristics investigated in the present study appear to correspond with sport-specific demands, which vary across ski disciplines. Alpine skiers exhibit moderate to high MIC, likely reflecting the substantial isometric demands placed on the outside limb during turning. Ski jumpers are distinguished by high muscle power, as evidenced by jumping performance. Cross-country skiers display moderate lower-body strength, suggesting a greater reliance on technique, and high upper-body strength, which is closely associated with performance. Resistance training has been shown to improve these neuromuscular parameters; therefore, training programs tailored to the specific demands of each discipline are recommended. Alpine skiers may benefit from incorporating isometric contractions into their resistance training, whereas explosive training is advised for ski jumpers to enhance muscle power. Strength training targeting both upper and lower body is suggested for cross-country skiers. However, muscle morphology remains poorly investigated in ski athletes. Further research is needed to better characterize neuromuscular profiles and to examine adaptations to resistance training across different ski disciplines.

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Abbreviations

The following abbreviations are used in this manuscript:

1RM	one-repetition maximum
SJ	squat jump
CMJ	countermovement jump
CMJas	countermovement jump with arm swing
CMJ_{30}	countermovement jump for 30 s
MIC	maximal isometric contraction
RFD	rate of force development
CSA	cross-sectional area
%CSA	percentage cross-sectional area

References

1. Andersen, J.L.; Aagaard, P. Effects of strength training on muscle fiber types and size; consequences for athletes training for high-intensity sport. *Scand. J. Med. Sci. Sports* **2010**, *20*, 32–38. [CrossRef] [PubMed]
2. Müller, E. Training muscle strength. *Ergonomics* **1959**, *2*, 216–222. [CrossRef]
3. Josephson, R.K. Dissecting muscle power output. *J. Exp. Biol.* **1999**, *202*, 3369–3375. [CrossRef] [PubMed]
4. Beachle, T.R.; Earle, R.W.; Wathen, D. *Resistance Training*; Human Kinetics: Champaign, IL, USA, 2000; pp. 395–425.
5. Cormie, P.; McGuigan, M.R.; Newton, R.U. Developing maximal neuromuscular power: Part 2—Training considerations for improving maximal power production. *Sports Med.* **2011**, *41*, 125–146. [CrossRef]
6. Blazevich, A.J. Effects of physical training and detraining, immobilisation, growth and aging on human fascicle geometry. *Sports Med.* **2006**, *36*, 1003–1017. [CrossRef]
7. Ingjer, F. Development of maximal oxygen uptake in young elite male cross-country skiers: A longitudinal study. *J. Sports Sci.* **1992**, *10*, 49–63. [CrossRef]
8. Tønnessen, E.; Haugen, T.A.; Hem, E.; Leirstein, S.; Seiler, S. Maximal aerobic capacity in the winter-Olympics endurance disciplines: Olympic-medal benchmarks for the time period 1990–2013. *Int. J. Sports Physiol. Perform.* **2015**, *10*, 835–839. [CrossRef]
9. Virmavirta, M.; Komi, P.V. Electromyographic analysis of muscle activation during ski jumping performance. *J. Appl. Biomech.* **1991**, *7*, 175–182. [CrossRef]
10. Huang, Y.; Jiang, L.; Chen, X.; Sun, Q.; Zhang, X.; Tan, X.; Du, Y.; Zhang, F.; Wang, N.; Su, R.; et al. Musculoskeletal simulation of professional ski jumpers during take-off considering aerodynamic forces. *Front. Bioeng. Biotechnol.* **2023**, *11*, 1241135. [CrossRef]
11. Hoff, J.; Helgerud, J.; Wisloeff, U. Maximal strength training improves work economy in trained female cross-country skiers. *Med. Sci. Sports Exerc.* **1999**, *31*, 870–877. [CrossRef]
12. Therell, T.; Jansson, D.; Theos, A. Effects of Core Strength Training on Skiing Economy in Elite Junior Cross-Country Skiers. *Res. Q. Exerc. Sport.* **2022**, *93*, 608–614. [CrossRef] [PubMed]

13. Stöggl, T.; Schwarzl, C.; Müller, E.E.; Nagasaki, M.; Stöggl, J.; Scheiber, P.; Schönfelder, M.; Niebauer, J. A comparison between alpine skiing, cross-country skiing and indoor cycling on cardiorespiratory and metabolic response. *J. Sports Sci. Med.* **2016**, *15*, 184. [PubMed]
14. Johansen, J.-M.; Goleva-Fjellet, S.; Sunde, A.; Gjerløw, L.E.; Skeimo, L.A.; Freberg, B.I.; Sæbø, M.; Helgerud, J.; Støren, Ø. No change–no gain; the effect of age, sex, selected genes and training on physiological and performance adaptations in cross-country skiing. *Front. Physiol.* **2020**, *11*, 581339. [CrossRef] [PubMed]
15. Alhammoud, M.; Hansen, C.; Meyer, F.; Hautier, C.; Morel, B. On-field ski kinematic according to leg and discipline in elite alpine skiers. *Front. Sports Act. Living* **2020**, *2*, 56. [CrossRef]
16. Terzis, G.; Stratakos, G.; Manta, P.; Georgiadis, G. Throwing per formance after resistance training and detraining. *J. Strength Cond. Res.* **2008**, *22*, 1198–1204. [CrossRef]
17. EÁlvarez-San Emeterio, C.; González-Badillo, J.J. The physical and anthropometric profiles of adolescent alpine skiers and their relationship with sporting rank. *J. Strength Cond. Res.* **2010**, *24*, 1007–1012. [CrossRef]
18. Gołaś, A.; Wilk, M.; Stastny, P.; Maszczyk, A.; Pajerska, K.; Zając, A. Optimizing half squat postactivation potential load in squat jump training for eliciting relative maximal power in ski jumpers. *J. Strength Cond. Res.* **2017**, *31*, 3010–3017. [CrossRef]
19. Stöggl, T.; Mueller, E.; Ainegren, M.; Holmberg, H.C. General strength and kinetics: Fundamental to sprinting faster in cross country skiing? *Scand. J. Med. Sci. Sports* **2011**, *21*, 791–803. [CrossRef]
20. Nilsson, R.; Theos, A.; Lindberg, A.S.; Ferguson, R.A.; Malm, C. Lack of predictive power in commonly used tests for performance in alpine skiing. *Sports Med. Int. Open* **2021**, *5*, E28–E36. [CrossRef]
21. Patterson, C.; Raschner, C.; Platzer, H.P. Power variables and bilateral force differences during unloaded and loaded squat jumps in high performance alpine ski racers. *J. Strength Cond. Res.* **2009**, *23*, 779–787. [CrossRef]
22. Janura, M.; Cabell, L.; Svoboda, Z.; Elfmark, M. Evaluation of explosive power performance in ski jumpers and Nordic combined competitive athletes: A 19-year study. *J. Strength Cond. Res.* **2016**, *30*, 71–80. [CrossRef] [PubMed]
23. Jordan, M.J.; Aagaard, P.; Herzog, W. A comparison of lower limb stiffness and mechanical muscle function in ACL-reconstructed, elite, and adolescent alpine ski racers/ski cross athletes. *J. Sport Health Sci.* **2018**, *7*, 416–424. [CrossRef] [PubMed]
24. Nilsson, R.; Theos, A.; Lindberg, A.S.; Malm, C. Predicting competitive alpine skiing performance by multivariable statistics—The need for individual profiling. *Front. Sports Act. Living* **2025**, *6*, 1505482. [CrossRef] [PubMed]
25. Rahmani, A.; Viale, F.; Dalleau, G.; Lacour, J.R. Force/velocity and power/velocity relationships in squat exercise. *Eur. J. Appl. Physiol.* **2001**, *84*, 227–232. [CrossRef]
26. Cross, M.R.; Rivière, J.R.; Coulmy, N.; Morin, J.B.; Samozino, P. Lower limb force-production capacities in alpine skiing disciplines. *Scand. J. Med. Sci. Sports* **2021**, *31*, 848–860. [CrossRef]
27. Mygind, E. Fibre characteristics and enzyme levels of arm and leg muscles in elite cross-country skiers. *Scand. J. Med. Sci. Sports* **1995**, *5*, 76–80. [CrossRef]
28. Ørtenblad, N.; Nielsen, J.; Boushel, R.; Söderlund, K.; Saltin, B.; Holmberg, H.C. The muscle fiber profiles, mitochondrial content, and enzyme activities of the exceptionally well-trained arm and leg muscles of elite cross-country skiers. *Front. Physiol.* **2018**, *9*, 1031. [CrossRef]
29. Gejl, K.D.; Hvid, L.G.; Andersson, E.P.; Jensen, R.; Holmberg, H.C.; Ørtenblad, N. Contractile properties of MHC I and II fibers from highly trained arm and leg muscles of cross-country skiers. *Front. Physiol.* **2021**, *12*, 682943. [CrossRef]
30. Wagner, C.M.; Sandbakk, Ø.; Röhrs, D.; Schiemann, S.; Schmidt, T.; Keiner, M. High-Volume resistance training improves Double-Poling peak oxygen uptake in youth elite Cross-Country skiers and biathletes: A pilot study. *Appl. Sci.* **2024**, *14*, 2774. [CrossRef]
31. Øfsteng, S.; Sandbakk, Ø.; van Beekvelt, M.; Hammarström, D.; Kristoffersen, R.; Hansen, J.; Paulsen, G.; Rønnestad, B.R. Strength training improves double-poling performance after prolonged submaximal exercise in cross-country skiers. *Scand. J. Med. Sci. Sports* **2018**, *28*, 893–904. [CrossRef]
32. Losnegard, T.; Mikkelsen, K.; Rønnestad, B.R.; Hallén, J.; Rud, B.; Raastad, T. The effect of heavy strength training on muscle mass and physical performance in elite cross country skiers. *Scand. J. Med. Sci. Sports* **2011**, *21*, 389–401. [CrossRef] [PubMed]
33. Rønnestad, B.R.; Kojedal, Ø.; Losnegard, T.; Kvamme, B.; Raastad, T. Effect of heavy strength training on muscle thickness, strength, jump performance, and endurance performance in well-trained Nordic Combined athletes. *Eur. J. Appl. Physiol.* **2012**, *112*, 2341–2352. [CrossRef] [PubMed]
34. Gross, M.; Lüthy, F.; Kroell, J.; Müller, E.; Hoppeler, H.; Vogt, M. Effects of eccentric cycle ergometry in alpine skiers. *Int. J. Sports Med.* **2010**, *31*, 572–576. [CrossRef] [PubMed]
35. Paavolainen, L.; Häkkinen, K.; Rusko, H. Effects of explosive type strength training on physical performance characteristics in cross-country. *Eur. J. Appl. Physiol. Occup. Physiol.* **1991**, *62*, 251–255. [CrossRef]
36. Østerås, H.; Helgerud, J.; Hoff, J. Maximal strength-training effects on force-velocity and force-power relationships explain increases in aerobic performance in humans. *Eur. J. Appl. Physiol.* **2002**, *88*, 255–263. [CrossRef]

37. Terzis, G.; Stattin, B.; Holmberg, H.C. Upper body training and the triceps brachii muscle of elite cross country skiers. *Scand. J. Med. Sci. Sports* **2006**, *16*, 121–126. [CrossRef]
38. Fitze, D.P.; Franchi, M.V.; Fröhlich, S.; Frey, W.O.; Spörri, J. Biceps femoris long head morphology in youth competitive alpine skiers is associated with age, biological maturation and traumatic lower extremity injuries. *Front. Physiol.* **2022**, *13*, 947419. [CrossRef]
39. Romero-Morales, C.; Villafañe, J.H.; Jácome-López, R.; Tullio, M.; Strelczuk, A.; Miñambres-Martín, D.; Lara-Cabrero, J.L.; Jiménez-Sáiz, S.L. Gender differences in core muscle morphology of elite alpine skiers: Insights from ultrasonography. *Sensors* **2024**, *24*, 4073. [CrossRef]
40. Fitze, D.P.; Franchi, M.V.; Müller Brusco, C.; Engeler, N.; Frey, W.O.; Spörri, J. Hamstrings and quadriceps muscle size and strength in female and male elite competitive alpine skiers. *Front. Physiol.* **2025**, *15*, 1444300. [CrossRef]
41. Mahieu, N.N.; Witvrouw, E.; Van de Voorde, D.; Michilsens, D.; Arbyn, V.; Van den Broecke, W. Improving strength and postural control in young skiers: Whole-body vibration versus equivalent resistance training. *J. Athl. Train.* **2006**, *41*, 286.
42. Álvarez-San Emeterio, C.; Antuñano, N.P.G.; López-Sobaler, A.M.; González-Badillo, J.J. Effect of strength training and the practice of Alpine skiing on bone mass density, growth, body composition, and the strength and power of the legs of adolescent skiers. *J. Strength Cond. Res.* **2011**, *25*, 2879–2890. [CrossRef] [PubMed]
43. Vitale, J.A.; La Torre, A.; Banfi, G.; Bonato, M. Effects of an 8-week body-weight neuromuscular training on dynamic balance and vertical jump performances in elite junior skiing athletes: A randomized controlled trial. *J. Strength Cond. Res.* **2018**, *32*, 911–920. [CrossRef] [PubMed]
44. Spiliopoulou, P.; Zaras, N.; Methenitis, S.; Papadimas, G.; Papadopoulos, C.; Bogdanis, G.C.; Terzis, G. Effect of concurrent power training and high-intensity interval cycling on muscle morphology and performance. *J. Strength Cond. Res.* **2021**, *35*, 2464–2471. [CrossRef]
45. Methenitis, S.K.; Mpampoulis, T.; Spiliopoulou, P.; Papadimas, G.; Papadopoulos, C.; Chalari, E.; Evangelidou, E.; Stasinaki, A.-N.; Nomikos, T.; Terzis, G. Muscle fiber composition; jumping performance, and rate of force development adaptations induced by different power training volumes in females. *Appl. Physiol. Nutr. Metab.* **2020**, *45*, 996–1006. [CrossRef] [PubMed]
46. Ferland, P.M.; Comtois, A.S. Classic powerlifting performance: A systematic review. *J. Strength Cond. Res.* **2019**, *33*, S194–S201. [CrossRef]
47. Holmberg, H.C.; Lindinger, S.; Stöggl, T.; Eitzlmair, E.; Müller, E. Biomechanical analysis of double poling in elite cross-country skiers. *Med. Sci. Sports Exerc.* **2005**, *37*, 807–818. [CrossRef]
48. Philpott, L.K.; Forrester, S.E.; van Lopik, K.A.; Hayward, S.; Conway, P.P.; West, A.A. Countermovement jump performance in elite male and female sprinters and high jumpers. *Proceedings of the Institution of Mechanical Engineers. J. Sports Eng. Technol.* **2021**, *235*, 131–138. [CrossRef]
49. Zaras, N.D.; Stasinaki, A.-N.E.; Krase, A.A.; Methenitis, S.K.; Karampatsos, G.P.; Georgiadis, G.V.; Spengos, K.M.; Terzis, G.D. Effects of tapering with light vs. heavy loads on track and field throwing performance. *J. Strength Cond. Res.* **2014**, *28*, 3484–3495. [CrossRef]
50. Zaras, N.; Stasinaki, A.N.; Spiliopoulou, P.; Arnaoutis, G.; Hadjicharalambous, M.; Terzis, G. Rate of force development, muscle architecture, and performance in elite weightlifters. *Int. J. Sports Physiol. Perform.* **2020**, *16*, 216–223. [CrossRef]
51. Missina, S.S.; Kriuchkov, A.S.; Dikunets, M.A.; Myakinchenko, E.B. Cross-Sectional Areas of Various Muscle Fibers in Skeletal Muscles of Athletes Training for Endurance, Strength, or Speed-Strength. *Hum. Physiol.* **2022**, *48*, 535–545. [CrossRef]
52. Friederich, J.A.; Brand, R.A. Muscle fiber architecture in the human lower limb. *J. Biomech.* **1990**, *23*, 91–95. [CrossRef]