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Applied Physiology of Amateur Wrestling

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Contents

Summary The general physiological profile of the successful wrestler is of one having high anaerobic power (mean range of 6.1 to 7.5 W/kg for arms; mean range of 11.5 to 19.9 W/kg for legs); high anaerobic capacity (range for arms 4.8 to 5.2 W/kg; range for legs 7.4 to 8.2 W/kg); high muscular endurance; average to above average aerobic power (range 52 to 63 ml/kg/min); average pulmonary function (range 1.90 to 2.02 L/kg/min for $\dot{V}_{Emax}$); normal flexibility; a high degree of leanness (range 3.7 to 13.0% fat) excluding heavyweights; and a somatotype that emphasises mesomorphy. Training methods include wrestling, and nonwrestling activities for increasing strength and power (i.e. resistance training), and to improve cardiovasular fitness (i.e. endurance training). Unfortunately, data on the isolated effects of wrestling on fitness and the type of training programme most effective for success in wrestling are scarce. The practice of weight loss is commonly used by wrestlers to enhance performance. Rapid weight loss has profound adverse effects on the wrestler's physiology but little effect on strength or anaerobic power performance as measured in the laboratory. In contrast, muscular endurance appears to be impaired by the rapid weight loss. Current research on weight loss and performance in wrestlers has taken 2 directions: (a) towards nutritional treatments to prevent suboptimal muscular endurance, and (b) towards the development of programmes to estimate minimal weight based on body composition techniques and thereby prevent weight reductions.

Wrestling is frequently acknowledged as the oldest of all sports. It was one of the few original events in the ancient Olympics and its heritage can be traced across cultures, from pictures alongside Egyptian hieroglyphics to the murals in Chinese tombs (Kent 1968). Today, 2 styles of the sport are common to almost all cultures: Graeco-Roman, the classic style in which only upper body moves are allowed, and freestyle, which includes upper body and leg wrestling, are offered in Olympic and other international competition.

In all styles of wrestling, the objective is to establish physical control over the opponent, but the means of deciding which wrestler meets this objective varies among the national styles of wrestling. Furthermore, the criteria for winning have changed periodically at the international level. For example, in the ancient Olympics, victory was recognised when one competitor verbally surrendered to the other. Today, the champion of an international bout is decided by either a fall (when an opponent's scapulae are held to the mat for a moment) or, if no fall occurs, by a scoring system that quantifies which wrestler is most superior in respect to controlling the opponent. Along with the variations in the scoring system the match duration differs among styles and eras. The time limit has varied from 'no limit' in the ancient Olympics to 15 minutes in the 1950s to only 5 minutes in current international competition.

Modifications in the scoring system and match duration may dictate the type of athlete who will be successful in wrestling. Periodic rule changes may also influence the methods of training used by successful wrestlers. In this review, the profile of physiological capacities of amateur wrestlers is examined with the intent of identifying attributes that are important for success. The methods and effects of training for wrestling are also discussed. Finally, the weight loss practices of wrestlers are reviewed. The latter topic is significant because competitors must have a specified bodyweight (weight class) to be eligible to compete and because of the perception among wrestlers and coaches that weight reduction is necessary for success.

This paper focuses on physiological issues as they apply to competition at the senior wrestler international level. However, because data from this group are limited, inferences are also drawn from age-group, junior level and collegiate wrestlers, particularly from the US.

1. Profile of Amateur Wrestlers

1.1 Anaerobic Characteristics

1.1.1 Strength

Strength can be defined as the maximum ability to generate force independent of time and distance of movement. It is dependent upon the ability of the nervous system to recruit motor units, the ability of the muscle to utilise the energy anaerobically (ATP-PC) for muscle contractions and the amount (cross-sectional area) of muscle fibres present. Because of the relationship to cross-sectional area and therefore size, strength is often analysed relative to bodyweight, that is relative strength.

Early studies on wrestlers focused on isometric, or static strength. A summary of the literature on static (isometric) strength of wrestlers is presented in table I. While isometric contractions are important in the sport, they are associated with 'holding' rather than 'moving' an opponent. At the international level of competition, rule changes in the 1970s placed an emphasis on aggressive wrestlers and scoring rather than holding and blocking the opponent, i.e. 'stalling'. Consequently, dynamic strength of wrestlers (e.g. the force during maximal isokinetic, concentric or eccentric contractions) has received more attention in recent years. Dynamic strength values are found in table II. The values in tables I and II are relative to bodyweight.

In making comparisons, if should be realised that relative strength does not completely account for size differences. Song and Garvie (1980) report that, as expected, absolute strength is greater in the heavier wrestler than in the lighter wrestler; however, the reverse is true for relative strength. Therefore, caution should be taken before making conclusions on comparisons of the relative strength of 2 groups of wrestlers (e.g. successful *vs* unsuccessful), when the absolute bodyweights may be different.

Table I. Static strength (kg/kg bodyweight)[a]

Reference	Study group	Grip	Elbow flexion at 90°	Trunk extension	Leg lift	Back lift
Sady et al. (1984)	Age group					
	15 wrestlers				5.2	2.1
	13 controls				4.1	1.9
Freischlag (1984)	Junior					
	104 wrestlers	0.56				
	73 controls	0.54				
Silva et al. (1981)	Junior World					
	8 qualifiers	0.60				
	7 nonqualifiers	0.69				
Stine et al. (1979)	College					
	5 All-American	0.85				
	6 moderately successful	0.85				
	8 least successful	0.84				
Kroll (1954)	35 college	0.74			3.4	2.7
Rasch et al. (1967)	21 college	0.76			2.2	2.2
	32 US seniors	0.70			3.0	2.3
	11 Japanese	0.92			2.2	2.8
Taylor et al. (1979)	5 Canadian	0.70			4.3	2.6
Song and Garvie (1980)	Seniors					
	15 Canadian	0.75	0.37	0.66		
	19 Japanese	0.73	0.40	0.68		
Nagle et al. (1975)	US Olympians					
	8 successful	0.76				
	18 unsuccessful	0.79				

a Grip strength (right hand or average of both hands) determined with a grip dynamometer. Other strengths determined with a cable tensiometer.

Table II. Dynamic strength in flexion and extension (J/kg bodyweight) tested on Cybex® equipment

Reference	Level	Forearm (flex/ext)	Lower leg (flex/ext)	Shoulder (flex/ext)	Hip (flex)
Housh et al. (1989)	195 scholastic				
	30°/sec	0.81/0.95	1.58/3.04		
	180°/sec	0.53/0.53	1.05/1.66		
	300°/sec	0.38/0.40	0.77/1.04		
Housh et al. (1990)	122 scholastic				
	30°/sec			0.97/1.71	
	180°/sec			0.84/1.31	
	300°/sec			0.73/1.17	
Kelly et al. (1978)	13 college				
	180°/sec		0.99/1.44		1.29
Sharatt et al. (1988)	Canadian senior				
	180°/sec	0.86/0.85	1.41/1.81		
	240°/sec	0.72/0.73	1.16/1.35		

When comparing successful wrestlers with less successful or the experienced to the novice, it appears that greater strength is advantageous. Cisar et al. (1987) suggest that in scholastic wrestlers, a composite of isokinetic strength measurements discrimates the successful wrestler from the least successful. Stine et al. (1979) report similar trends among collegiate wrestlers, with greater isokinetic strength in successful wrestlers than in less successful wrestlers. The greatest differences were presented in the tests for upper body strength. In contrast, Silva et al. (1981) reported no differences in isometric grip strength of the successful and less successful wrestlers contending for the Junior World games team. Likewise, Nagle et al. (1975) saw no differences in the isometric grip strength among the Olympic team contenders. Discrepancies in the findings of these studies (Cisar et al. 1987; Nagle et al. 1975; Silva et al. 1981; Stine et al. 1979) could be due to the type of strength test (isokinetic *vs* isometric) or the level of competition (scholastic and college *vs* international, i.e. Junior World and Olympic).

1.1.2 Power

By definition, power is the amount of work accomplished per unit of time. In wrestling, opponents are matched by size (bodyweight) and presumably power. However, it is possible for opponents at the same weight class to differ in relative power. In theory, greater power would be advantageous in wrestling because, unlike other sports, victory can be decided before the time limit of the contest has expired, by a fall or a technical fall.

Power in wrestlers is associated with quick, explosive manoeuvres that lead to control of the opponent. The sources of energy for these quick, explosive exertions are the phosphagens (ATP-PC) and glycogen (anaerobic glycolysis). The 2 most commonly used tests to evaluate the maximum ability of wrestlers to generate power and anaerobically utilise the energy stores are the Margaria stair climb (test duration approximately 1 second) and the Wingate anaerobic test (test duration 30 to 40 seconds). A summary of the literature using these 2 tests is presented in table III. Units for the Margaria stair climb test results have been converted to watts per kg bodyweight for comparison purposes. For the Wingate test results, peak anaerobic power (maximum power in a 5-second interval) and anaerobic capacity (mean power for the 30-second interval) are listed.

Compared with other athletes, wrestlers' anaerobic performances are more similar to power athletes than endurance athletes. On the basis of equivalent bodyweights (W/kg), Bar-Or (1987) reports that distance runners and ultra marathoners have leg power values of 8.9 and 9.3 W/kg, re-

Table III. Anaerobic power (W/kg of bodyweight)

Reference	Level	Arms		Legs	
		capacity[a]	peak[a]	capacity[a]	peak[a]
Sady et al. (1984)	Age group[b]				
	15 elite				7.5
	13 controls				4.8
Housh et al. (1991)	Junior			7.8	10.1
Horswill et al. (1989)	Junior				
	18 elite	6.0	7.5	8.6	10.7
	18 nonelite	5.2	6.4	7.4	9.0
Jacobs (1980)	11 college			8.2	11.5
Horswill et al. (1979)	31 college				19.9
Horswill et al. (1990)	12 college	4.8	6.1		
Bar-Or (1987)	11 college			9.4	12.0
Horswill et al. (1989)	31 seniors	5.2		7.4	
Di Prampero et al. (1970)	10 Olympians				17.0

a Capacity: mean power for 30 seconds; peak: maximum power for 5 seconds.
b Wrestlers: 11.3 years; controls: 10.7 years.

spectively. In contrast, powerlifters had values of 9.5, college wrestlers 9.4, and gymnasts 9.1 W/kg. Similarly, the anaerobic power of the upper and lower body of scholastic wrestlers (table III) appears to be greater than the corresponding values in nonathletic men of similar age. Blimkie et al. (1988) report that for arm performance of nonathlete adolescent males, mean anaerobic capacity ranges from 3.6 to 5.0 W/kg and mean anaerobic power were 5.3 to 6.7 W/kg. From Inbar and Bar-Or (1986), a mean range was estimated for anaerobic capacity of the legs (6 to 7 W/kg) and power (7.5 to 8.5 W/kg) of nonathlete adolescent males. The literature values on most wrestlers at any level (table III) exceed the sixty-fifth percentile of anaerobic capacity and anaerobic power of the legs of nonathletic adult males (Maude & Shultz 1989).

Anaerobic power may help differentiate between successful and less successful wrestlers. The anaerobic power and capacities of elite junior wrestlers are greater by as much as 13% than those of nonelite wrestlers of similar weight, age and wrestling experience. This may be due to differences in the relative amount of muscle (Horswill et al. 1989) or possibly differences in the neuromuscular recruitment. Because the Wingate test is relatively new, there are no other published studies comparing the anaerobic power of successful and less successful wrestlers.

Anaerobic power is closely related to the fibre composition of the skeletal muscle (Inbar & Bar-Or 1986; Coyle et al. 1979). The histochemical profile of wrestlers is limited to a few reports that suggest that wrestlers do not have a superior capacity for anaerobic power at the cellular level. From Bergh and coworkers' (1978) study it is estimated that senior wrestlers on the Swedish national team averaged approximately 56% fast twitch fibres for lower body muscles (gastrocnemius or vastus lateralis). In that report, wrestlers appeared to have the greatest variability in percentage of slow twitch fibres among the trained athletes; however, the sample size was small (n = 5). In another study (Tesch et al. 1982) 8 Swedish senior wrestlers had a mean of 53% fast twitch fibres in the lower body (vastus lateralis). In comparison, the upper body muscle (deltoid) of the same wrestlers was lower in fast twitch fibres at 39%.

Data on Canadian wrestlers match the results of Bergh et al. (1978). Eight Canadian Graeco-Roman wrestlers had an average of 51% fast twitch fibres in the vastus lateralis (Taylor et al. 1979).

Sharratt et al. (1986), also sampling the vastus lateralis, reported that for 21 Canadian freestyle wrestlers the average percentage of fast twitch fibres was 52%. Interestingly, the authors of that study observed that the cross-sectional area of the fast twitch fibres was larger than other athletes. However, Taylor et al. (1979) suggested that cross-sectional area is related to size of the wrestler.

1.1.3 Muscular Endurance

In this review, muscular endurance is defined as the ability to sustain muscular performance at a high intensity, i.e. at or near 100% of maximum force or power, for more than 30 seconds, but less than 2 minutes. The capacity of the muscle to maintain maximum power for this duration of time is thought to be due to its capacity to undergo anaerobic glycolysis, buffer metabolic acids, and, to a lesser extent, aerobically metabolise fuel for energy. Unfortunately, there is no universally accepted method of evaluating these capacities relative to physical performance. A variety of tests have been used in wrestlers as well as other athletes, making comparisons somewhat difficult.

In one study (Nagle et al. 1975), Olympic team contenders performed the maximum number of bench press repetitions possible using a 50lb (23kg) weight. The first team members performed an average of 67 repetitions, which was significantly more than an average of 49 repetitions performed by contenders not making the team. Because the physical characteristics of the 2 groups were similar, the authors concluded that dynamic endurance may be a critical physiological factor for success. In contrast, other researchers (Silva et al. 1981), using an identical protocol, found that among somewhat younger wrestlers (trying out for the US Junior World team) there was no difference between the performances of the successful (0.98 reps/kg) and less successful peers (1.10 reps/kg). However, when Silva et al. (1981) used discriminant function analysis to determine if the overall physiological profile could discriminate the successful from less successful wrestler, dynamic endurance in both absolute and relative terms were 2 of the 3 variables that accounted for 48% of the variance in predicting success.

In a study using a different protocol, Canadian freestyle wrestlers performed 2 runs to exhaustion on a treadmill (Sharratt et al. 1986). The runs, which were separated by 4 minutes of rest, were made at a speed of 8 mph (12.8 km/h) and an incline of 20% grade. Wrestlers stayed on the treadmill for an average of 56 seconds and 45 seconds for the first and second run, respectively. Treadmill times and blood lactate concentrations, which averaged 14.0 mmol/L at the end of the second run, were comparable with those of athletes in other anaerobic sports (Sharratt et al. 1986).

Recently, a test was developed for assessing the effects of weight loss and diet on muscular endurance in wrestlers. The test, which involves intermittent, high intensity arm cranking, simulates the upper body muscle effort and metabolism incurred in a wrestling match (Hickner et al. 1991). When evaluating well conditioned collegiate wrestlers with this test (Horswill et al. 1990), venous lactate concentrations were approximately 14 mmol/L immediately following the arm ergometry and the wrestlers performed slightly over 37kJ of work in a total of 2 minutes of intermittent arm cranking. The test may be useful for monitoring training and the muscular endurance of wrestlers, although it has not been validated for such use.

Perhaps future research on wrestling might focus on the contribution of muscular endurance to success in the sport, and the mechanism by which dynamic endurance is improved. Enzyme activity levels for phosphofructokinase in the vastus lateralis muscle from Canadian freestyle wrestlers are similar to those of other anaerobically trained wrestlers (34.5 μmol/g wet weight muscle/min; Sharratt et al. 1986). However, other factors such as the buffering capacity of the muscle and blood need to be investigated to determine how wrestlers may differ from other athletes, and how successful wrestlers differ from the less successful wrestler.

1.1.4 Flexibility

The extent to which an appendage or body segment can be moved through a range of motion, or flexibility, would appear to be an important element in wrestling. Surprisingly, research indicates that wrestlers are no more flexible than nonwrestlers. Leighton (1957) showed that overall, wrestlers had less flexibility than other strength athletes such as weightlifters and gymnasts. However, considering the joint specificity of flexibility, Leighton found wrestlers to have a greater rotation and abduction/adduction of the shoulders than nonathletic controls. While neck flexibility was also high in the wrestlers, wrist flexibility was lower than the nonathletes.

Comparing the successful wrestler with the less successful wrestler, Stine et al. (1979) and Song and Garvie (1980) showed that flexibility may be a discriminating variable. For collegiate wrestlers, the sit and reach measurements were greater for the most successful group than for the moderately and least succesful wrestlers (Stine et al. 1979). At the international level, the Japanese wrestlers had greater overall flexibility than their Canadian counterparts (Song & Garvie 1980). Apparently, no relationship exists between strength and flexibility or between size of the wrestler and flexibility (Song & Garvie 1980).

1.1.5 Reaction Time/Speed of Movement

Reaction time, or the speed at which a person moves in response to a stimulus, is a critical element in most sports. Research supports this in general, i.e. athletes move more quickly in response to a stimulus than do nonathletes (Keller 1942). However, the work of several researchers would not support that reaction time is a critical attribute for success in wrestling. Kroll (1958) reported no difference in the response times of successful and nonsuccessful high school wrestlers in performing offensive and defensive movements specific to the sport of wrestling. Likewise, Rasch et al. (1961) found no difference in the response times of nonwrestlers, college wrestlers, US national wrestlers and Japanese team members. In the latter study, a standard test for reaction time was used as opposed to a wrestling-specific test. The data of Stine et al. (1979) also did not reveal differences in reaction times of successful and less successful collegiate wrestlers performing a standard reaction test.

More recently, a series of tests for reaction time have been developed specifically for wrestling; the tests not only measure the speed of movement in reaction to the stimulus but also account for the technical ability with which the movement is completed (Taylor et al. 1979). Unfortunately, the sample size in that initial study was small (n = 8) and all the wrestlers were of high calibre. To this point, the series of tests has not been used to compare reaction times of successful and less successful wrestlers but such information could be very useful in profiling champion wrestlers.

1.2 Aerobic Characteristics

1.2.1 Cardiovascular

Tests for cardiovascular fitness are dependent upon pulmonary function and the perfusion-to-diffusion ratio, oxygen-carrying capacity of the blood, cardiac output, capillarisation of the muscle, and the oxidative capacity of the skeletal muscle cells. Assessment of cardiovascular fitness frequently applies a progressive workload test that pushes the athlete to exhaustion while measuring peak oxygen uptake (peak $\dot{V}O_2$).

A summary of the studies on peak $\dot{V}O_2$ peak of wrestlers at various levels is presented in table IV. In general, wrestlers have peak $\dot{V}O_2$ values of between 50 and 60 ml/kg/min using a treadmill running protocol. Putting this into perspective withother athletes, elite wrestlers have peak oxygen uptake capacities that are average to above average compared with untrained and spring trained individuals but are below average compared with the endurance athlete. For example, some of the highest peak $\dot{V}O_2$ values reported are in excess of 80 ml/kg/min for crosscountry skiers; distance runners had peak $\dot{V}O_2$ values between 70 and 80 ml/kg/min, while swimmers average more than 60 ml/kg/min (Saltin & Åstrand 1967). Weightlifters and sprinters have $\dot{V}O_2$ peak values between 45 and 55 ml/kg/min (Fahey et al. 1975; Saltin and Åstrand 1967) while untrained subjects averaged just over 40 ml/kg/min (Saltin & Åstrand (1967).

The data of Morganroth et al. (1975) may help explain the physiological limitations of the peak oxygen uptake of wrestlers. These authors found that collegiate wrestlers have cardiac stroke volumes and left ventricular volumes similar to nonathletes but smaller than those of endurance-trained athletes. The wall and septum of the left ventricle were greater in the wrestler than in the nonathlete and endurance athlete. The authors explain that the hypertrophy is due to the increased afterload during the isometric contractions performed by wrestlers. The left ventricle must increase the contraction force to generate a pressure that will overcome the increased peripheral resistance. This causes a training adaptation of increased mass in the ventricle wall. Because wrestling does not demand the high cardiac output or stroke volume of endurance sports, an expansion of the left ventricle chamber with training does not occur. These data are supported by Cohen et al. (1987), who studied adolescent age wrestlers and found larger septal and posterior walls of the left ventricles of adolescent wrestlers compared with age-matched controls. Somewhat in contrast, Cohen et al. (1987) found larger resting stroke volumes, lower resting heart rates and lower diastolic blood pressures in the wrestlers than in controls. The discrepancy between Morganroth et al. (1975) and Cohen et al. (1987) might be explained by the age difference of the subjects. Younger wrestlers such as in the Cohen et al. study may be involved in numerous sports while collegiate wrestlers like those in Morganroth and colleagues work tend to specialise in one sport. Therefore, the younger wrestlers might exhibit the effects of other training as well as wrestling. Also, it is possible that only those wrestlers with the genetic potential for left ventricular wall hypertrophy continue competing through college.

At the muscle cell level, only one study is available on the biochemical profile of the aerobic capacity of wrestlers. Sharratt et al. (1986) measured the succinate dehydrogenase activity in the vastus lateralis of senior wrestlers as an indicator or aerobic potential. The investigators reported a mean activity of 7.3 μmol/g wet weight of muscle/min, and activity level indicative of endurance adaptations but not to an exceptional level. Obviously with slightly more than 50% of the fibres in the skeletal muscle of wrestlers being fast twitch (Bergh et al. 1978; Sharrat et al. 1986; Taylor et al. 1979), less than 50% are slow twitch, which implies an average aerobic capacity at the cellular level.

While studies on the cardiac function and muscle chemistry are insightful, they do not provide all of the answers to the limitations of the cardiovascular endurance capacities of successful wrestlers. As yet, no one has investigated such aspects as the capillary density of the muscle tissue of elite wrestlers or the role of the plasma volume on endurance capacity of elite wrestlers.

In reviewing studies comparing the peak oxygen uptake of successful and less successful wrestlers, it appears that oxygen uptake is not a major determinant of success. Nagle et al. (1975), Stine et al. (1979), and Horswill et al. (1989) show that at 3 levels, Olympic, collegiate and scholastic, the peak oxygen consumption is not significantly different between successful and less successful counterparts. From our observations (unpublished) and a review of the values in table IV, there does appear to be a tendency for a difference in peak oxygen uptake among wrestlers in different styles of competition. Specifically, freestyle wrestlers (Nagle et al. 1975; Sharratt et al. 1986) seem to have a higher peak oxygen uptake than Graeco-Roman competitors (Gale & Flynn 1974; Taylor et al. 1979). It is not known whether a difference truly exists or a higher peak oxygen uptake is more important in freestyle than Graeco-Roman competition.

The protocol for most of the studies (Clarke et al. 1984; Gale & Flynn 1974; Horswill et al. 1989; Nagle et al. 1975; Sharratt et al. 1986; Stine et al. 1979; Taylor et al. 1979) consists of running on a treadmill to determine the peak oxygen uptake. However, the relevance of such a test to the sport of wrestling should be questioned. Perhaps a more valuable tool for profiling is the evaluation of peak oxygen uptake of segments of the body, i.e. peak oxygen uptake during arm cranking or leg cycling. It is possible, as suggested by Seals and Mullen (1982), that the peak $\dot{V}O_2$ determined on the treadmill is average but the aerobic capacity of the isolated upper body of trained athletes such as wrestlers might be well above average. Therefore, such

Table IV. Peak oxygen uptake (ml/kg/min)

Reference	Level	Treadmil	Arm crank	Cycling
Clark et al. (1984)[a]	Age group[a]			
	23 wrestlers	51.5		
	22 controls	48.0		
Sady et al. (1984)	Age group			
	15 elite wrestlers	54.0		
	13 active controls	45.6		
Horswill et al. (1989)	Junior			
	18 elite	52.6		
	18 nonelite	51.5		
Sharatt (1984)	Junior World	55		
Seals & Mullin (1982)	10 collegiate	62.4	40.6	45.4
Horswill et al. (1990)	12 collegiate	53	41	
Stine et al. (1979)	Collegiate			
	5 All-American	61.1		
	6 moderately successful	59.9		
	8 least successful	55.3		
Fahey et al. (1975)	2 US senior			64.0
Nagle et al. (1975)	US Olympic freestyle			
	8 successful	60.9		
	18 unsuccessful	55.9		
Gale & Flynn (1974)	US Olympic freestyle and Graeco-Roman			
	9 successful	54.3		
	18 unsuccessful	54.8		
Sharatt et al. (1986)	Canadian freestyle	61.8		
Song & Garvie (1980)	Seniors			
	15 Canadian			54.5
	19 Japanese			55.6
Saltin & Åstrand (1967)	10 Swedish seniors	57		
Taylor et al. (1979)	7 Canadian Graeco-Roman	50.4		

a Wrestlers age 8.5 years; controls 8.4 years.

a test might be a sensitive device for profiling the fitness of the elite wrestler. The motion of arm cranking is more similar to the motions in wrestling (e.g. pummelling) than is running. Furthermore, as Boileau et al. (1984) suggest, the contribution of central and peripheral fitness to peak oxygen uptake may vary between the upper and lower body. Specificially, peripheral fitness tends to make a larger contribution to peak oxygen uptake for arm cranking than does central fitness (Boileau et al. 1984). If the peripheral fitness is an important element in wrestling, then a test such as arm cranking for peak oxygen uptake may be more relevant than the standard treadmill run.

It should be noted that the majority of studies on the maximum aerobic power of elite wrestlers were conducted before 1980. Until that time, international matches were at least 9 minutes in length. Through the 1980s, the match duration for world-level competition was 6 minutes (two 3-minute periods separated by a 1-minute rest period); currently matches are 5 minutes in duration without a rest period. Therefore, as Sharratt (1984) notes, it is possible that aerobic power and cardiovascular endurance are not as critical for match success as previously suggested. Unfortunately, there are not enough data available to determine whether peak $\dot{V}O_2$ values of current elite international wrestlers have decreased relative to the abbreviation of the match duration.

1.2.2 Pulmonary

With a few exceptions, research on the pulmonary system of wrestlers has been incidental to cardiovascular fitness testing. The exceptions are the work of Rasch and Brandt (1957) and Sharratt et al. 1986. Rasch and Brandt (1957) examined vital capacity, forced vital capacity, total lung capacity, and maximal breathing capacity of US Olympic wrestlers. They report mean values of 5.23L for vital capacity, 4.16L for the forced expired volume in 1 second, 6.54L for the total lung capacity, and 163.6ml for the maximum breathing capacity. All values tended to be higher than those that were predicted from the equations developed for normal young adult males; however, the differences were not statistically significant. For the forced expired volume, 80% of the volume was expired in the first second while 94.7% was expired by the end of the second second.

Almost 30 years later Sharratt et al. (1986) found similar volumes for international competitors on the Canadian national team. Wrestlers who averaged 72.8kg had mean values of 4.9L and 83.4% for vital capacity and forced expiratory volume in 1 second, respectively (Sharratt et al. 1986). The mean maximum voluntary ventilation for 12 seconds was 181 L/min and during maximal exercise, the minute ventilation was 132.5 L/min (BTPS). The conclusions of Sharratt et al. were similar to those of Rasch et al.: pulmonary volumes and functions of the wrestlers were greater than the nonathlete but were average compared with other well trained athletes. The point should be made that wrestling bouts at the time of Rasch and colleagues' study were roughly twice the duration (15 minutes) of matches at the time of Sharratt and colleagues' study (6 to 9 minutes), suggesting that pulmonary function is not a particularly critical factor in the physiology of the sport.

During maximal aerobic exercise, the average minute ventilation ranges from 129 L/min (BTPS) in elite adolescent wrestlers (Horswill et al. 1988) to 156.6 L/min in first team members of the US Olympic freestyle team (Nagle et al. 1975). Nagle et al. (1975) reported no significant difference in the maximal minute ventilation of members of the first team (156.6 L/min) and second team (140.3 L/min) vying for the Olympic team. Silva et al. (1981) also found no difference between successful (155.7 L/min BTPS) and less successful (146.1 L/min) Junior World wrestlers. In contrast, Horswill et al. (1989) found significant differences between elite (127 L/min) and nonelite (111 L/min) junior wrestlers. Possibly first and second team members such as those studied by Nagle et al. (1975) and Silva et al. (1981) are quite homogeneous and could all be considered elite.

It is of interest to note Sharratt's (1984) observations on pulmonary function of wrestlers. Sharratt reports that in the elite senior level wrestlers, maximum minute ventilation was low relative to the peak oxygen uptake values and high lactate levels. Sharratt suggests that elite senior wrestlers may hypoventilate during maximum exercise as a result of becoming conditioned to years of restricted breathing, and that successful wrestlers may be more tolerant of lactate physiologically or psychologically compared to the less successful wrestler. Sharratt's observations would support the need for research on the muscular endurance and the contribution of the muscle and blood buffering capacity to muscular endurance in the wrestler.

1.3 Body Composition and Physique

Optimal body composition is a concern of the wrestler because competitors are matched by bodyweight and must 'make weight' prior to each meet. The majority of wrestlers attempt to maximise the amount of lean tissue, minimise the amount of body fat, and minimise the total bodyweight. Often, though, lean mass is reduced during weight reduction; this is discussed in detail in the last section of this article. The degree to which wrestlers attempt to control weight and body composition varies. The wrestlers in the US seem to be more focused on weight reduction than the Europeans and

Asians who tend to grow into the heavier weight classes as their careers transpire (Sharratt et al. 1986).

Body composition of wrestlers has been assessed by using the criterion method of underwater weighing (Katch & Michael 1971; Oppliger et al. 1991; Sady et al. 1982; Sinning 1974; Widerman & Hagan 1982) or one of a number of field tests including skinfold thickness (Freischlag 1984; Horswill et al. 1988; Katch & Michael 1971; Park et al. 1990; Sinning 1974), skeletal width measurements (Oppliger & Tipton 1988; Tcheng & Tipton 1973), and most recently the bioelectrical impedance analysis (Oppliger et al. 1991). At present, no work has been reported on the bone mineralisation or variations in hydration state of the lean body mass of wrestlers.

Whether measured in-season (during training and competition) or off-season, most wrestlers are very lean, possibly due to the year-round training and/or their genetic makeup. Off-season values for percentage body rat range from 8 to 16%; in the well-trained state (table V), wrestlers appear to be between 3 to 13% fat, which is exceptionally lean compared with nonathletes and most other athletes (Boileau et al. 1989; Wilmore & Costill 1988). The lightest wrestlers are reported to be the leanest (deGaray et al. 1974; Horswill et al. 1988; Katch & Michael 1971); however, there does not appear to be a relationship between the level of success and the percentage of body fat. The data reported here do not include heavyweights, since heavyweights have not had a maximum weight restriction on their weight class until recently. Traditionally, more weight, including fat, has been thought to be advantageous in terms of success for heavyweights.

Regarding the composition of the lean tissue, no difference was found between collegiate wrestlers and weight-matched sedentary controls for the amount of fat-free weight as measured by underwater weighing (Mendez et al. 1983). However, the wrestlers were estimated to have a greater amount of skeletal muscle as calculated from urine excretion of 3-methylhistidine. This research suggests that the compartmentalisation of the fat-free body may differ between wrestlers and nonathletes. In other words, despite having similar amounts of fat-free weight, wrestlers had more skeletal muscle while the sedentary controls may have had more bone mass.

In terms of physique, the wrestler is thought to have a somatotype that accentuates the mesomorphic character (very high muscularity, low linearity, low fat). This notion is supported by Cisar et al. (1987) who report that successful scholastic wrestlers had tendencies for lower scores for body breadth and linearity-to-fatness, but greater muscularity scores. Interestingly, the body build and body composition profile only discriminated the average wrestler from the novice, not the highly skilled wrestler from the average or novice wrestler.

In Olympic wrestlers, deGaray et al. (1974) and Tanner (1964) also report very high ratings for the mesomorphic characteristic and low endo- and ectomorphy. deGaray et al. (1974) found that Graeco-Roman and freestyle wrestlers together had an average somatotype of 2.3 (endomorphy), 6.4 (mesomorphy), and 1.6 (ectomorphy); no difference was observed between Graeco-Roman and freestyle wrestlers for the ratings. Scores for endomorphy and mesomorphy tended to increase and the ectomorphy ratings tended to decrease in progression from the lightest wrestlers to the wrestlers in the heaviest weight class.

In contrast to these reports, the observations of Kroll (1954), Rasch (1958), and Sady et al. (1982) indicate that wrestlers are only slightly above average in the mesomorphic rating and do not differ greatly from nonathletic control subjects. These discrepant findings compared to data on Olympic wrestlers (deGaray et al. 1974; Tanner 1964) could be in part due to the population of wrestlers sampled: Kroll (1954), Rasch (1958), and Sady et al. (1982) limited their studies to US athletes at 3 levels (scholastic, senior, and prepubescent), whereas deGaray et al. (1974) and Tanner (1964) measured top calibre senior wrestlers from around the world. Alternatively, just as the sport provides an opportunity for males of all sizes to compete, wrestling may also provide an opportunity for males of all

Table V. Percentage fat of wrestlers

References	Study group	Skinfold[a]	Underwater weighing[a]
Sady et al. (1984)	Age group[b]		
	23 elite		12.7 (34.2)
	23 nonwrestlers		22.9 (39.0)
Horswill et al. (1988)	39 elite juniors	7.2 (64.4)	11.0 (64.4)
Katch & Michael (1971)	94 juniors		6.9
Cisar et al. (1971)	55 juniors		10.7
Silva et al. (1981)	Junior World		
	8 qualifiers	7.3 (82.1)	
	7 nonqualifiers	7.3 (73.3)	
Stine (1979)	College		
	5 All-American	3.7 (71.8)	
	6 moderately successful	4.0 (61.4)	
	8 least successful	4.2 (69.0)	
Sinning (1974)	37 college		8.8 (74.8)
Kelly et al. (1978)	13 college		10.4 (77.1)
Mendez et al. (1983)	16 college		10.3 (70.6)
Sharatt et al. (1986)	Canadian senior	8.2	
Song & Garvie (1980)	Seniors		
	15 Canadian	11.0 (75.4)	
	19 Japanese	12.5 (78.4)	
DiPrampero et al. (1970)	10 Olympians	13.0	
Fahey et al. (1975)	2 US seniors		9.8 (81.8)
Nagle et al. (1975)	US Olympian		
	8 successful	8.3 (77.7)	
	18 unsuccessful	8.2 (73.8)	
Flynn & Gale (1974)	US Olympian		
	9 successful	9.8 (75.66)	
	18 unsuccessful	10.5 (70.96)	

a Parentheses indicate mean weight in kg, otherwise weight was not listed.
b Elite: age 11.0 years; nonwrestlers: age 11.2 years.

shapes to compete. Therefore, in a population of wrestlers with all weight classes represented, a regression to the mean somatotype may occur and overall difference from the body build of the nonwrestler population would not be observed. The differences in somatotypes across weight classes noticed by deGaray et al. (1974) support this.

1.4 Implications of the Profile for Success in Wrestling

While no one physiological characteristic stands out to separate the successful wrestler from the less successful wrestler, the implication of the overall profile of the successful wrestler is that it establishes standards for selecting potentially successful candidates in the sport. For example, Nagle et al. (1975) found that almost 45% of the variance in discriminating between successful and unsuccessful Olympic contenders could be accounted for with physiological variables alone. By including the scores for psychological variables with the physiological model, Nagle et al. (1975) could account for approximately 85% of the variance in success. Using slightly difference analyses, Stine et al. (1979) found a correlation of 0.76 between the physiological values and the success level of collegiate wrestlers when the variables were analysed by ranking. Finally, Silva et al. (1981) reported that their physiological model accounted for 48% of the variance in predicting success of Junior World team members. Like Nagle et al. (1975), Silva et al. found that the variance accounted for in success was substantially increased (to 79%) when the physiological and psychological models were combined. All of these authors (Nagle et al. 1975; Silva et al. 1981; Stine et al. 1979) cautioned against applying their models for the selection of potentially successful wrestlers, but all authors indicated that their models showed promise for such use. It should be noted though that with the trend of shortening the duration of international matches and an emphasis on an aggressive style of wrestling that promoted high point scoring manoeuvres in international competition, strength, anaerobic power, and anaerobic capacity are likely to become increasingly dominant features of successful wrestlers.

A second implication of the profiles may set the standards around which training regimens are developed. In other words, if in the assessment of a certain attribute a wrestler is found to be below average compared with the successful wrestler, then the wrestler may be encouraged focus his training on that attribute. Training is known to increase physiological work capacities by 5 to 20% (Wilmore & Costill 1988); however, the genetic makeup will ultimately limit the absolute levels the individual can achieve.

Therefore, an alternative approach might be for the wrestler to develop strategies and techniques for competition that best suit his profile and exploit his strengths. For example, the wrestler with a high oxygen uptake and moderate anaerobic capabilities might approach competition with the intent of maintaining a constant and high intensity effort for the full match duration, accept the probability that he will be behind in scoring early in the match, but rely on his endurance capabilities to win by the end of the match. In contrast, the wrestler with high anaerobic power but a low peak $\dot{V}O_2$ may take an approach of attempting to score high point moves and win within the match duration (i.e. by technical fall or fall) or accumulate such a lead in points that the opponent could not surpass him. To apply the recommendation of Sharratt (1984) with some modification, the powerful wrestler would execute flurries of moves that last no more than 12 seconds. Short periods of low intensity activity between the intense flurries may allow for the recovery of high energy fuels (ATP-PC) for subsequent efforts without an excessive decrease in muscle pH that causes fatigue.

2. *Physiological Responses of Training for Wrestling*

Training for competition typically consists of wrestling, and supplemental nonwrestling activities for strength and power (i.e. resistance training) and cardiovascular fitness (i.e. endurance training). The activity of wrestling is thought to contribute to the development of either anaerobic or aerobic fitness besides technical skill development. Unfortunately, little research has been done on the physiological responses to wrestling or training for wrestling to verify this (Taylor 1975). The lack of data could be due to several reasons. From the standpoint of acute effects, the pattern of exertion in wrestling is sporadic and unpredictable; consequently, techniques such as indirect calorimetry cannot be used because the requirement of steady-state exercise is not met. Also, because of the high degree of physical contact in the sport, it is difficult to keep electrodes, telemetry devices or indwelling catheters in place to measure physiological responses during wrestling. The lack of information on the long term effects of training may not receive great amounts of interest because of limited implications for the health benefits of the general public.

2.1 Acute Response

Energy expenditure during wrestling is approximately 13 to 14 kcal/min (AAHPER 1971; Wilmore & Costill 1988), although it is not clear from the references how the rate of energy expenditure was estimated. Both aerobic and anaerobic pathways are thought to contribute to the energy production (Johnson & Cisar 1987). However, due to the explosive nature of the sport, it is likely that the majority of the energy comes from anaerobic processes. Houston et al. (1983) reported 21.5% reduction in the glycogen concentration in the vastus lateralis as a result of a 6-minute freestyle match. Blood lactate concentrations rose almost 10 times and blood pH decreased from 7.31 to 7.06. From the decreases in glycogen, the authors (Houston et al. 1983) concluded that there is fairly uniform recruitment of slow twitch, oxidative fast twitch, and glycolytic fast twitch muscle fibres during wrestling. The anaerobic nature of the sport is supported by reports of decreases in urine pH in response to competition in a 1-day tournament. Mean pH values decreased from 5.43 to 4.73 but pH returned to normal, i.e. 6.03, by 40 hours following the tournament (Rasch et al. 1958). Rasch et al. concluded that the metabolites produced during wrestling caused the decrease in pH. Zambraski et al. (1975) also reported a decrease in urinary pH associated with competition (from 6.46 to 6.28), although the decrease was not statistically significant.

Acute changes in blood chemistry have been reported by 2 groups of investigators. Grassi et al. (1983) found elevation in creatine kinase, or creatine phosphokinase (CPK), after a short but undefined period of training by wrestlers. Increased CPK concentrations are associated with muscle trauma sustained during contact or eccentric contractions (Schwane et al. 1983; Tiidus & Ianuzzo 1983), both of which are common to the sport of wrestling. Nonessential fatty acids and alanine aminotransferase (glutamic pyruvic transaminase) levels were also increased but no changes occurred for aspartate aminotransferase (glutamic oxaloacetic transaminase), triglycerides, HDL-cholesterol and total cholesterol (Grassi et al. 1983). Farris (1943) studied the effects of wrestling on the blood count and found dramatic increases in red blood cells, neutrophils and lymphocytes, and moderate increases in polymorphonuclear cells. Farris explained that the increase in lymphocytes (104%) was due to an increase in lymphocytosis, which indicated the 'strenuosity' of the sport. It is possible that the increases in red and white blood cell concentrations reported by Farris are a result of plasma being forced out of the vascular space because of increased hydrostatic pressure under the intense, static contractions and increased systolic blood pressure, and because of an increase in osmotic pressure as a result of the production of metabolites by the muscle.

2.2 Chronic Response

2.2.1 Anaerobic Characteristics

To develop power and strength, wrestlers spend significant amounts of time wrestling and undergoing resistance training (Johnson & Cisar 1987). Several descriptive studies have evaluated the effect a season of wrestling on anaerobic performance. The findings show that strength and muscular endurance increase in wrestlers at the prepubescent (Clarke et al. 1984), scholastic (Freischlag 1984) and collegiate (Song & Cipriano 1984) levels. Other researchers report no change in the anaerobic arm power of scholastic wrestlers (Park et al. 1990) and no change (Rasch et al. 1967; Kelly et al. 1978) or a decrease (Kelly et al. 1978) in various strength measures of collegiate wrestlers during the season. However, an increase in various strength measures was observed during the post-season (Kelly et al. 1978).

Using cross-sectional designs, other researchers have shown that the isokinetic strength of the shoulders of scholastic wrestlers increases across age (Housh et al. 1988, 1989, 1990). Furthermore, when the values are corrected for bodyweight, the values exceeded the strength of other athletes and of nonathletes (Housh et al. 1990). The strength changes appear to be due to not only an increase in lean tissue mass but also neural factors such as the ability to recruit more muscle (Housh 1989). The increase in strength across age groups of adolescent wrestlers suggests that numerous seasons of participating in wrestling contribute to significant strength development.

Unfortunately, several factors confound the results of these studies. First, in most of the studies (Housh et al. 1988, 1990; Kelly et al. 1979; Park et al. 1990; Song & Cipriano 1984), control subjects were not included. Consequently, it is difficult to determine the extent to which participation in wrestling contributes strength and power improvements. This is particularly important when studying maturing wrestlers, for whom growth and development alone will cause large changes. Secondly, the nutritional status of the wrestler is not always considered in the study design. The resistance training used to improve anaerobic capabilities may also promote muscle hypertrophy. However, most wrestlers attempt to maintain or reduce their body mass, which may prevent or minimise increases in lean body mass (Park et al. 1990). As a result, the positive effects of training on power and strength may be attenuated or annulled when wrestlers control or reduce their bodyweight.

A final confounding factor is the type of training used by wrestlers. Because combinations of training are used (i.e. wrestling, endurance training and resistance training), it is not possible to determine the training effects of wrestling *per se* on the development of power and strength. Several investigators believe that training simultaneously for endurance and strength is detrimental to strength gains (Dudley & Djamil 1985; Dudley & Fleck 1987; Hickson 1980). Even within the domain of resistance training, different routines of training have varying effects on muscle physiology and anaerobic performance (Berger 1962; Costill et al. 1979).

Taylor (1971) compared the training responses in a group of wrestlers participating in a muscular endurance cardiovascular interval training programme with the responses in a group of wrestlers on the same team who received a strength-cardiovascular endurance training treatment. The strength-cardiovascular enduration regimen was designed to increase strength of various body segments and at the same time produce improvements in the cardiovascular fitness. The strength-cardiovascular endurance programme consisted of 2 periods per day of resistance training at a resistance of 70% of the initial strength for the major muscle groups. The cardiovascular endurance element of this programme was a 2-mile run each day at maximum pace. The goal of the muscular endurance cardiovascular programme was to increase muscular endurance.

The muscular endurance-cardiovascular interval training programme consisted of circuit training once a day and repetitions of presumably intensive calisthenics twice a day to promote muscle endurance. The interval training for the cardiovascular fitness component consisted of 6 sprints of 440 yards (approximately 400m), with a 5 minute recovery between each sprint. The results for the pre- and post-training testing of fitness showed that the wrestlers in the muscular endurance group gained significant strength in the back and legs and had significant gains in muscular endurance for 5 of 6 tests. In contrast, the strength-cardiovascular–trained group had no improvements in strength and although muscle endurance scores increased in 3 of 6 tests, the improvements were less than that of the muscular endurance–trained group. Unfortunately, Taylor did not compare how the 2 modes of training affected wrestling performance.

2.2.2 Aerobic Characteristics

Aerobic training serves 2 purposes for wrestlers. First, aerobic training improves cardiovascular fitness and possibly muscular endurance. Secondly, aerobic training plays a dual role in 'making weight' for competition: (a) aerobic training requires a high volume of energy expenditure, which promotes the reduction of body fat and bodyweight, and (b) as discussed in detail in section 3, aerobic training creates a metabolic heat load that induces sweating for the purpose of rapid weight loss (i.e. dehydration).

Research shows that with a season of training, peak oxygen uptake may increase (Song & Cipriano 1984) or not change (Clarke et al. 1984; Kelly et al. 1978). As an indirect measure of the aerobic effects of training, Shavers (1974) showed decreases in resting heart rate, resting blood pressure, heart rate during submaximum exercise and blood pressure during submaximum exercise after 25 weeks of training by college wrestlers.

Related to the long term effects of training on aerobic fitness of the athlete is the lipid profile. Tsopanakis et al. (1986) found that in a cross-sectional study of well trained athletes, senior wrestlers were not different from control subjects for total lipids, total cholesterol (mean value 183 mg/100ml), triglycerides (85.5 mg/100ml), high density lipoprotein cholesterol (46.7 mg/100ml) or the ratio of total to high density lipoprotein cholesterol (3.68). The lack of a difference between wrestlers and the controls despite differences in lipid levels between the endurance-trained athletes and the controls (Tsopanakis et al. 1986) suggests that training for wrestling is limited in its ability to effect metabolic adaptations similar to the adaptations induced by endurance training.

Like the characteristics of anaerobic fitness, it is difficult to discern whether changes or lack of changes in aerobic fitness are due largely to wrestling *per se* or the secondary training (running and other aerobic training) that wrestlers perform. Fahey et al. (1975) report that of their power-trained athletes, the wrestlers had the highest peak $\dot{V}O_2$ but also spent more time in aerobic training than other power athletes. Taylor (1971), found that a strength-cardiovascular–trained group significantly decreased the resting heart rate by 16% (from 74 bt/min to 62 bt/min) while the muscular endurance-interval–trained group had no change in resting heart rate after training. The group receiving the muscular endurance–interval training had reductions in both systolic and diastolic blood pressures compared to the strength-cardiovascular group, which showed an increase in systolic blood pressure and no change in diastolic blood pressures.

2.2.3 Body Composition

The adaptations in body composition as a result of training for wrestling can vary. Training for strength and power tends to decrease the percentage body fat by increasing the amount of lean tissue without necessarily changing the absolute amount of fat. This type of training, which results in muscle hypertrophy and possibly increased bone mass, may increase the bodyweight. In contrast, aerobic training requires considerable expenditure of energy and tends to decrease the percentage body fat by reducing the amount of fat without necessarily changing the amount of muscle. As a result, the bodyweight will most probably decrease.

Few studies are available on the changes in body composition of mature wrestlers. In a case study (Widerman & Hagen 1982), a decrease in the fat-free mass of this wrestler during his training for competition was found. Percentage body fat and fat mass also decreased. In collegiate wrestlers, Kelly et al. (1978) reported that body density, percentage body fat and fat-free mass did not change for college wrestlers (n = 13) during the wrestling season. There were tendencies of an increase in the mean values of body density and fat-free mass, and a decrease in percentage body fat and bodyweight. The authors attribute the lack of changes to the year-round conditioning of the wrestlers and the fact that all wrestlers were measured at a time when they did not have to make weight.

In contrast, Taylor (1971) found small but significant decreases in percentage body fat estimated from skinfold thicknesses of wrestlers undergoing 12 weeks of training. Skinfold thicknessess were reduced whether conditioning consisted of a strength and cardiovascular training programme or an interval training programme for endurance.

In prepubescent wrestlers, Clarke et al. (1984) found no change in skinfold thicknesses, somatotype or weight after a 3-month training period. These athletes did not lose weight during training. Freischlag (1984) and Park et al. (1990) reported decreases in weight and skinfold thicknesses during the competitive season for scholastic wrestlers. In the latter study, percentage fat and fat-free weight estimated from skinfold thickness decreased. Due to the limitations of the skinfold technique, it is difficult to conclude accurately that these wrestlers indeed lost lean body mass. Regardless, it appears that weight (Sinning et al. 1976; Tipton & Tcheng 1970), fat-free mass and fat mass (Sinning et al. 1976) are regained after the scholastic season concludes.

For the physically maturing wrestler, succession from one weight class to the next is normal. Often weight gain is feared because of an unfounded association between competing in a heavier weight class and a reduced chance for success. The wrestler appears to be able to grow and increase the bodyweight but maintain a low percentage of body fat because the composition of the weight gain is predominantly lean tissue (Housh et al. 1988). With proper resistance training and concurrent training to develop technical skills and psychological skills (ability to concentrate, set goals, relax, etc.), the young wrestler need not fear growing into a heavier weight class for competition.

3. *Weight Loss*

As discussed above, all competitors in wrestling are required to attain a specific bodyweight (weight class) prior to competing in a regulation bout. The weight class system is designed to reduce the risk of injury between opponents by eliminating vast differences in size and strength and to allow athletes of all sizes and physical abilities to compete on an equal level.

In terms of the administration, wrestlers are checked for their weight during a specified time period before competition (the official weigh-in). The weigh-in is usually conducted by an individual not associated with the competitors (e.g. athletic trainer, physician, wrestling official or tournament administrator). The inability of a wrestler to reach the weight class by the close of the weigh-in results in disqualification from competition.

Many wrestlers choose to reduce their weight to reach a weight class lower than the normal bodyweight instead of competing at their natural weight. The strategy of weight loss is used in hopes of gaining advantages of strength, power and leverage over a wrestler who does not reduce weight for the same weight class. The issues of 'making weight' and the effects on the wrestler's physiology and performance are discussed below.

3.1 Methods of Weight Loss

Numerous methods are employed to reduce bodyweight for wrestling competition. The most common techniques include reducing food intake, fasting and starvation; reduction of or abstention from water intake; exercise to burn calories; exercise to induce sweating (metabolic dehydration); thermal dehydration, such as sitting in a sauna (Steen & Brownell 1990; Woods et al. 1988); and spitting (Weissinger et al. 1991). Less commonly used methods include use of laxatives and forced vomiting to empty the GI tract (Weissinger et al. 1991; Woods et al. 1988); diuresis-induced water loss by consuming a high protein diet, taking contrast showers (Short & Short 1983) or ingesting pharmacological agents (Steen & Brownell 1990; Woods et al. 1988); and, at the international level, blood letting, which is the practice of withdrawing blood before the weigh-in and reinfusing the blood after the weigh-in (Buschschluter 1977).

The methods of weight loss may vary depending on the level of competitors. Differences in the relative amount of weight and the methods of weight reduction are evident between US scholastic and US collegiate wrestlers (Steen & Brownell 1990). Unfortunately there are no data on weight loss practices of wrestlers at the international level. At the scholastic level in the US, the degree of weight reduction is regulated by the national and state associations governing activities in high schools. At the collegiate level in the US, the NCAA or NAIA regulate the degree of weight reduction but regulation is more relaxed than at the scholastic level. Internationally, there is no regulation of the extent of weight reduction other than the prohibition of using laxatives and diuretics to lose weight. The lack of regulation at the international level combined with the 12- to 18-hour period between the weigh-in and competition may promote great percentages of weight loss at the international level, but the amounts have yet to be reported.

3.2 Effects of Weight Loss

3.2.1 Performance

Numerous studies have been done to examine the effects of rapid weight loss on physical performance by wrestlers. Performance indices include isometric strength, isokinetic strength, isotonic strength, anaerobic power, anaerobic capacity, muscular endurance, peak oxygen uptake (peak

$\dot{V}O_2$) and physical work capacity estimated from heart rate. In 1 case, a unique test was used to simulate manoeuvres and agility specific to the sport of wrestling (Klinzing & Karpowicz 1986).

The majority of the studies show that there is no statistical difference between anaerobic power, strength or peak $\dot{V}O_2$ uptake before and after rapid weight loss (table VI). Why rapid weight loss does not severely compromise power and strength during short, quick efforts is not known, but several plausible theories for a lack of a decrement in power performance can be formulated. First, the muscle is fairly self-contained for short duration, maximal efforts and is not dependent upon blood-borne nutrients such as glucose or oxygen. Therefore, a decrease in blood flow to the muscle during dehydration (Horstman & Horvath 1973) should not present a limitation. A second explanation is that the excitability of the muscle is fairly resistant to perturbations in the mineral and water content in the dehydrated state (Costill et al. 1976). This implies that the nervous system can still recruit the

Table VI. Effects of weight loss on performance

Level	No. of subjects	Mean weight loss (%)	Performance assessment	Effect on performance	Reference
Juniors	104	4.0	Grip strength	Strength increased but less than in controls	Freischlag (1984)
	15	5.0	Arm power	No change	Park et al. (1990)
College	10	0.4-3.85	Peak $\dot{V}O_2$	No change	Bock et al. (1967)
	4	3.0	Peak $\dot{V}O_2$	No change	Kelly et al. (1978)
	12	3.2	Leg power	No change or decrease depending on diet	McMurray et al. (1991)
	46[a]	3.5-4.2	Peak $\dot{V}O_2$ workload at peak	No change or decrease in peak $\dot{V}O_2$ depending on method of weight loss; decrease in workload	Caldwell et al. (1984)
	6	4.5	Isometric strength, reaction time	No change	Tuttle (1943)
	8	4.8	PWC predicted from heart rate	Decreased PWC	Herbert & Ribisl (1972)
	7	4.9	Isokinetic strength; leg power; peak $\dot{V}O_2$	Decrease in power, strength, and peak $\dot{V}O_2$	Webster et al. (1990)
	11	2-5	Leg power	No change	Jacobs (1980)
	8	5.0	Circuit drills	No change in time to complete 1st circuit; slower time for 2nd circuit	Klinzing & Karpowicz (1986)
	11	5.0	Isometric strength; isometric endurance	No change in strength or endurance	Serfass et al. (1984)
	12	6.2	Interval arm power	No change or decrease in power depending on diet	Horswill et al. (1990)
	10	7.1	Isometric strength	No change	Singer & Weiss (1968)
Seniors	32	Not listed	Isometric strength	No change or an increase	Ahlmann & Karvonen (1961)
	1	8.0	Isokinetic strength; isotonic strength	No change	Widerman & Hogan (1982)
	4	8.0	Peak $\dot{V}O_2$; anaerobic capacity; isokinetic strength	Decrease in strength only; no change in other tests	Houston et al. (1981)

a Other athletes also studied.

Key: Junior = adolescent competitor at the scholastic level; Senior = national team member competing at Olympic or international level; peak $\dot{V}O_2$ = peak oxygen uptake; PWC = physical work capacity estimated from heart rate of 170; arm or leg power measured with Wingate test.

muscle for a contraction. Finally, with rapid weight loss, there is not a decrease in the muscle concentrations of ATP and phosphocreatine, the primary energy source for brief, intense efforts (Houston et al. 1981).

In contrast to brief, high-power performance, sustained or repeated performance lasting more than 30 seconds at near-maximal effort appears to deteriorate with rapid weight loss (Horswill et al. 1990; Klinzing & Karpowicz 1986; Webster et al. 1990). Reduced muscle blood flow in the dehydrated state may slow nutrient exchange, waste removal and heat dissipation from the muscle during the relaxation between contractions and impede its ability to recover. Also, muscle glycogen is significantly decreased with rapid weight reduction (Houston et al. 1981). Finally, the buffering capacity of the muscle and blood may be compromised after rapid weight loss (Horswill et al. 1990). Therefore, the wrestler may not have the capacity to recover adequately after an intense effort, energy reserves for the subsequent performance remain low and subsequent physical performance is decreased.

In examining the effects of rapid weight loss on aerobic performance and cardiovascular fitness of wrestlers, Ribisl and Herbert (1970) and Herbert and Ribisl (1972) used heart rate as an indirect measure to show that physical work capacity was reduced. However, their conclusions may not be correct because physical work capacity was estimated from heart rate and not actually measured. Cardiovascular function during maximal work does not appear to be hampered according to Kelly et al. (1978) and Bock et al. (1967) who found no change in peak oxygen uptake after a reduction of up to 9.5% of bodyweight in collegiate wrestlers. Also, Houston et al. (1981) found no change in peak oxygen uptake following an average bodyweight loss of 8% by international-calibre wrestlers.

The major limitation of all previous studies on weight loss and physical performance in wrestlers is that inferences cannot be made to actual wrestling performance. Success in competitive wrestling includes large technical and psychological components; thus, it is difficult to extrapolate from performance in the laboratory to success on the mat in actual competition. In 1 study (Stine et al. 1979), the collegiate wrestlers who achieved All-American status, an indicator of success, tended to lose more weight than did those who failed to achieve All-American status, although the difference may not have been statistically significant. Currently, investigations are under way to determine the relationship between bodyweight variation and success in tournament competition.

3.2.2 Diet

No reports are available about the practices of international competitors and only 2 reports are available on collegiate wrestlers. Steen and McKinney (1986) found that college wrestlers from several universities consumed diets composed of approximately 15% protein, 33 to 37% fat and 43 to 47% carbohydrate, the composition being somewhat dependent on the time of the season (preseason, mid-season, etc.). During periods of weight reduction, the authors found that 37% of the wrestlers studied consumed less than two-thirds of the recommended dietary allowance (RDA) for energy; the authors indicate, though, that this prevalence is likely to be an underestimate. While exact values for energy intake were not reported, Steen and McKinney (1986) observed that for one 53.6kg wrestler, daily energy intake ranged from 334 kcal on the day before a match to 4214 kcal the next day after 'making weight'. Regardless of whether the wrestlers were attempting to reduce bodyweight, the authors found deficiencies in the intakes of B_6, vitamin A, vitamin C, zinc, magnesium, thiamine and iron.

Short and Short (1983) report that collegiate wrestlers at one university consumed diets that were 29 to 39% fat, 40 to 53% carbohydrate, and exceed 1g of protein per kg bodyweight per day. Comparing energy intake over a year, average intakes varied from 1964 kcal/day in-season to between 2634 and 3667 kcal/day before and after the season, respectively. Unfortunately, the sample size varied for each period of data collection so it is not possible to conclude whether intake actually decreased. However, like Steen and McKinney (1986), the authors cited great day-to-day variability. Specifically, 1 wrestler's energy intake varied from 78 kcal/day to 11 000 kcal/day, depending upon whether the athlete was attempting to 'make weight'. Wrestlers' diets tended to be low in vitamin A, thiamine, iron and vitamin C, as well as calcium, riboflavin and niacin during weight loss. In the post-season assessment, only vitamin A intake remained low.

Among scholastic wrestlers, where dietary deficiencies may have a greater impact because growth is still occurring, Horswill et al. (1990c) observed that the mean daily calorie intake in the preseason was approximately 41 kcal/kg. The composition of the energy was roughly 52% carbohydrate, 34% fat and 14% protein with the protein intake averaging well over 1g/kg bodyweight. During the season when the wrestlers were losing weight, energy intake decreased 37% to approximately 27 kcal/kg. At the reduced level of energy intake, all macronutrients were signficantly lower although the average protein intake remained at 0.9 g/kg, which was greater than the RDA for these subjects (Committee on Dietary Allowances 1989). Micronutrient intakes were not analysed. It is likely, though, that with decreased intakes of macronutrients, the diets of these adolescent wrestlers would be deficient in some of the micronutrients during the season.

3.2.3 Metabolism

Research on animals and humans who repeatedly lose and regain weight (called 'weight cycling') suggests that the resting metabolic rate may be permanently suppressed. This finding has spurred an interest among sports scientists studying wrestling because wrestlers may 'weight cycle' 15 times in a season and 100 times in a career (Steen et al. 1988; Steen & Brownell 1990). One group of researchers used a cross-sectional design to show that during the off-season, scholastic wrestlers who practised weight cycling to make weight for competition had a significantly lower resting metabolic rate than wrestlers of equal size, age and body composition who did not weight cycle (Steen et al. 1988). In contrast, other researchers found a transient decline in metabolic rate of collegiate wrestlers (Melby et al. 1990). Once weight was regained, the resting metabolism returned to the preseason rate. Interestingly, these latter researchers report that wrestlers had metabolic rates far in excess of predicted values and significantly greater than rates of a nonwrestling but active reference group. If anything, rapid weight loss appeared to normalise temporarily the metabolic rate of the wrestlers to the level of the reference group.

The concern over the reduced resting metabolic rate is that, later in life, the former wrestler who had practised 'weight cycling' may have problems controlling his weight and may be susceptible to obesity (Steen et al. 1988). One recent account supports this hypothesis using survey information of past practices for weight loss and current weight-for-height of former college wrestlers (Gunderson & McIntosh 1990). However, the conclusion of greater risk among wrestlers who 'weight cycled' may be incorrect without the measurement of body composition. The genetic disposition of one who wrestled in college would probably cause more muscle-for-height and therefore a greater weight-for-height value than the average nonwrestler of a similar age.

In terms of metabolism during exercise after rapid weight loss, an increase in fat utilisation and decrease in carbohydrate oxidation is hypothesised. McMurray et al. (1991) support this by showing that after a 3.2% weight loss, fat oxidation increased by 8 to 11% in college wrestlers performing a standardised exercise bout. Elevations in plasma glycerol levels before exercise (Horswill et al. 1990a) and an attenuated lactate response after a standard exercise (Horswill et al. 1990; McMurray et al. 1991) have been reported in college wrestlers. The reduction of carbohydrate utilisation could be due to the reduction of muscle glycogen (Houston et al. 1981) or potentially the weight loss–induced elevation of plasma free fatty acids, which suppress glycolysis (Randle et al. 1963).

Regarding other metabolic changes, no changes were found at rest for haemoglobin concentration, haematocrit, lactic acid concentration and pH after rapid weight loss (Horswill et al. 1990); however, blood base excess was found to be significantly lower than at rest before weight loss. The decrease in base excess was hypothesised to be caused by excess ketone body production, which is known to occur with restricted food intake (Cahill 1976). Zambraski et al. (1975) report that 17 to 18% of their scholastic wrestlers exhibited ketonuria at the time of the weigh-in after weight loss.

Mnatzakanian and Vaccaro (1984) found that dehydration by collegiate wrestlers increased serum concentrations of sodium, potassium and haematocrit but decreased the plasma volume. The authors further found that after a brief, 5-hour period of rehydration, all haematological values returned to normal levels. The increase in haematocrit (Mnatzakanian & Vacarro 1984) is not necessarily a contradiction to the recent report of Horswill et al. (1990). Caldwell et al. (1984) report that the method of weight loss affects haematocrit, haemoglobin and serum electrolytes in different ways.

Finally, researchers observed that rapid weight loss contributed to changes in the lipoproteins of wrestlers (Jauhiainen et al. 1985). Depending on how the weight was lost, i.e. exercise *vs* thermal dehydration *vs* diuretic use, wrestlers showed increases in apoprotein levels (in the case of thermal dehydration and diuretic use) or no change with instead increases in high density lipoproteins and decreases in triglycerides (with exercise-induced dehydration). Because changes were not consistent among all lipids, it is doubtful that the increases were simply due to a concentration effect of the loss of plasma volume.

3.2.4 Nutritional Status

With the need to make a competitive weight class one change in nutritional status is a reduction in body mass. The magnitude of this reduction varies among wrestlers. From published data (Tipton & Tcheng 1970), it can be estimated that the median level of weight loss in scholastic wrestlers is between 4 and 5% of bodyweight, and approximately 65% of the wrestlers lose between 4 and 9% of bodyweight in a relatively short time (17 days) before competition. The lightest wrestlers, who tend to be the leanest, lose the greatest amount of weight relative to their preseason weight (Landwer et al. 1975; Tipton & Tcheng 1970).

Other research supports the findings of Tipton and Tcheng. Steen and Brownell (1990) compared scholastic and collegiate wrestlers and found that per week collegiate wrestlers lose more weight than scholastic competitors. Because the authors present weight loss in absolute amounts only, percentages are estimated from their data by assuming that on average scholastic wrestlers weigh 63kg and collegiate wrestlers weigh 69kg. The estimates suggest that 49% of scholastic wrestlers lost between 2 and 3.6% of bodyweight per week while 82% of the collegiate wrestlers lost between 3.9 and 13.2% of their bodyweight. This estimate for college wrestlers is supported by Stine et al. (1979) who reported that competitors at the NCAA tournament lost 10 to 12% of their preseason bodyweight.

The reduction in bodyweight is accomplished by reductions in fat and fat-free weight. Using skinfold thicknesses and bodyweight, Park et al. (1990) estimated that scholastic wrestlers lost significant amounts of fat mass (1.6kg) and fat-free mass (1.7kg) during 12 weeks of the competitive season. Loss of lean tissue can also be estimated from the data of Freischlag (1984). Of a 2.7kg weight loss, approximately 2.1kg was lean tissue. In comparison, nonwrestling control subjects gained approximately 7.7kg of lean tissue over the same 12-week period (Freischlag 1984). Loss of glycogen may also contribute to the decrease in bodyweight. A 50% reduction in muscle glycogen occurred in international level wrestlers who trained and restricted foods and fluids under an experimental situation to 'make weight' (Houston et al. 1981).

Concluding that wrestlers lose lean tissue on the basis of indirect measurements could be erroneous because of the limitations of anthropometry. However, the loss of fat-free weight is supported by a very recent report (Roemmich et al. 1991) in which a criterion method of assessing fat-free mass (underwater weighing) was used. The authors report that scholastic wrestlers lost 0.9kg of fat-free weight when 1.9kg of absolute weight was lost. In a case study using underwater weighing, a competitor at the international level (Widerman & Hagen 1982) was measured to have lost 2.2kg and 2.1kg of fat-free weight and fat mass, respectively, as the wrestler approached the date of competition.

The effects of rapid weight loss on the change in body composition have led some to speculate that weight loss may stunt growth in young wrestlers (Hansen 1978; Smith 1984). However, no one has ever conducted a well controlled study of the effects of rapid weight loss and dieting on linear growth or growth velocity of young wrestlers. Furthermore, the results of the previously described studies utilising direct measures of body composition of wrestlers are questionable because all methods of assessment assume normal hydration. In reality, rapid weight loss causes large reductions in body water, which will affect the methods of assessing body composition and therefore may distort the estimated change. For example, acute dehydration can change the body density (Girandola et al. 1977) or bioelectrical impedance values (Brodie et al. 1991), such that a decrease in fat-free weight would be calculated in spite of the fact that the dry mass of skeletal muscle and bone tissue would not have truly changed.

Despite the lack of any well controlled studies on the growth rate of wrestlers during weight loss, there are biochemical data to suggest that the protein nutritional status of wrestlers is adversely affected by weight loss. The concentrations of rapid turnover plasma proteins commonly used to assess protein nutritional status (Shetty et al. 1979; Smith et al. 1975) were reported to decrease significantly in scholastic wrestlers studied for 12 weeks of their competitive season (Horswill et al. 1990). Specifically, plasma levels of prealbumin and retinol-binding protein decreased by 17 and 19%, respectively. Additionally, a significant decrease (7%) in the ratio of total essential amino acids to total amino acids in the fasting state was also observed (Horswill et al. 1990).

3.2.5 Endocrine

Weight loss may affect the endocrine function of wrestlers. Low concentrations of serum testosterone and prolactin have been reported in collegiate wrestlers during the competitive season when bodyweight and body fat were much reduced compared to postseason values (Strauss et al. 1985). Testosterone levels were 32% lower in-season than postseason, and in-season testosterone levels were directly correlated with the percentage body fat ($r = 0.72$). Despite finding a diminished protein nutritional status in scholastic wrestlers who had decreased their weight by 6.6%, changes in testosterone were not detected (Roemmich et al. 1989). Possibly because the scholastic wrestlers did not lose as much weight or decrease percentage body fat to the same levels as did the collegiate wrestlers (Strauss et al. 1985), there was not as much stress on the endocrine system of the scholastic wrestlers.

More recently, it was reported that in association with experimental weight loss in collegiate wrestlers, insulin-like growth factor I (IGFI) was decreased and growth hormone increased (McMurray et al. 1991). Under eucaloric conditions, an increase in IGFI is expected in conjunction with an increase in growth hormone because IGFI mediates the growth effects of growth hormone. The uncoupling of this relationship may be a mechanism by which growth is slowed or stopped when energy intake is restricted (McMurray et al. 1991). The implications are not as profound in the 'close to fully grown' college-age wrestler, but similar changes in the adolescent wrestler during weight loss might contribute to a slowed or stunted growth, at least temporarily.

3.2.6 Renal Function

Dehydration-induced weight loss decreases the plasma volume, which contributes to decreased blood flow to the kidneys (Zambraski et al. 1976). Consequently, dehydration in wrestlers is associated with decreased urine production, increased acidity and specific gravity of the urine, and the leakage of albumin and a kidney enzyme (leucine amino peptidase) into the urine (Zambraski et al. 1974, 1975, 1976). The presence of leucine amino peptidase is of concern since the appearance of this enzyme in the urine has been linked to mild renal ischaemia (Mason et al. 1964). The adverse changes remained present in the scholastic wrestlers even after a period of rehydration between the weigh-in and competition (Zambraski et al. 1976).

The changes observed by Zambraski et al. (1976) were similar to those seen by Mnatzakanian and Vaccaro (1984), who reported a decrease in sodium and an increase in the specific gravity of urine of collegiate wrestlers after a 4% reduction of bodyweight. The authors found that the changes were transient and in fact returned to near normal conditions in 5 hours, after the wrestlers were allowed to rehydrate. The time allowance of 5 hours for recovery between the weigh-in and competition is typical for the collegiate wrestler, whereas the scholastic wrestlers studied by Zambraski et al. (1975) had less time for recovery. There is no indication of whether the practice of dehydration causes any sustained damage to the kidneys of wrestlers later in life.

3.2.7 Thermoregulation

To date, no research has been conducted on how rapid weight loss affects thermoregulation in wrestlers.

Dehydration is a common method of weight loss among wrestlers. In other research, dehydration has been shown to decrease blood flow to the skin (Claremont et al. 1976) and muscles (Horstman & Horvath 1973). Consequently, an athlete's ability to sweat is decreased (Sawka et al. 1983), his temperature regulation is compromised, and the deep-body (core) temperature of the athlete rises (Claremont et al. 1975). With prolonged exercise or heat exposure, the athlete may be stricken with heat exhaustion or heat stroke. Because wrestlers are not likely to be fully rehydrated by the time they compete (Costill & Sparks 1973; Vaccaro et al. 1976; Zambraski et al. 1975) the ability to regulate body temperature and dissipate heat may be compromised. Potentially, there may be a percentage of wrestlers at risk for heat exhaustion or heat stroke at the time of competition; however, there are no data to substantiate this.

3.2.8 Other Medical Concerns

Case reports have cited pancreatitis (McDermott et al. 1956) and pulmonary embolism (Croyle et al. 1979) in association with rapid weight loss in wrestlers. Because rapid weight reduction has been shown to reduce phagocytic function of monocytes in athletes (Kono et al. 1988), there is speculation that wrestlers who practise weight loss may suppress the immune system and become more susceptible to illness during the competitive season. However, research findings would not support this. The rate of illnesses was not greater during the competitive season for scholastic wrestlers compared with nonwrestling controls (Freischlag 1984) or collegiate wrestlers compared with other college athletes who did not attempt weight loss during the competitive season (Strauss et al. 1988).

Psychologically, weight loss appears to affect wrestlers. Morgan (1970) has shown that collegiate wrestlers become more focused at the time of the weigh-in immediately after a period of rapid weight loss. This change may be considered positive for competitive purposes but other psychological variables are altered undesirably. Specifically, ratings of fatigue, tension, anger, depression and confusion increased while ratings of vigour decreased after rapid weight reduction in collegiate wrestlers (Horswill et al. 1990). It is not known whether the psychological effects of rapid weight loss impact on performance and physical health of the wrestler.

3.3 Interventions

The implication of these findings on the effects of rapid weight loss on performance by wrestlers is that rapid weight loss most probably will not impair power or strength and, in fact, might enhance these capacities relative to bodyweight (Jacobs 1980). It is possible to speculate then that rapid weight loss allows the wrestler to compete against a relatively weaker opponent. More importantly, the wrestler who does not practise rapid weight loss ends up in the role of the less powerful opponent.

The adverse consequences of rapid weight loss appear to be the loss of endurance and the physiological changes, described above, that are potential health risks. Therefore, 2 interventions have been attempted, one to help maintain muscular endurance for performance, and the other to limit the degree of rapid weight loss and thereby prevent health risks.

3.3.1 Dietary Manipulations for Performance

Complete rehydration and replenishment of muscle glycogen is thought to require at least 48 hours (Houston et al. 1981; Vaccaro et al. 1976; Zambraski et al. 1976). Therefore, the time between the weigh-in and competition is not considered sufficient for the recovery and optimal performance of the wrestler who has dehydrated and reduced muscle glycogen in the process of making weight, and wrestlers are warned not to lose weight rapidly for performance reasons (American College of Sports Medicine 1976).

Presently, though, no one has investigated the effects of different nutritional treatments on the wrestler's recovery or partial recovery between the time of the weigh-in and competition. While a complete recovery is not likely, partial recovery will occur in as little as an hour. Specifically, plasma glucose levels can be elevated (Fielding et al. 1987; Foster et al. 1979), muscle glycogen can be synthesised (Hultman et al. 1971; Ivy et al. 1988) and water can be absorbed to partially restore plasma volume (Allen et al. 1977; Costill & Sparks 1973), which helps restore cardiovascular dynamics in wrestlers (Allen et al. 1977). Because little is known about recovery after combined dehydration and glycogen depletion, this is an area for future research. The strategy that a wrestler takes for his recovery could have profound implications for performance particularly considering that, for tournaments at the US collegiate and international levels, competitors have 12 to 18 hours between the weigh-in and competition (i.e. the weigh-ins occur the afternoon or night before competition).

In an attempt to prevent loss of muscular endurance, the effect of a high carbohydrate diet during the days of training and weight reduction was investigated (Horswill et al. 1990). Muscular endurance during arm ergometry was found to be maintained when collegiate wrestlers consumed a high carbohydrate diet despite consuming a diet that was hypocaloric for the benefit of weight loss. In contrast, the same wrestlers showed a significant reduction in performance when fed a low carbohydrate diet equal in calories to the high carbohydrate treatment. The amount of weight loss was kept constant during the 2 weight loss periods for each wrestler.

Similar results have been shown in other groups of wrestlers (McMurray et al. 1991) and in weightlifters who use weight reduction methods similar to wrestlers (Walberg et al. 1988). McMurray et al. (1991) report that anaerobic power as measured by the Wingate test was maintained when wrestlers consumed a hypocaloric, high percentage carbohydrate diet. In contrast, the wrestlers consuming a hypocaloric, normal percentage carbohydrate diet lost a significant amount of anaerobic power (McMurray et al. 1991). Walberg et al. (1988) detected decrements in muscular endurance of weightlifters fed a low carbohydrate, high protein diet compared with weightlifters who maintained muscular endurance on a diet matched in calories but of a higher carbohydrate content. On the negative side, the subjects on the high carbohydrate diet appeared to lose more body protein than those subjects receiving higher daily amounts of protein (Walberg et al. 1988). These observations (Horswill et al. 1990; McMurray et al. 1991; Walberg et al. 1988) lend support to the recommendation of Steen and McKinney (1986) that wrestlers should consume at least 55% of their daily energy intake as carbohydrate.

3.3.2 Minimal Weight Estimation

The alternative to nutritional treatments for maintaining optimal performance in the face of rapid and severe weight loss is to regulate the amount of weight that a wrestler can lose. In the late 1960s in the US, research was conducted to determine if anthropometric techniques could be used to predict accurately the amount of weight that a wrestler could safely lose (Tipton et al. 1969). While the results of the study were promising, the methods were not widely publicised to coaches and the implementation of anthropometric testing for minimal weight was left to individual coaches and schools. As a consequence, the practice was not widely adopted.

Concern over rapid weight loss in wrestlers has prompted position statements by 2 voices of the medical community in the US. The American College of Sports Medicine (1976), in offering guidelines for weight loss in wrestlers, identifies the lowest (minimal) wrestling weight that will sustain good health and performance in the competitor as that weight at which 5% of the body is fat. The American Medical Association (Committee on Medical Aspects of Sports, 1967) also issued a position against rapid weight loss in young males who compete in wrestling.

Very recently in the US, programmes have begun under the jurisdiction of the scholastic athletic associations, or sport governing bodies at the scholastic level in individual states. The programmes involve predicting a minimum wrestling weight using anthropometry prior to the beginning of the season. The minimum weight establishes the lowest weight at which a wrestler can compete.

This alternative approach capitalises on minimising the amount of lean tissue and glycogen weight lost and optimising the amount of weight lost by decreasing body fat. In application, wrestlers are measured for skinfold thickness approximately 1 month before the start of the season. The results are used to calculate percentage body and fat-free weight using a population-specific equation. Minimum weight, defined as the weight at which the athlete will have 5% body fat (American College of Sports Medicine 1976), is then calculated by dividing the fat-free weight by 0.95.

Modifications of the programme vary from state to state. In some cases, 7% is set as the minimum leanness (in which case fat-free weight is divided by 0.93). Also, an allowance for measurement error of 2 to 3% may be given to the wrestler. If the wrestler contests the determined value and demands to wrestle at a lower weight than estimated, he may be remeasured by a direct method such as underwater weighing and then must present his case before the sport governing body.

It is possible and likely for a wrestler to be measured for body fat and be in excess of the 5% limitation but still use dehydration and other rapid weight loss techniques to reduce his bodyweight for competition. This practice would defeat the purpose of the minimum weight estimation. In light of this, it has been suggested that urinary specific gravity be measured at the time of the official weigh-in to disqualify a wrestler who shows signs of dehydration, i.e. a urinary specific gravity of over 1.015 (Hursh 1979). While the suggestion is in some ways a practical means to discourage dehydration (e.g. ease of measuring urine specific gravity using a hydrometer), it needs further thought and investigation. Specifically, a urine sample may be difficult to obtain from wrestlers who are anxious about competing or giving a urine sample. Also, the 'normal' variability of specific gravity of urine in adolescent males must be well established before a value for disqualification can be instituted.

Research continues on the cross-validation of the techniques for measuring minimum weight (Housh et al. 1989; Oppliger & Tipton 1988), on the development of equations for minorities that compete in wrestling (Roby et al. 1991) and on using new techniques to accurately and more precisely predict minimum weight (Horswill et al. 1990b; Oppliger et al. 1991). With continued research, problems such as invalid assumptions on the body composition of the wrestlers (Horswill et al. 1990b) and the lack of stability in the minimum weight value in the same individual over the course of the competitive season (Clarke 1974) may be solved. Provided solutions to these problems are found and the minimum weight programme can be self-sustaining financially and adequately enforced, the practice of drastic weight loss may come to an end, at least for scholastic wrestlers in the US.

4. Directions of Future Research

With a paucity of data on wrestling there are many paths for future research to take. Research on acute effects could include verification of the rate of energy expenditure during intense wrestling, the role of acid-base balance in fatigue, and the interaction of aerobic and anaerobic energy systems during wrestling and recovery between matches. The long term effects that need investigation include the influence of wrestling isolated from other types of training on: (a) the development of anaerobic pathways for energy metabolism during performance; (b) cardiovascular changes such as the left ventricle dimensions or peak oxygen uptake during upper body work; and (c) changes in the lean body mass, specifically muscle hypertrophy and bone mineralisation.

Another area for future research is that of optimal training for the sport. This might include examining the most effective use of wrestling, i.e. continuous versus interval wrestling, to produce the fitness levels needed for success. Overtraining in the wrestler should be studied also because wrestlers have a long season of competition at the scholastic and collegiate levels; lack a period for tapering and recovery during the season because of having to make weight; and may deplete carbohydrate or other critical nutrients stored in the body with repeated weight loss during the season. Research suggests that carbohydrate depletion is a symptom and possibly a causal factor of the overtraining syndrome (Costill et al. 1988).

Finally, because of the potential effect of weight reduction on physiological capacities and performance, future studies must account for the impact that dietary practices and weight reduction may have on the wrestler. In other words, the interaction between training adaptations and the effects of weight loss, short or long term, must be examined before appropriate or optimal training programmes can be identified for the sport. In addition, the long term effects of weight loss on the health (immune status, digestive function, renal function, etc.) and growth of the wrestler must be clarified. Such research should also include evaluating minimum weight programmes based on the body composition for their effect on the health and performance of the wrestler.

5. Conclusion

Amateur wrestling appears to demand well developed capacities for strength, power and muscular endurance relative to bodyweight. Also important but to a lesser degree are cardiovasular endurance, flexibility and reaction time. Because of the absence of research on the effects of training for wrestling, it is not known whether these physiological attributes are inherent in the wrestler or are developed as a part of training for the sport. The nutritional status and potentially the performance of the amateur wrestler may be susceptible to detrimental effects of dietary manipulation and other practices used to reduce bodyweight to the desired competitive weight class. To this point, however, research studies fail to show unequivocally that the wrestler's performance on the most is diminished or enhanced as a result of weight reduction.

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