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Applied Physiology of Water-Skiing

Scott H. Leggett, [1] Kevin Kenney[1] and Terry Eberhardt[2]

1 UCSD Orthomed, La Jolla, California, USA

2 Eberhardt Physical Therapy, Shreveport, Louisiana, USA

Contents

Summary Water-skiing is a physically demanding sport involving highly coordinated movements, extreme upper body torques, sustained isometric contractions and near maximal stresses on the anaerobic system. Due to the physical demands of the sport, elite skiers have developed physiological characteristics similar to other elite athletes. However, until recently little research has focused on the kinesiology, physiology and physical conditioning of water-skiing.

Competitive water-skiing requires significant physiological attributes specific to the sport. The process of turning a slalom ski (fig. 1), taking off from a 1.83mjump (fig. 2), or manoeuvering a trick ski (fig. 3) involves factors of which many people are unaware of.

In short, a slalom ski course consists of 6 buoys and 2 end-gates. A successful pass consists of skiing through both gates and around each buoy in approximately 18 seconds without falling. A tow boat will stop briefly at the end of each pass and shorten the tow line, until the skier misses a buoy or falls in the course.

The anaerobic power, muscular strength and skill required for this event are remarkable. Isometric torques in excess of 950 N • m and speeds over 80 krn/h have been observed in the slalom course at the professional level (American Water Ski Association, personal communication). The rope length at this level of competition literally does not match the perpendicular distance between the tow boat and the buoy. Thus, skiers must use the length of their body to extend around the buoy.

The trick event is similar to the slalom event except the rope length is held constant while the skier performs in a straight path. Two consecutive trials are allowed to perform as many tricks as posSible in 20 seconds. Boat speed may vary depending on the sex and skill of the skier. In similar fashion, the jump competition allows 3 consecutive passes (jumps) with brief rest periods between each pass. Jump lengths will vary and the world record is set at over 61m (220 feet).

To date, there is a paucity of data in the scientific community on the sport of water-skiing. Therefore, the purpose of this article is 3-fold: first, to describe the muscular demands of the sport; secondly, to review the physiological profiles of water-skiers; and thirdly, to review the rationale of current recommended training regimens for waterskiers.

Fig. 1. The process of turning a slalom ski.

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Fig. 2. A skier taking off from a 1.83m jump.

1. Musculature Requirements

There are 3 events for traditional water-skiing: slalom, jump and tricks. In the sections which follow, the anatomical components required for the slalom and jump events are analysed for muscular conditioning implications. Since the trick event requires so many variations of movements and is so individualised, we have chosen not to critique the exact muscular requirements of this event. The muscles used in the 3 phases of slalom and jump turns are summarised in table I.

1 .1 Slalom

There are 3 phases in the slalom turn.

7.7.1 The Deceleration Phase

The deceleration phase is when the skier begins to slow their ski down to initiate the turn. Normally it begins as soon as the skier has crossed the second wake behind the boat, however at slower boat speeds she/he may have to wait until 2 to 3m after the second wake. In other words, deceleration and the changing of the edge of the ski to help facilitate deceleration varies according to boat speeds and rope lengths. The faster the skier travels, the sooner they must start.

Anatomical position of the shoulders should be erect, facing square to the shore with the knees and ankle bent as far forward as possible, and with the handle held close into the body with arms flexed. This action requires sustained isometric contraction of the quadriceps, gluteus maximus, latissimus dorsi, biceps and forearm flexors. Proper body position is maintained by strong continuous contraction of the rectus abdominis, trapezius, back extensors, hip flexors, gluteus maximus and the calf (gastrocnemius and soleus).

From this proper body position, the edge change is quite smooth and quick. The speed that is accu-

Fig. 3. A skier manoeuvering a trick ski.

mulated from the pull through the wakes keeps momentum going away from the buoy as the waterskier begins the deceleration phase. This is when the skier rolls the ski onto its inside edge. This action puts weight on the front of the ski, thus unweighting the tail of the ski so it can begin to decelerate for a smooth turn.

The knees are pushed forward while keeping the upper body in the same position. This requires coordinated contraction of the hamstrings and quadriceps, while the hip muscles (flexors and extensors) control the motion of shifting the ski to the inside edge. At the same time as the skier changes edges and pushes with the knees, the outside hand comes off the handle and starts the second phase of the turn called the reach.

7. 7.2 The Reach Phase

The reach phase begins as the skier starts to extend their inside arm towards the direction of the pull of the boat. The skier does not put the handle

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down towards the water nor above the shoulder, but reaches out to a natural position and allows room to get around the buoy. Strong contraction of the latissimus dorsi and pectoralis major is required for execution of this action, as well as a firm grip from the forearm flexors. The skier must stay in the correct position and force the head to stay up. Proper execution requires the rectus abdominis, neck extensors, gluteus maximus, quadriceps and calf to stabilise and maintain this correct position. During the reach, the ski rolls onto its inside edge even more, which in turn slows the skier down and sets her/him up for the turn, and the final phase of the turn — the acceleration phase.

l. 1.3 The Acceleration Phase

The acceleration phase is very important in finishing the slalom turn. One of the keys to achieving a great run is the pulling in of the handle quickly at the end of the turn.

In order to bring in the handle (towards the skiers torso), the skier must have reached (maximally) toward the boat during the turn. At the finish of the turn, the handle needs to be pressed against the outside hip to ensure proper anatomical body position for the pull. To get it there requires 2 motions, and they involve both arms and great strength.

Using the handle arm, the skier pulls the handle straight in toward the outside hand utilising the latissimus dorsi, biceps and forearm flexors. The skier must reach straight out, then pull straight in. The outside elbow is lifted up to shoulder height to keep the body up and balanced. The outside hand is kept about waist high to be ready to retrieve the handle quickly. At the same time, the outside arm reaches for the handle, meeting it about half way. The motion of the outside arm coming to meet the handle helps to turn the shoulders toward the wake, in the direction of the pull and increases acceleration.

Positioning of the arms and pulling the handle to the hip primarily requires the latissimus dorsi, trapezius, deltoids, biceps and forearm flexors. The back extensors keep the back flexed, and the shoulders and chest are held up and erect by contraction of the trapezius and rhomboids. The arms are in at

Table l. Muscles used in the 3 phases of slalom and jump

Deceleration phase
Rectus abdominus
Biceps
Forearm flexors
Hip flexors
Gluteus maximus
Quadriceps
Gastrocnemius and soleus
Latissimus dorsi
Back extensors
Trapezius
Reach phase
Pectoralis major
Latissimus dorsi
Rectus abdominus
Forearm flexors
Gluteus maximus
Quadriceps
Gastrocnemius and soleus
Neck extensors
Acceleration phase
Latissimus dorsi
Rectus abdominus
Upper trapezius
Rhomboids
Biceps
Forearm flexors
Deltoids
Back extensors
Gluteus maximus
Quadriceps
Hamstrings
Gastrocnemius and soleus

the centre of gravity while the ankles, knees and hips are slightly bent. This is maintained through isometric contraction of the leg muscles (gluteus maximus, hamstrings, quadriceps and calf).

1 .2 The Jump

1.2.7 Deceleration and Turn Phase

The deceleration and turn phase begins as the skier is gliding up on the right side of the boat and begins to slow the jump skis down by edging out away form the boat. With precise turning the skier manoeuvres the skis approximately 90^0 to the left while trying to maintain as much water speed as possible. This phase is very important because the skiers must begin with good anatomical position in order to prevent the boat from pulling them out of position when they begin the acceleration phase. The anatomical position begins with the shoulders erect, facing square across the boat wake, with the knees and ankles bent forward pushing 70 to 80% on the right ski and 20 to 30% on the left ski. The handle is held down at the centre of gravity with the right arm flexed at the elbow and the left arm slightly extended and reaching across the body. Skiers try not to allow the boat to pull their arms and shoulders out of this position because this would allow their skis to flatten out and lose the acceleration and direction needed to make it to the jump and to achieve maximum distance. This action regains sustained isometric contractions of the quadriceps, hamstrings, gluteus maximus, latissimus dorsi, rotator cuff, biceps, and forearm flexors. Proper body position is maintained by strong continuous contractions of all the muscles mentioned above. This position takes the skier to the acceleration and cut phase.

1.2.2 Acceleration and Cut Phase

The acceleration and cut phase begins after completion of the turn and is carried through the jump ramp. This cut phase should be a pendulum type cut that is completed as the skier leaves the jump ramp. The two most important aspects of the cut are: first, the timing which allows skiers to begin the acceleration and build it considerably until they contact the jump ramp. Secondly, the body position must be maintained in order to achieve maximum acceleration and maximum lift off the jump ramp.

1.2.3 The Extension and Lift Phase

The extension and lift phase occurs at the time of impact with the jump ramp, there is only a brief opportunity to get maximum extension of legs and hips while the skier is on the jump ramp. This extension is very important in achieving maximum lift and distance. The anatomical position begins with an even back and shoulders, and by extending the hips and legs at the precise time of input onto the jump ramp. This position requires precise tim-

Table II. Descriptive characteristics of professional (Prof.) and junior (Jr) elite water skiers

Skiers	Age	Height	Weight	Body fat	Fat-free weight	Fat weight
	(years ± SD)	(cm ± SD)	(kg ± SD)	(0/0 ± SD)	(kg ± SD)	(kg ± SD)
Jr elite males (n = 26)	15.9± 1.2	174.6±9	65.6 ± 11.6	7.2 ± 3.1	63.3 ± 8.7	5.9±3.1
Jr elite females (n = 26)	15.3±1.2	164.6 ± 6.1	56.2 ± 7.3	17.5 ± 4	45.8 ± 5.5	10.5 ± 3
Prof. males	26 ± 4.1	182.5 ± 3.4	77.8±3.1	7.6 ± 2.5	71.5 ± 8.4	6.0 ± 2.3
Prof. females	25.2 ± 6.2	162.8 ± 5.3	55.5 ± 4.0	17.1 ±3.o	45.9 ± 6.4	9.5 ± 2.4

Abbreviation: n = number of skiers; SD = standard deviation.

ing and quick contraction of the quadriceps, hip extensors, gluteus maximums and back extensors.

2. Descriptive Characteristics of Water-Skiers

The only physiological profile reported for this sport is at the professional level. Leggett et al.[141 have reported a thorough description of this group and how they compare to other elite and professional athletes. We will review these comparisons again in the context of this chapter.

Currently, there are no data reported on junior water-skiers in the literature. Nor are there many comparative data to junior athletes. Therefore, for the purposes of this chapter, we will report on our experiences with 4 consecutive elite junior testing camps (1990 to 1994) held at the United States Olympic Training Center in Colorado Springs.

We have chosen to contrast the junior elite skiers with the professional (senior) skiers in order to provide a more comprehensive profile. In addition no data are available for weekend or nationally competitive amateur skiers. We are hopeful that these data may formulate the basis of normative data so that comparisons of future elite skiers can be made.

2.1 Body Composition

2.7.7 Professional

Leggett et al.[21 '221 reported an average percentage body fat for the professional water-skiers of 8 and 17% respectively for males and females (table II). These values are less than values reported for sedentary men (13.4%) and women (24.8%) of

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similar age. Both male and female professional water-skiers' low body fat is comparable to elite endurance athletes, except for elite distance runners who have considerably less percentage body fat.[9'201 Professional skiers are also comparable to power sport athletes such as speed skaters. Pollock et. al.[241 reported male speed skaters to average 7.4% and female speed skaters, 16.5% body fat. Total bodyweight and fat-free weight (FFW) are also similar for professional male water-skiers and speed skaters. Percentage fat for professional female water-skiers is similar to the female speed skaters but their total bodyweight and FFW are somewhat higher.

Percentage fat for male professional soccer players is approximately which is slightly higher than the values noted for male professional skiers. Average percentage fat for football players has been reported at approximately 13%. By position, Gettman et al.[5J and Wilmore & Haskell[301 have reported defensive backs to be considerably leaner (6.7 and 8.3% fat, respectively) than the players at other positions. Although the percentage fat for football defensive backs is similar to male water-skiers, their total weight and FFW are about 10% higher than the male water-skiers.

2.1.2 Junior Elite

The average percentage body fat for the junior elite skiers was 7 and 17.5% respectively for males and females (table Il). Total bodyweight and FFW were higher for the male professional skiers when compared to the junior males. The comparisons were similar between the professional and junior females (table II). These comparisons seem reasonable in that females by this age are closer to mature bodyweight than are the males. The lower FFW for the junior males is due to age related development.

In summary, these data lend support to a characteristic body composition profile for waterskiers. Professional water-skiers and football backs, are average in height for athletes, but are heavier and have more FFW than the average person. Raven et. al.[1 61 suggested the low percentage fat of elite runners and soccer players to be related to the amount of aerobic training used in preparation for those two sports. Since professional waterskiers and football backs do not traditionally perform high levels of aerobic training, this would not be a reasonable explanation. Therefore, many of the training responses noted may be due primarily to the volume of water-skiing performed and/or natural selection. Due to the fact that the junior males were similar in percentage body fat to the professional male water-skiers and football backs, this characteristic body composition is more likely due to natural selection since the volume of skiing by the juniors has not yet reached that of the professionals.

2.2 Aerobic and Anaerobic Power

2.2.7 Professional

Although water-skiing does not require a high level of lower body aerobic power, it may be advantageous during competition and training. Since training volume is normally high, a higher aerobic power may help resist fatigue from repeated anaerobic activity.

Aerobic power for professional and junior elite water-skiers is greater than values reported for sedentary populations of similar age (table Ill). Comparison of aerobic power of professional water-skiers with athletes from other sports show them to have moderate levels of endurance capacity. Historically, athletes participating in sports requiring high levels of anaerobic power maintain V02max values ranging from 49.2 ml/kg/min for professional football players[5,301 to approximately 57 ml/kg/min for weight lifters.[171 On the other

Table Ill. Aerobic and anaerobic comparisons between junior (Jr) elite and professional (Prof.) water skiers

Skiers	V02max (ml/kg/min)	Peak power (W/kg)	Peak lactate (mN)

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1 .2.2 Junior Elite

Very little difference in aerobic and anaerobic power exists between the professional and junior water-skiers (table IV). Junior and professional males were similar in V02max, peak powers and peak lactate as were the females. There was a small absolute difference independent of age in V02max between the males and females when expressed per total bodyweight but again not when expressed by lean body mass.

Peak anaerobic power reported in the literature for the Wingate test ranges from 11 W/kg for 1 Okm runners, and ultra-marathon participants to 12 W/kg for gymnasts and power-lifters.[l] This far exceeds the anaerobic power output reported for both professional and junior water-skiers.

Jr elite males	55.52	8.02 ± 2.8	15.3± 1.4
Jr elite females	47.07	6.38 ± 1.8	14.2± 1.7
Prof. males	54.55	9.92 ± 1.3	15.2± 1.2
Prof. females	49.60	9.18±1.4	13.4± 1.5

Abbreviations and symbol: SD = standard deviation; W = watts; V02max = volume of maximum oxygen consumption.

end of the spectrum, athletes who participate in sports requiring high levels of aerobic power such as cross-country skiers[27] and elite endurance runners[18,19] have V02max values normally in excess of 70 ml/kg/min.

Male athletes in sports requiring a balance of anaerobic and aerobic power typically have V02max values that range from 58.4 ml/kg/min for professional soccer players [26] to 64.9 ml/kg/min for speed-skaters which is comparable to elite skiers.[24] Female speed skaters were reported at 62.5 ml/kg/min[24] which is greater than the junior elite and professional female water-skiers. Also, comparing aerobic power relative to fat-free mass, the junior elite professional female water-skiers are equivalent in aerobic power when compared with male water-skiers. This is, however, typical of elite athletes but not for average people.

Table IV. Flexibility and strength test scores of professional (Prof.) and junior (Jr.) elite water skiers

Skiers	Flexibility	Strength			
	sit and reach (cm ± SD)	sit-ups	pull-ups	bench press (kg ± SD)	leg extension
Jr elite males	25.7 ± 17.8	51.6±7	14.6 ± 4.1	60.4 ± 12.2	92.2 ± 21.4
Jr elite females	33.3 ± 14	7.5	7.2 ± 3.7	33.9 ± 4	75 ± 15.2
Prof. males	46 ± 16	49 ± 9	20 ± 6	78.6 ± 8.2	145.5 ± 15.5
Prof. females	50.0 ± 4	37±6		38.2 ± 9.5	83.6± 12.3

Abbreviation: SD = standard deviation.

In summary, water-skiers appear to have an average capacity for aerobic and anaerobic lower body activities. This trend is present for both junior and professional skiers. Water-skiing does not require a high level of lower body aerobic and anaerobic power due to the fact that most of the demand is on the strength attributes of the trunk and upper body musculature.

2.3 Strength

2.3.7 Professional

Muscular strength is the main functional requirements for water-skiing. The dynamic seated row (upper back) values for professional waterskiers are high compared to average, particularly with respect to the bench press (chest) values (table IV). The seated row measures back and arm flexion strength. The pulling action for this exercise is very similar to the pulling action required during waterskiing. Upper back strength of professional waterskiers is normally twice that of their chest press strength. Non water-skiers show less of a difference between chest and upper back strength. Upper back strength is approximately only 50% greater than chest strength.[141

Raven et al.[26] have reported average chest press strength for male soccer players to be 73.2 ± 4.1 kg which is comparable to the 78.6 ± 8.2kg noted for professional water-skiers. The number of pull-ups achieved by both males and females was in the 95 percentile compared to available norms.[25] This high ranking in pull-ups is also indicative of high back and arm flexion strength for water-skiers. Since a large portion of the required strength for water-skiing is supplied by the latissi-

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mus dorsi, trapezius, and deltoids,[3J the high seated row strength values are not surprising. The greater seated row relative to chest press strength levels creates an imbalance of upper body strength and appear to be a specific training response inherit to the sport of water-skiing.

The lumbar extension strength of the professional water-skiers is also unique. The professional male water-skiers are as strong in the more extended range of motion (ROM) as in the flexed ROM (fig.s 4 and 5). The average person is weaker in the latter 36^0 of a 72^0 to 0^0 lumbar extension ROM.[6-8,23] This is probably due to the fully extended position that is required for successful competitive water-skiing. True lumbar extension strength and ROM can be demonstrated using an isolated system to stabilise the pelvis and eliminate hip extensor involvement (fig. 6). The water-skier actually places the pelvis in a forward position with the torso locked in full extension and the hands down at hip level where the pull from the tow boat is applied.

Interestingly, when water-skiers are trained in a full ROM they show large strength improvements in the first half of the ROM compared to the latter half of ROM.[12] It is likely that water-skiing provides a sport specific ROM response for the isolated lumbar extension muscles.

2.3.2 Junior Elite

The junior elite skiers showed a very similar response to the strength measurements as the professional group (table IV). The upper body strength scores were all high indicating a high upper body strength capacity. Unfortunately, no measurement of seated row strength was available to document the high ratio of back to chest strength as seen within the professional water-skiers. However, there are notable differences in the number of pullups that the juniors can do compared to the professional skiers. This may indicate that there is not as strong of upper back development at the younger ages.

The unique lumbar extension strength curve as seen with the professional male skiers was not present with the junior skiers. Therefore, these particular strength attributes of professional skiers appear to be true sport specific training adaptations.

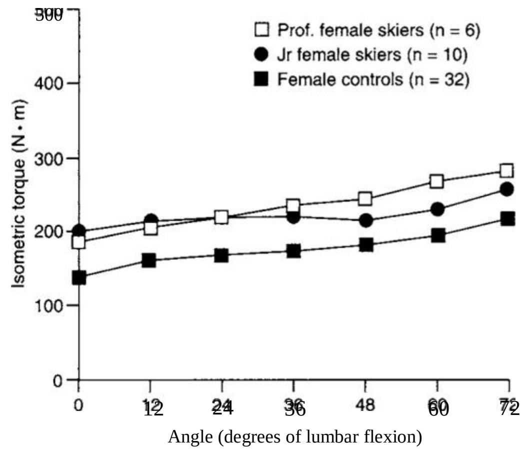

Fig. 4. Lumbar strength curves for professional (Prof.) and junior
(Jr) elite female water-skiers and controls.

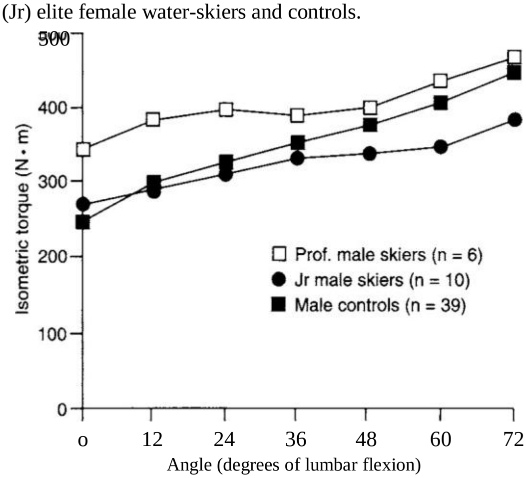

Fig. 5. Lumbar strength curves for professional (Prof.) and junior (Jr) elite male water-skiers and controls.

3. Strength and Conditioning for Water-Skiing

Strength and conditioning programmes are the foundation of any athletic training programme. The primary objectives of a water-ski training programme are increase overall strength and cardiovascular fitness, decrease risk of injuries and enhance competitive skiing performance.

3.1 Training Principles

Before initiating a strength and conditioning training programme for skiers it is helpful to understand some of the basic principles of training: overload, specificity, and reversibility.

The overload principle states that in order to increase the physical capacity of muscles, the muscles must be progressively exercised at a level above what they are ordinarily accustomed. Variables of the overload principle include frequency, intensity and time (FIT). Frequency of exercise refers to the number of times a specific exercise or activity is performed per week. Intensity refers to the workload at which the exercise is performed. Times refers to the amount of time spent performing the exercise. All three of these overload variables (FIT) must be included in a training programme to make the programme successful. In order to avoid over training, the off-water training volume and duration will progressively decrease, while intensity will progressively increase as the competitive season draws closer. The overload principle applies to on-water training as well.

The principle of specificity refers to the type of adaptation that takes place as a direct result of training. The development of muscles is specific to the type of stress placed upon those muscles. Strength and conditioning training programmes should stress muscles that are used during the sport or activity. Therefore, training for trick skiing does very little to enhance ski jumping performance. There is a carry over from one event to another but not enough to significantly improve performance. On-water and off-water training should be specific to the competitive task.[15]

The principle of reversibility is often referred to as the use it or lose it principle. Simply stated, gains will be lost if overload is not continued. Fitness is lost twice as fast as it is gained. Therefore, it is important to incorporate resistance training and aerobic conditioning during the in-season training programme in order to maintain strength and fitness levels gained in the off-season. Research has shown that strength and conditioning gains can be maintained with less training as long as the intensity of training is sufficient to incite overload.

Once these basic training principles are understood, one must look to develop a complete training programme. When planning such a programme one must consider all training principles and overload variables and include resistance, cardiovascular (aerobic and anaerobic), and flexibility training. Each training session should be broken down to include a warm-up, training activity, and a cooldown.

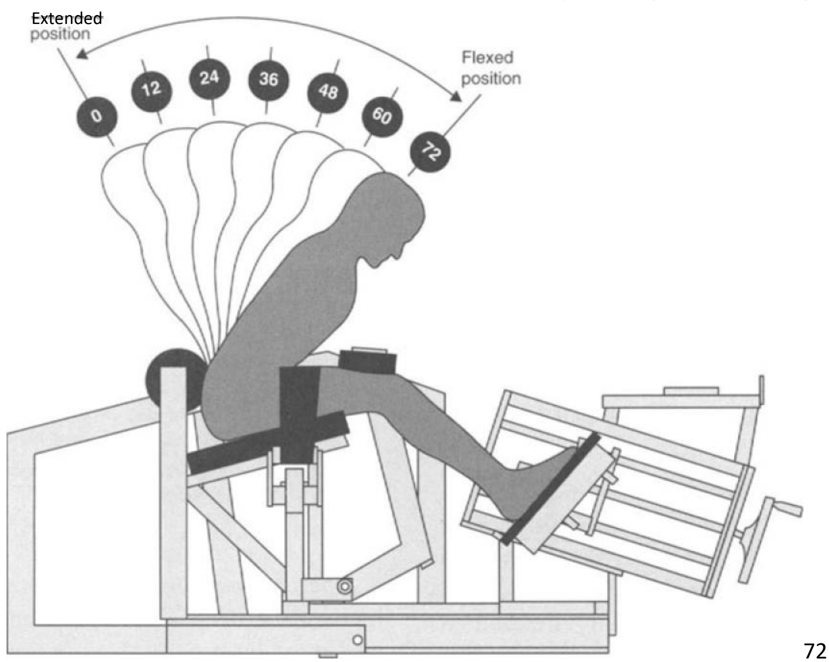

Fig. 6. True lumbar extension strength and range of motion (ROM) can be demonstrated using an isolated system to stabilise the pelvis and eliminate hip extensor involvement. The water-skier actually places the pelvis in a forward position with the torso locked in full extension and the hands down at hip level where the pull from the tow boat is applied.

3.2 Periodisation

The concept of periodisation training programmes is not new. Eastern European weight lifters have used these training programmes for years with great results. The periodisation scheme is based on Selye's general adaptation syndrome (GAS). The GAS theory states that the body must undergo 3 phases when adapting to a new stimulus (i.e. a new training programme).

The first phase is alarm. During this phase the body is confronted with a new stimulus. As the body makes adjustments to adapt to the changing environment, muscle soreness and joint stiffness

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will develop and athletic performance will decrease.

The second phase is adaptation. As the body attempts to meet the challenges of the new stimulus, it adapts to the stimulus and athletic performance is enhanced.

The third phase is staleness or over training. Once the body adapts to the new stimulus, there are no more challenges to be met and athletic performance neither increases or decreases. Periodisation training attempts to avoid over-training and staleness by varying the programme throughout the entire season. These programmes can be modified to meet the demands of any sport or activity (endurance or power sports).

Periodisation training programmes break an entire training year into 4 macro cycles. Each macro cycle can last anywhere from 6 to 12 weeks depending on the length of the sports season and the number of competitive events. Each macro cycle can then be broken down into smaller or micro cycles lasting from 2 to 3 weeks. Each macro and micro cycle should have their own specific goals that need to be addressed during the cycle.

The initial macro cycle is the general conditioning cycle (off-season). This cycle is characterised by the use of high volume (sets, reps, duration) and low intensity (weights, % heart rate) of training. The primary goal of this cycle is to improve overall fitness, increase muscle mass and prepare the body for the upcoming season. This is the building block of the entire training programme and not a time to burn out. The volume of training will gradually decrease and intensity will gradually increase over the next 2 training periods. The next 2 cycles are the strength and transition cycles (off- and preseason). The goal of these 2 cycles is to increase maximal strength and speed. The fourth and final macro cycle is the peaking cycle (in-season). During this cycle all the work that was performed in the previous three will come together. The goal is to bring the athlete up to maximal performance. The varying of the volume and intensity of training allows for the body to adapt physiologically to the competitive season. Each macro cycle should be followed by a week or two of active rest. Active rest consists of performing light activities not usually included in the training programme (i.e. hiking). They should be performed at a low intensity, allowing the body to fully recover physically and psychologically, from the stresses placed upon it during the preceding training cycles. Active rest period are especially beneficial when an athlete has reached a plateau or is becoming 'burned out'. Active rest periods can range from one day up to a week. [41

4. Training Session Components

4.1 Warm-Up

The warm-up, performed prior to a workout, enables the body to make a smooth transition from rest to exercise. The primary objectives of a warmup are to increase blood flow to the working skeletal muscles and raise muscle tissue temperature. The increase in blood flow to the skeletal muscles increases the amount of oxygen that is readily available for muscle contractions. Increasing muscle tissue temperature decreases the viscosity in the muscles, increases joint ROM, and allows nerve impulses to travel faster enhancing the speed of muscle contractions and reaction time. Temperature increases in the muscle also accelerate enzyme activity which speeds up the rate at which haemoglobin and myoglobin are metabolised. This increases the ability of working muscles to extract and use transported oxygen. Research suggests that a properly conducted warm-up can reduce the risk of injuries.

There are 2 types of warm-ups that are most commonly used in the athletic setting: general and specific. The general warm-up involves activities that use large muscle groups such as jogging or cycling. Because of the nature of these activities and the number of muscles used, general warm-ups are capable of raising muscle tissue temperatures. Specific warm-up involves performing movements that are specific to the activity or sport (i.e. a basketball player taking free throw shots, waterskier taking a slalom run).

The specific warm-up has advantages over the general warm-up because it increases the tissue

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temperature of the specific muscle that will be used during the activity and it allows for rehearsal of the activity. Whichever method of warming up is chosen, it is important to follow some simple guidelines.

In order for the athlete to gain maximum benefits from a warm-up, it must be long and intense enough to increase muscle tissue temperature. However this is often a fine line. If the warm-up is not long enough, there is little benefit to the athlete, but if too long or too intense the athlete may become fatigued. Five to 15 minutes is usually the recommended length for pre-event warm-ups. This time may vary depending on the ambient temperature, the amount of clothing worn by the athlete, and the genetic make-up of the athlete. Individuals will respond differently. One athlete may be warmed up after 10 minutes, while another athlete may take 20 minutes. Athletes should listen to their body and make changes in their warm-ups accordingly. A rest period of 5 to 10 minutes should immediately follow the warm-up just prior to competition. Muscle tissue temperatures have been shown to stay elevated for up to 45 minutes following a warm-up, therefore re-warming the muscles is not necessary.[10,29]

4.2 Cardiovascular Training (Aerobic and Anaerobic)

A cardiovascular conditioning programme should be designed to improve both general (aerobic) and specific (anaerobic) conditioning for waterskiing. Since water-skiing is primarily anaerobic in nature, the largest portion of cardiovascular training will consist of activities that are anaerobic or interval types of training. In order to perform high intensity interval training the athletes must have enough general fitness to tolerate the stress placed on the body. Similar to strength training, the volume of conditioning work will decrease while the intensity will increase with each training cycle.

4.2.1 Aerobic Conditioning

Aerobic conditioning (with oxygen) is the ability to sustain low intensities (70 to 85% of heart rate reserve (HRR), [see table V — for calculation of HRR] of exercise for long periods of time (30 to 90 minutes). Examples of this would include a slow 6 to 8km run or a 16 to 32km bike ride. This intensity is a very good way to do a large volume of training. Aerobic training is used primarily in the off-season to build a solid foundation of fitness before beginning more sports-specific training.

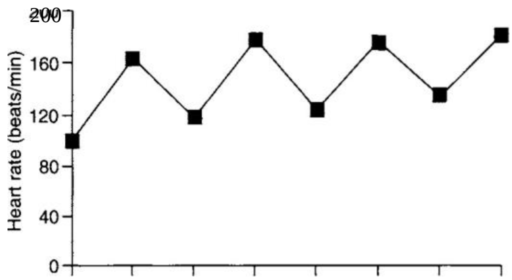
4.2.2 Anaerobic Conditioning or Interval Training

Anaerobic training (without oxygen) is performed by doing higher intensities (85 to 95% HRR) of exercise for short periods of time (l to 3 minutes). During interval training sessions the anaerobic system is stressed to its near maximal limit; and, due to its repetitive nature, the aerobic system is also stressed. These workouts are performed in intervals with a work-rest ratio. The work-rest cycles are at a high intensity for a short period followed by an 'active' rest period for varying amounts of time. A general recommendation would be 90 seconds work per 30 seconds rest. HRR would be 85 to 95% during the work period and 65 to 75% during the rest period. An example of an interval session might be 4 x 400m runs (90 seconds) or 4 x 800m bike rides (90 seconds), with a slow jog or bike ride at a pace equal to 65 to 75% HRR for the rest interval. These sessions will be performed mainly during the pre-season, transition periods

Table V. The heart rate formula for determining heart rate (HR) reserve. This procedure accounts for relative differences in resting HRa

Formula	[(220 — age) — (resting HR)] x % workload +(resting HR)
Example	For a 20-year old, resting HR = 60, at 70% maximum HR
	[(220 - 20) - 60] x 0.7 + 60 = 158 beats/min
	140 x 0.7 = 98 + 60 = 158 beats/min
	80% = 172 beawmin
	90% = 186 beats/min

a N.B. Take HR before, during and after training. Count pulse for 10 seconds and multiply by 6 to calculate HR. Always take HR at the end of a high interval.



6.71 6.71 8.53 8.53 9.75 9.75 10.67 10.67 pre post pre post pre post pre post

Rope length (metres)

Fig. 7. Heart rate response before (pre) and after (post) a slalom run in tournament slalom skiing. Measurements on the x-axis indicate the amount of metres removed from the standard 22.86m rope after each successful slalom run. Data compiled from actual on-water skiing.

and into the competitive season, where the intensity is peaked.

The following are types of cardiovascular training: rowing, cycling, running, stair-climbing, rollerblading.

4.2.3 Rationale for Interval Training

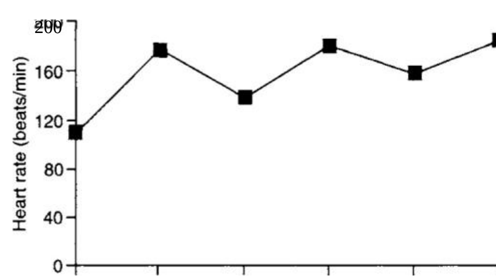
For competitive water-skiers who participate in only 1 or 2 events or try to focus more on 1 event, variations in training intervals and intensity may be appropriate. Slalom skiing places demands greater than 90% of heart rate maximum during a pass while dropping approximately 35 to 40% between passes (fig. 7). Jumping places equally as high demands on the cardiovascular system but does not drop as low between jumps because of no 'down time' as in the slalom event (fig. 8). During the trick event there is very little fluctuation in heart rate and the intensity is much lower. Therefore, depending on which event is focused on, the training may need to be adjusted. Skiers wishing to focus on all events should train according to the event (slalom, jump, tricks — in that order) requiring the greatest intensity. Specific exercises and intensity's have been published elsewhere and are available from the American Water Ski Association (Winter Haven, Florida).

4.3 Resistance Training

The primary objectives of resistance training is to improve sport performance and decrease the risk of injury. By increasing the strength of skeletal muscles and other soft tissue structures (ligaments, tendons), a skier will be prepared to handle the physical stresses placed upon the body during competition and training. Resistance training programmes should emphasise strengthening muscles that are specific to the physical task and progressively overload these muscles. Table VI summarises a recommended variation or periodisation scheme for resistance training.141

4.3.1 Choosing the Best Resistance Exercises

When developing a resistance training programme, choosing the best exercises for the programme is important. Choose exercises that are specific to the sport and exercises that increase musculature in injury prone areas of the body (i.e. shoulders, knees, back). Ultimately the needs of the athlete will determine which exercise will be used. Previously in this chapter we detailed the primary muscle used during the slalom and jump events. Exercises can be easily selected to address each muscle group. A well rounded programme should always be a primary focus incorporating all major muscle groups. As the season approaches, the number of exercise can be reduced to the primary muscle groups used during the event.



Jump 1 Jump 1 Jump 2 Jump 2 Jump 3 Jump 3 pre post pre post pre post

Fig. 8. Heart rate response before (pre) and after (post) skijumping. Data compiled from actual on-water skiing.

Table VI. Recommended off-water strength training periodisation for water-skiing

	General conditioning (post-season)	Strength cycle (off-season)	Transition cycle (pre-season)	Peaking cycle (in season)	Active rest (recreational activity)
Sets	3-5		2-3	1-3	1 week between each training period
Repetitions	15-20	10-12	8-10	8-10	
Intensity	Low	Medium	High	Low-medium	
Volume	High	High	Medium	Low	

4.3.2 Combining Strength and Cardiovascular Training

Time is a potential problem or limitation that most skiers face with exception of a few professional water-skiers. Most competitive skiers maintain full careers and responsibilities and discipline themselves to fit in practice time. Therefore it is difficult to perform off-water strength and conditioning. Also, skiers do not necessarily require the same strength and conditioning that other sports such as basketball and football require. A minimum level however, is recommended to achieve optimal performance, decrease injuries and allow for a longer career. Young skiers tend not to take off-water training seriously because they are able to compete effectively based on their talents and stay in shape. They normally participate in several other sports either during the season or the off-season of waterskiing which naturally contributes to their conditioning level. As skiers age however, a disciplined programme is almost mandatory to be successful and stay healthy.

Therefore a solution to the time crunch is circuit weight training (CWT). CWT incorporates strength and cardiovascular exercises into a short, high intensity work out. CWT can also involve interval training as well. For most skiers, this is probably the best choice of exercises and time.

4.4 Cool-Down

The cool-down is an extremely important, but often forgotten, component of a training session. The cool-down is a period of light exercise that is performed immediately following a training session. The primary objectives of the cool-down are to gradually return all metabolic functions to their pre-exercise levels and return pooled blood from the working skeletal muscles back to the central circulatory system. The cool-down also aids in the removal of lactic acid and other cellular waste products from the muscles, decreasing muscle soreness. Similar to the warm-up, the cool-down should last between 5 to 10 minutes. The length of time may vary depending on environmental conditions, the age and fitness level of the individual and the nature and intensity of the exercise.

4.5 Other Resistance Training Considerations

4.5. Resistance Training for Junior Skiers

The advantages and disadvantages of strength training in preadolescence are still in debate. However, the benefits appear to warrant consideration. It is widely believed that heavy resistance training over stresses the epiphyseal or growth plate, tendon insertions and joint surfaces increasing the risk of injury in the young athlete since these structures are not yet fully developed. Prior to engaging in a resistance programme, all juniors should have a comprehensive medical examination. It is recommended that for children the intensity should be kept low and the number of repetitions high, while avoiding maximal or near maximal lifts. All training sessions should be supervised. For a more detailed explanation of resistance training for children, please refer to the National Strength and Conditioning Associations (NSCA) position statement.141

4.5.2 Plyometrics

Plyometrics or jump training is often used by athletes whose sport demands explosiveness (i.e. ski-jumping). The primary objective is to increase the excitability of the nervous system for improved reactive ability of the neuromuscular system.[21] By improving the functioning of the neuromuscular system it will produce quicker and more explosive movements. Examples of this type of training include step-ups, lunges, bounding, and side to side jumps. Caution should be taken with the type of exercises chosen. There are many of these exercises that are not only dangerous but do not follow the basic rule of common sense.

Plyometric training, when performed correctly, can greatly enhance athletic performance. However, if it is over-used, used incorrectly, or the wrong selection of exercises are used it can often ruin an athlete's season or 'career', due to the extreme stresses placed on the body. Plyometrics are only for the advanced athlete and should be implemented only after an adequate base of strength has been achieved. Plyometrics should never be used by novice or junior skiers. Other safety considerations for plyometric training include: using good supportive shoes, performing exercises on pliable surfaces, and the use of proper progression.

Plyometric exercises should be performed at the completion of a typical training session, while the athlete is fatigued. This should simulate the athlete's physical state during intense competition. Again, caution should be taken with plyometrics training. The single most important aspect of plyometric training is common sense.[lll]

5. Conclusions

Water-skiing is a physically demanding sport involving highly coordinated movements, extreme upper body torque, sustained isometric contractions, and near maximal stress on the anaerobic system. Due to the physical demands of the sport, elite skiers tend to have a low percentage of body fat and slightly above average aerobic and anaerobic capacities. They also have unique strength characteristics such as greater lumbar strength in the extended angles and an upper body back to chest strength ratio of approximately 2 : l.

These physiological profiles are important because they serve as a reference point when developing off-water strength and conditioning training programmes. The elite skier's data allows for comparisons for age group athletes to test themselves.

Though extensive data has been collected by the laboratories at the United States Olympic Training Center and the University of Florida, there is limited data on the actual demands of event skiing. The goal for future research is to develop event (on-water) specific physiological characteristics of water-skiers. The better we understand the physiological demands of the sport, the better we can prepare our athletes.

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Correspondence and reprints: Scott Leggett, UCSD OrthoMed, 4150 Regents Park Row, #300, La Jolla, CA 92037, USA.