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# Relationships of strength, endurance, aerobic capacity and experience to alpine ski racing performance

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RELATIONSHIPS OF STRENGTH, ENDURANCE, AEROBIC CAPACITY AND EXPERIENCE

TO ALPINE SKI RACING PERFORMANCE

BY

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The Author would like to take this opportunity to express his appreciation to Homer Anderson, who, as Ski Coach and close personal friend, was the major influence in any success he has achieved.

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# CHAPTER I

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### INTRODUCTION

Skiing is possibly one of the fastest growing sports in the United States. In a talk at the 1972 meeting of the United States Ski Association, Mr. Charles Gibson, President of the United States Ski Association, estimated that the number of skiers in the United States increases by 15 to 20 percent each year. The popularity has increased so much that in some areas, namely in the Northeastern states, the number of lift tickets sold each day is restricted so that there will not be an overcrowding on the slopes. Because of this and the ever-increasing expense involved with alpine skiing, many people have turned to cross-country skiing and touring. At any rate, skiing in all its phases is rapidly becoming one of the most popular sports in America today.

As is true with most sports, skiing also has a highly developed competitive faction, and as is also true for most sports, the competitive program sets the trend for the rest of the participants to follow. Competitive skiers, probably more so than in any other sport, affect the recreational interests in the sport. There have been vast improvements in both equipment and technique in skiing in the past ten years. These improvements have been developed both by and for the competitor but have been passed on to the general skiing public.

These improvements probably began with the introduction of the polyethylene or kofix base which was applied to the sole of the traditional wooden ski. The wooden ski had been the only ski known to man since the inception of the sport but soon to come was an aluminum ski developed by an aircraft engineer by the name of Howard Head. The wooden ski had been satisfactory but tended to break down with continuous use. The Head ski seemed to eliminate most of this problem. For a period of time aluminum skis ruled the skiing world. After a few years, fiberglass was introduced into ski production. At first it was used in combination with wood or metal, or both. Some manufacturers then developed skis made entirely of fiberglass or fiberglass wrapped around a styrofoam-type core. Competitive skis today are primarily fiberglass or epoxy resin combined with, or covering wood, metal or foam.

This evolution took place in approximately fifteen years, a relatively short period of time, yet the difference in skis has necessitated a complete evolution in skiing technique.

While skis were evolving so were other aspects of the sport. Boots changed from rather soft leather boots that were laced to stiffer boots that buckled. The buckle boots changed from leather to plastic with the introduction of the Lange boot. Further development resulted in a boot which was very stiff (almost unbendable any place on the boot) and which had a back that proceeded to the mid-calf of the racer's leg.

Other improvements included changes in clothing. The baggy clothing of the fifties gave way to the tight-fitting clothes of the early sixties, then to the skin-tight racing suits of the late sixties and early seventies. The importance of clothing in racing is emphasized by Joubert and Vuarnet (7). In their book they state: "at 62 miles per hour a person in regular racing pants and parka encounters 10 percent greater resistance than one in a natural silk, silicone-treated racing suit." These clothes were primarily developed and designed for the competitor to decrease wind resistance, but they too became a trend in fashion for the recreational skier.

These changes obviously had to have some impact on the techniques involved in racing. The first fiberglass skis had very stiff tips which made it necessary to apply much pressure to the tips by leaning forward. Soon the Americans noticed that the French seemed to be skiing much faster than they were and one of the most obvious technical differences was that they were sitting back on their skis and jetting them forward upon completing a turn. One man in particular seemed to have mastered, if not invented, this new technique. His name was Jean-Claude Killy and he won three gold medals in the 1968 Olympics. With the recognition of this new technique, ski makers began moving the stiffness back to the waist of the ski and boot makers developed the high back boot so the skier could just sit back, as if in a chair, and steer his skis down the hill.

We learned many other things from the French, as well as from other Europeans in regard to competitive skiing. These countries were and still are the primary alpine ski powers in the world. We realized that while our teams consisted of advanced recreation-type skiers, their teams were composed of people who did nothing but ski-race most of the calendar year. Our young racers were exposed to the pressures of college, the draft, and the hard, cold reality of earning a living during and after their competitive years. However, their competitors could drop out of school at almost any age, and if good enough could be subsidized or even paid very good salaries while competing for their respective countries. Their governments also arranged for post-competitive employment or pension programs to alleviate the problem of earning a living. Because of these factors their training programs were much more intense. Coaches in the United States spent a great deal of time putting their charges through intense strength and endurance programs, often incorporating such games as soccer and speedball for improving balance, coordination and reflexes as well as hoping to improve cardiovascular fitness. The European powers did these things too; in fact, the members of the French team even incorporated boxing into their program. Their big advantage, at least in the mind of the author, was that the French and Austrian competitors were skiing all day, every day, from the time they were very young. Their on-snow training was not restricted to the winter months. The national teams trained on snow practically the year around, utilizing glaciers in the Alps during the warmer months. They competed or trained every day during the season. Their program revolved around running as many race courses as possible. They did not have to concern themsleves with course preparation or repair, this was all taken care of. The only thing they had to do was race on as many courses as they possibly could.

The coaches of the United States team noticed this and began establishing programs which emphasized actual on-snow training throughout the year. Summer training camps began springing up anywhere there was enough snow. Junior skiers began receiving tremendous amounts of attention at very early ages. Training programs were still concerned with developing strength and endurance but the new emphasis seemed to be on running ski courses. The apparent reasoning was that there is nothing like ski racing to condition ski racers.

## THE PROBLEM

The purpose of this paper was to examine the relationships between alpine ski racing performance and variables such as maximum phasic strength, phasic muscular endurance, static muscular endurance, aerobic capacity, and ski racing experience in twenty male alpine ski racers.

Because the data was already gathered the author decided to relate some of the measured variables to each other. Because these relationships did not include ski racing performance they were designated sub-problems. The sub-problems with which this study was concerned were the relationships between (1) phasic muscular endurance and aerobic capacity, and (2) strength and endurance.

Training programs for alpine ski racers in the United States have long utilized exercises to develop strength and endurance as primary components of their programs. Ski racing experience was also derived from training programs. In most cases this was considered the end result rather than a means to the end; that end result being a very high rate of proficiency. Because aerobic capacity is sometimes used as a determinant of general body conditioning, it was decided to relate this measure to ski racing performance to determine the relationship between the general physical condition of the individual and his ski racing performance. This paper attempts to relate alpine ski racing performance to strength, endurance, aerobic capacity and ski racing experience in an effort to determine which of these variables may have the greatest influence on performance.

An analysis of testing procedures showed that the aerobic capacity test and the phasic muscular endurance test utilized the same muscle groups and had similar movements. As a sub-problem, it was decided to find if a relationship existed between the tests.

An investigation of strength and endurance relationships was the second sub-problem. Various studies have found conflicting results when relating strength to endurance. This study attempted to clarify those findings.

## BASIC ASSUMPTIONS

The following assumptions were basic to this study:

1. Phasic strength, phasic endurance, and static endurance are essential to alpine ski racing.
2. Phasic strength, phasic endurance and static endurance can be measured reliably by the methods described in Chapter II.
3. The extensors of the knee is the muscle group upon which skiers are primarily dependent.

4. A 90 degree angle of the knee is representative of the knee angle when strength and endurance are used most in alpine ski racing.

LIMITATIONS OF THE STUDY

The following limitations related to the number of subjects and the muscle group tested:

1. The study was limited to twenty male subjects attending the University of Montana. The subjects were all members of the Varsity Ski Team. Their ages ranged from 18 to 25.
2. The study was limited to the knee extensor muscle group.
3. The study was limited in that some subjects were probably involved in more extraneous activities than were other subjects.
4. The study was limited in that the tests were administered only once.

DEFINITIONS

The following terms are defined as they were used in this study.

Knee extension. Extension at the knee when the leg is moved in a direction that increases the posterior angle at the knee.

Maximum phasic strength. The amount of contraction force, measured in pounds that the knee extensors can attain by shortening the length of the muscles in a single contraction.

Phasic muscular endurance. The number of contractions of the knee extensors at a rate of thirty contractions per minute, with a resistance of two-times the subject's body weight (relative endurance).

Static muscular endurance. The amount of time the subject could exert a sufficient force by sustained contraction of the knee extensors to hold a weight equal to the subject's body weight.

Ranked ski racing ability. Ranking, by the Varsity Ski Coach, of the 20 subjects according to ability.

Aerobic capacity. "Body's capacity to bring in oxygen and deliver it to the tissue cells where it is combined with foodstuffs to produce energy" (3). Aerobic capacity is measured in ml/kg/min.

Alpine Ski races. Races held on downhill, slalom, or giant slalom courses.

Downhill racing. It is primarily a test of speed, courage and ability to make high speed turns and maintain an aerodynamic body position.

Slalom racing. This race was designed to test the agility, quickness, technique, and balance while racing through a series of closely linked gates.

Giant Slalom racing. It was originally intended to be a toned-down downhill but has now become a combination of slalom and downhill in that it required a great deal of speed as well as much agility and technique.

Isotonic contraction. The same as a phasic contraction.

Isometric contraction. The same as a static contraction.

Absolute endurance. Uses the same load for everyone (4).

Relative endurance. Measured by using a given percentage of each individuals maximum voluntary contraction as the load (4).

# CHAPTER II

## METHODS AND PROCEDURES

### SUBJECTS

The twenty top-ranked alpine ski racers from the University of Montana Varsity Ski Team for the year 1969 were used as subjects. The subjects all had racing experience and were involved in the varsity training program and competing in collegiate or regional ski racing competition. The subjects ranged in age from 18 to 25 years. Ski racing experience ranged from 1 to 15 years. All subjects were in good physical condition and free from any leg injuries. The physical characteristics are shown in Table 1.

TABLE 1.

PHYSICAL CHARACTERISTICS OF SUBJECTS

| Subject | Weight Pounds | Height Inches | Age Years |
|---|---|---|---|
| C.M. | 157 | 68 | 18 |
| M.D. | 161 | 71 | 19 |
| R.L. | 141 | 69 | 21 |
| J.W. | 140 | 67 | 25 |
| D.C. | 140 | 70 | 20 |
| A.W. | 165 | 72 | 19 |
| K.H. | 151 | 68 | 18 |
| M.R. | 152 | 68 | 19 |
| M.H. | 172 | 72 | 19 |
| G.K. | 147 | 68 | 19 |
| R.H. | 135 | 64 | 19 |
| D.H. | 198 | 73 | 18 |
| O.S. | 126 | 66 | 20 |
| D.T. | 181 | 74 | 22 |
| P.T. | 139 | 69 | 18 |
| J.M. | 159 | 68 | 20 |
| G.G. | 145 | 69 | 18 |
| J.M. | 192 | 72 | 18 |
| D.C. | 149 | 67 | 19 |
| R.G. | 167 | 72 | 21 |

## TESTS, EQUIPMENT AND PROCEDURES

The tests administered to the subjects were given to determine static and phasic leg endurance and phasic leg strength. The leg extensor portion of a Universal Gym was used for the testing. Meyers and Piscopo (9) found higher reliability with the cable tension method than with the manuometer push device, however, because of the subjects familiarity with the Universal Gym it was designated as the testing device.

The knee extensors were selected for testing. Elbel (6) and Tuttle (13) used the extensors for testing leg strength and endurance and found high reliability. In skiing it is generally agreed that this is the muscle group in the legs upon which the skier is most dependent.

Since the study dealt with leg strength and endurance, the author felt that the load determination for the endurance tests should be related in some way to the load the legs must support in reality. It was, therefore, decided that the body weight or a multiple of the body weight would be used for the endurance loads. Because of this type of load determination, this study actually measured the relative endurance of the subjects. The load for the static endurance test would be the body weight of the subject. The reason for this was that, normally speaking, the only time the racer is in a truly static position is when he is in the tuck or Egg position and in this position he must support only his body weight.

For the twenty subjects which were utilized in this study, one body weight averaged 31.6 percent of the maximum phasic strength. This figure was derived by dividing the sum of the body weights of the twenty subjects by the sum of their strength scores.

The load for the phasic endurance test was two times the subject's body weight. It was felt that one body weight would not be representative of the resistance incurred in making a sharp, high speed turn. The Official American Ski Technique Manual (12) says that, "the skier exerts muscular forces to balance himself contrary to the action of the centripetal force (resistance from the side). He feels this as added weight. Thus, the skier supplies some of the energy to accomplish the turn." In addition, the skier is already supporting his own body weight and fighting slippage on the snow. Three body weights would, in some cases have been more than the subjects' maximum strength. Two body weights averaged 63.2 percent of the maximum phasic strength of the twenty subjects. This figure was derived by dividing the sum of 2 times the body weight of the subjects by the sum of their strength scores.

The angle of the ski racer's knees, both in a tuck or Egg position and during a sharp turn was determined to be approximately 90 degrees. It was decided, therefore, to initiate the phasic strength and phasic endurance moves with the knees at a 90 degree angle. The static endurance test was done with the knee held at 90 degrees. All angles were checked with a goniometer which measures joint angles.

The subjects were tested in groups of three. Test appointments were scheduled from 7:00 to 9:30 P. M., Monday through Thursday during a week near the end of the ski racing season. Subjects were asked to refrain from skiing on the test day and complied with the request.

When the subject arrived at the testing room, he disrobed and recorded his height and weight. Next, the subject completed the personal information section of the test result sheet. The tester then explained the purposes and procedures of the tests to the subject. After displaying a thorough understanding of the procedures, the subject dressed in gym attire and prepared to start the testing.

Maximum Phasic Strength.

The subject was then seated and asked to place his feet on the pedals of the Universal Gym. The angle of the knee was measured with the goniometer to determine proper seat adjustment. The first test was that of maximum phasic strength. In order to reacquaint the subject with the apparatus the subject was asked to lift a weight estimated to be far below his maximum. After as many attempts as the subject desired, his maximum phasic strength was determined. He was given up to five minutes rest between attempts if he so desired, although, Martens (8) reported that Berger found a two minute resting period was sufficient for full recovery between strength tests.

Phasic Muscular Endurance.

After a five to ten minute rest, the subject was positioned for the phasic muscular endurance test. The subject was placed in the same position as for the maximum phasic strength test. The closest increment to two times the subject's body weight was separated from the stack.

Beginning with the knees at 90 degree flexion the subject raised the weights by pushing the pedals ahead until the knees were fully extended. The knee was then flexed until it returned to nearly 90 degrees; however, the weights were not allowed to touch the stack. This insured continuous work on the part of the extensors. The repetitions were done to the sixty beat pace of a metronome. The subject extended to one and flexed to the next, resulting in thirty contractions per minute. The subject was encouraged to maintain the rhythm. When he could no longer do so the test was discontinued and the number of repetitions was recorded.

Static Muscular Endurance.

After completing the phasic muscular endurance tests, the subjects were allowed to relax for one-half hour in preparation for the static muscular endurance test. After this rest period, the subject was placed in a position so that when the equivalent of one body weight was elevated a distance of approximately two inches, the knee angle was 90 degrees. The stop watch was started as soon as the knee reached the desired angle. Time was kept until the subject could no longer hold the weights at the desired height above the stack. The time was then recorded in minutes and seconds.

It was decided to administer both endurance tests in the same testing period to simulate the conditions in ski racing. A competitor will seldom compete in a downhill race in which only static or only phasic muscular endurance is required.

Aerobic Capacity.

The fourth test, the aerobic capacity test, was administered to the subjects following an afternoon team meeting. The subject, after resting five to ten minutes, removed all excess clothing and was ready to take the test. During the rest period the methods and procedures were explained to him. At the end of the resting period the resting pulse was recorded. The subject then began the test. The metronome was set for 90 beats per minute and the subject maintained the beat. The test was similar to the Astrand-Rhyming Step Test (1). The subject placed one foot on a bench 15 3/4 inches (40 centimeters) high, then the other. He then stepped down with the first foot, then the other. This procedure was done in four beats at a rate of 22.5 full steps per minute and continued for five minutes. The subject was then told to sit down and his pulse wzs taken during the period of 15 to 30 seconds after completion of the exercise. After being multiplied by four, the pulse rate was then recorded on the test result sheet.

The aerobic capacity test was designed to predict one's ability to do strenuous work. A calculator devised through a cooperative study by the Missoula Equipment Development Center and the Human Performance Laboratory at the University of Montana was used to interpret results and establish the rank order based on predicted aerobic capacity scores (ml of oxygen per kg of body weight). (See Appendix D.)

INTERPRETATION OF SCORES

The tests were administered only once to all twenty subjects; however, a phasic strength test was administered to six of the subjects previous to the testing for this study. The scores were obtained from a single test of each of the measures. Maximum phasic strength was measured in pounds; phasic muscular endurance was measured in repetitions, which could be converted to minutes and seconds, and static muscular endurance was measured in minutes and seconds. The aerobic capacity was recorded as ml $O_2$ per kg per minute as derived from the Forest Service Calculator via a combination of post-exercise pulse rate and body weight. These numbers were all subjected to rank-order correlation statistical procedures.

# CHAPTER III

## ANALYSIS AND DISCUSSION OF RESULTS

### METHOD OF ANALYSIS

Spearman's Rank-Order Correlation Coefficient (Rho) (5) was used to evaluate all the relationships derived from the test results. The Spearman formula is:

$$P = 1 - \frac{6\Sigma D^2}{N(N-1)}$$

N = the number of pairs

p = rho, the rank order correlation coefficient

D - difference between set of ranks

According to Downie and Heath (5), "Rho is a product moment correlation coefficient for ranked data. For all practical purposes, it may be interpreted the same as r."

### ANALYSIS OF RESULTS

The reliability of the maximum phasic strength test is shown in Table 2. The results are based on a test-retest of six of the twenty subjects. Included in the table are the rank on trial one, the rank on trial two, the means of trials one and two, and the Spearman Rank-Order Correlation Coefficient.

TABLE 2

TEST-PRETEST OF MAXIMUM PHASIC STRENGTH

| Subject | $T_1$ | $R_1$ | $T_2$ | $R_2$ | D | $D_2$ | |
|---|---|---|---|---|---|---|---|
| J. W. | 660 | 1 | 660 | 1 | 0 | 0 | |
| D. T. | 480 | 2 | 510 | 2.5 | 0.5 | 0.25 | |
| A. H. | 450 | 3.5 | 480 | 4 | 0.5 | 0.25 | |
| K. H. | 450 | 3.5 | 510 | 2.5 | 1.0 | 1.00 | |
| R.G. | 420 | 5 | 450 | 5.5 | 0.5 | 0.25 | |
| R.L. | 390 | 6 | 450 | 5.5 | 0.5 | 0.25 | |
| | X=475 | | X=510 | | | ≤D2=2.0 | p=0.94* |

*Statistically significant beyond .01 level of confidence

The test was given four weeks before the retest. In this period the mean increased slightly more than one increment or 30 lbs. The mean on trial two, which was 510 pounds, was figured for six subjects. The mean on the same trial for twenty subjects was 508.5 pounds. The closeness of the two means shows that the six subjects were somewhat representative of the twenty subjects.

TABLE 3

REALTIONSHIP OF SKIING ABILITY TO SELECTED MEASURES

| Test | Rho |
|---|---|
| Ranked ability to maximum phasic strength | 0.13 |
| Ranked ability to phasic muscular endurance | 0.24 |
| Ranked ability to static muscular endurance | -0.13 |
| Ranked ability to racing experience | 0.67* |
| Ranked ability to aerobic capacity | -0.07 |
| Phasic muscular endurance to aerobic capacity | 0.33 |

*Significant beyond .01 level of confidence

A correlation of 0.13 was obtained between ranked ability and maximum phasic strength. This coefficient was not statistically significant. Maximum phasic strength ranged from 390 pounds to 660 pounds, attained by two subjects. The skiers ability was ranked from one through twenty by the Varsity Ski Coach. The ranking was done on the basis of a season's competition and workouts. The best skier was ranked number one to correspond with the best performance during the season.

Ranked ability and phasic muscular endurance had a correlation coefficient of 0.24. This was also not statistically significant. Phasic muscular endurance ranged from 31 to 300 repetitions.

Static muscular endurance ranged from one minute, five seconds, to nine minutes, eighteen seconds. Static muscular endurance and ranked ability had a correlation coefficient of -0.13, a slight but non-significant negative relationship. In no way was ranked ability found to be significantly related to maximum strength, phasic muscular endurance, or static muscular endurance.

Regarding ski racing experience, it is interesting to note the high correlation found between ranked ability and racing experience. As previously mentioned, racing experience ranged from one to fifteen years. A correlation coefficient of 0.67 was found between experience and ability. This was significant well beyond the .01 level of confidence.

The results of the study may seem to dictate the need for an increased amount of "on-snow" conditioning programs. It is obvious that a competitor must be in good physical condition when he begins his "on-snow" program. Good physical condition lessens the chance of injury and enables the individual to make a wider range of movements and continue the exercise a greater length of time. It is the author's contention that this can be accomplished in a minimal amount of time and that, partially because of the findings of the study, the majority of the conditioning should be carried on in an actual ski racing environment (See Appendix "E").

The relationship between aerobic capacity and ranked ability, produced a correlation coefficient of -0.07. This was not statistically significant.

The correlation coefficient for the relationship between phasic muscular endurance and aerobic capacity was 0.33. This was not statistically significant.

## DISCUSSION OF RESULTS

The results of this study showed that of the five variables which the author attempted to relate to ski racing performance, only experience showed a statistically significant relationship. The other four, static and phasic endurance, phasic strength, and aerobic capacity showed no significant relationship to alpine ski racing performance. One reason for this may have been that in order to achieve a high level of proficiency in a complex motor skill such as ski racing, an individual may have to possess or develop proficiency in a combination of the variables tested as well as others not considered in this study. Experience may simply be an accumulation of these other variables.

A study done by Dr. Marvin I. Clein and Associates (2) may help to confirm this hypothesis. Clein's study dealt with the physical and psychological makeup of the members of the United States National Ski Team in order to determine what traits may be the most desirable for a particular event.

Dr. Clein, Director of the Human Performance Laboratory at the University of Denver, got the idea for the test from the testing that exercise physiologist, Dr. Thomas Cureton, performed on Roger Bannister one year prior to Bannister's running of the first sub-four minute mile. Cureton subjected Bannister to a battery of tests which he felt should measure the crucial variables present in this particular man for this particular event. This was done to attempt to locate any inadequacies that might be present in order to remedy them and assist Mr. Bannister in becoming a more efficient runner. As we know the results were satisfactory, therefore, Dr. Clein decided to do the same with alpine ski racers.

To initiate the study, Dr. Clein had to determine what factors seemed to influence ski racing ability. After reviewing photographs of racing techniques used by the best in the world, such as Jean-Claude Killy, Karl Schranz, Billy Kidd, and Patrick Russel, Dr. Clein, along with Rick Chaffee, a member of the National Team, determined that the physical requirements necessary to become an alpine ski racer were the following:

1. Aerobic (work with $O_2$)
2. Anaerobic (work without $O_2$)
3. Flexibility
4. Strength and power
5. Coordination (refers to tempo)
6. Relaxation
7. Balance

The team of testors then devised a battery of tests which would produce information regarding (1) personality, (2) motor abilities, (3) organic fitness, and (4) physique.

"More specifically, we were looking for answers to such questions as: What personality inhibitions might be affecting the athletes present level of performance? What was his present capacity to perform a motor task (his general athletic ability)? What was his present level of fitness? What was his cardiac response to various exercise loads? How efficiently could he use osygen?" said Dr. Clein.

The published study goes into greater detail in regards to the personality types than it does in regards to the physiological results. However, the results are quite interesting. A brief summary of their findings regarding personality is as follows:

1. The best male slalom racers seemed to be introverted and extremely self sufficient.

2. The male downhill racers were significantly more dominant, aggressive and ruthless than were the best slalom racers. This was also the personality type of the less successful slalom racers. However, it is quite possible that the less successful slalom racers were the same individuals as the best downhill racers.

3. The Women's A team members were more introverted than the men.

4. The Women's B team members were dominant, aggressive and competitive, much the same as the top men downhill racers.

(For comments by the author regarding these findings, see Appendix C.) Clein also devised a mechanism designed to measure decision-making time. This mechanism combined a problem-solving situation with a reaction time measuring device. The decision-making time was determined by subtracting pure reaction time from the time required to solve the problem and react. It was theorized by psychologists that decision making in that particular task would be influenced by the level of self-confidence. After collecting and analyzing the data, it was determined that there was indeed a definite relationship.

Clein also measured the team in regards to "organic fitness". This was a term used by Clein and included measures of strength, power, agility, flexibility and endurance. The exact tests given and the statistics derived are not available but Dr. Clein states that, "as a group, both men and women displayed much better than average athletic ability". However, he goes on to say, "unexpectedly, our tests revealed that a top ranked slalom racer, Rick Chaffee, measured low in agility. This quality refers to the ability to change body positions and is an obvious factor in slalom racing." He then continues, "Chaffee's many other outstanding qualities (i.e., intelligence, technique, perserverance, sincerity of effort) have compensated for this shortcoming and have allowed him to excel in this event."

It seems quite obvious that an activity as complex as alpine ski racing requires the right mixture of these variables if success is to be accomplished.

Another possibility is that the more proficient one becomes in technique, the less he must rely on strength and endurance. This may hold true in skiing as well as any other activity. A beginner attempting to do a certain maneuver will not do it nearly as well or as effortlessly as the experienced individual. The beginner must make up in strength and endurance what he lacks in skill and technique. Because the tests were given near the end of the season, the less capable racers may have been using more strength and endurance trying to perfect their technique than the more experienced racers who were relying on their more efficient technique.

The less experienced racers were practicing daily in an effort to make the team. This was possible because they were, for the most part, underclassmen who could afford to cut down on their credit load. The more experienced racers were generally upperclassmen with more restricting schedules. Thus, they had less time to practice. If, in fact, skiing does increase muscular strength and endurance, this could have been an important reason for the lack of relationship.

Another cause of the low coefficient of correlation for the strength, endurance, ability relationships could have been the fact that the more seasoned competitors, who for the most part were returning lettermen, knew the physical demands of the sport. The less experienced competitors may have trained much harder in the Fall training program, not only in an effort to make the traveling team, but because they did not know the demands of the sport.

The static muscular endurance test was of special interest. Coaches seem to agree on the importance of being able to maintain the aerodynamic or Egg position in the downhill event. Joubert and Vuarnet (7) state that "a flat disc, a sphere, and an egg-shaped object, presenting the same circular surface area and moving at 44 miles per hour, encounter the following wind resistances: the disc - 246 pounds; the sphere -110 pounds; and the egg - 22 pounds.

The continue, "the frontal surface area of a skier in a standing position is approximately 65 percent greater than that of a skier in an Egg position; this corresponds to a speed difference of at least 20 percent."

"A simple extension of the arms increases the frontal surface area by 25 percent lowering the maximum speed by at least 11 percent. This checking action is reduced by 50 percent if the arms are extended forward just in front of the legs instead of being held out at the sides."

"Two skiers both weighing 165 pounds, equipped and dressed alike, the first in the Egg position and the second standing with arms folded, reach speeds of 90 miles per hour and 59 miles per hour respectively."

"The Egg requires a certain amount of special muscle development, which can be achieved through long, repeated runs in this position. For most skiers, however, a systematic weight-training program with knee-bends and back exercises is needed to develop the necessary buttock, back and neck muscles."

To illustrate the importance of body position, the 1967 United States National Team underwent a series of wind tunnel tests in order to determine the most efficient aerodynamic body position for each racer. A body position like that of the Egg was found to be most efficient. In order to hold this position the individual must be able to endure severe muscular pain such as is encountered in the static endurance test in this study.

de Vries (4) stated that, "the duration of the isometric contraction is limited by the finite energy supply and the buildup of acid metabolic end-products. Thus, the contracting muscle group utilizes its only available source of direct energy, the breakdown of ATP and creatine phosphate, and subsequently, the energy available from the breakdown of glycogen. Neither of these sources can be replenished because the circulation is occluded; consequently, the duration of this isometric contraction becomes a function of the rate of energy depletion and the concomitant drop in tissue pH that decreased the contractility of the muscle." Phasic or isotonic contractions permit and even promote free blood flow which replenishes the energy to the muscles.

The racer may be required to hold the tuck position for only one or two minutes, but the combination of the continuous isotonic contractions of the leg and the isometric muscular contractions of the extensors causes an extremely uncomfortable burning sensation. Authorities do not seem to agree on the cause of this sensation other than that it is the result of fatigue. de Vries (4) states that the accumulation of lactic acid drives pH down and eventually causes muscle contractions to cease. However, as noted in Sharkey (10), Frumerie hypothesized that fatigue was the result of mechanical pressure on the nerve endings in the muscles, tendons and joints. It is for these reasons that an inadequately conditioned racer may be forced to come out of his tuck position unnecessarily. One can easily see how disastrous, in regards to the increase in wind resistance, this would be at speeds of 60-75 miles per hour, especially when most races are won or lost by tenths or even hundredths of a second.

In Astrand and Rodahl (1) Agnevick et al studied the elite Swedish

Swedish Alpine Ski racers. Bengt-Erik Grahn, one of the best special slalom racers in the world, was included in the study. In their testing they found high lactic acid levels present during skiing, in spite of a relatively short work time. They felt that this may be explained by the assumption that "certain muscle groups are engaged in intense static work".

They continued that "Alpine skiers are characterized by a great isometric strength in the stretch muscles of the legs." In summary they said "it may be pointed out that competitive Alpine Skiing places heavy demands on both aerobic and anaerobic motor power. Great strength in the muscle groups involved is required. In addition the technique will obviously determine the level of achievement. From the viewpoint of training it is important to learn to master a good technique in spite of a high lactic acid concentration in the muscles."

This study dealing with the University of Montana Alpine team found no statistical significance in relating aerobic capacity to performance or to strength. Possibly it would have found the same in relating anaerobic capacity to performance if such a relationship would have been attempted. The determinant may have been in a combination of both as was suggested in the Astrand-Rodahl text.

It was interesting to note that Astrand and Rodahl, when testing the six Swedish National Alpine Team members, found their average aerobic capacity to be 68 ml/kg/min. J. W., a foreign student from Norway, who was skiing on the University of Montana team, had an aerobic capacity of 71.9 ml/kg/min. The rest of the subjects ranged from 40.7 to 55.7 ml/kg/min.

It may also be interesting to note that the subjects in this study had a mean isometric contraction of 4 minutes and 55 seconds while the average duration of isotonic contractions, at a rate of thirty repetitions per minute, was 2 minutes and 16 seconds. The phasic muscular endurance test, however, used a resistance of two times the subject's body weight while the static muscular endurance test used only body weight resistance. Another fact to remember is that the phasic endurance test was given before the static endurance test.

One subject, G.G. had a maximum phasic strength score of 390 pounds. This ranked him last in the group. His endurance scores were quite different. On the phasic muscular endurance test he did 90 repetitions at 300 pounds, ranking him third. On the static muscular endurance test he ranked fourth with a time of 7 minutes and 47 seconds with a resistance of 150 pounds.

Another subject, J.W., had a muscular endurance score of 300 repetitions at 270 pounds. This was more than twice as many as the second ranked subject.

The second sub-problem deals with the relationships between strength and endurance. The results appear in Table 4.

TABLE 4

RELATIONSHIPS BETWEEN STRENGTH AND ENDURANCE

| Test | Rho |
|---|---|
| Maximum phasic strength to phasic muscular endurance | 0.49* |
| Maximum phasic strength to static muscular endurance | 0.07 |
| Phasic muscular endurance to static muscular endurance | -0.07 |

*Significant at .05 level of confidence

The coefficient 0.49 between maximum phasic leg strength and phasic muscular endurance concurs with the findings of Elbel (6). Martens (8) found a relationship of 0.04 when relating maximum phasic strength and endurance of the arm. It is very possible that the strength and endurance relationships of the legs may be entirely different from those of the arms. A possible explanation for this may be the fact that the legs are continuously supporting the weight of the body whereas the arms do not perform this type of function.

Another possible explanation is the distribution of red and white muscle fiber. de Vries (4) states that, "red muscle is better suited to long-term, slow, powerful contractions and is consequently found in the postural, extensor muscles; the white muscle is better differentiated for speed, and is found mainly in the flexor muscles." Martens (8) study, as well as most other studies involving the arm, is concerned with the flexor muscles of the arm. This study, as well as Elbels (6), and most other studies involving the legs, is concerned with the extensor muscles of the leg.

Maximum phasic strength, when related to static muscular endurance, produced a correlation coefficient of 0.07 which was not statistically significant. A statistically insignificant correlation coefficient of -0.07 was found when relating phasic muscular endurance to static muscular endurance. Martens (8) and Elbel (6) also found no significance in these relationships.

# CHAPTER IV

## SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

### SUMMARY

The primary purpose of this study was to investigate the relationships between Alpine ski racing performance and maximum phasic leg strength, phasic muscular endurance, static muscular endurance, aerobic capacity, and ski racing experience. Secondary purposes were to relate phasic muscular endurance to aerobic capacity and to relate strength to endurance.

Maximum phasic muscular strength was determined by the amount of weight the subject could elevate by extending the knee to 180 degrees. Phasic muscular endurance was determined by the number of repetitions the subject could do at a rate of 30 repetitions per minute with a resistance of two times the subject's weight. Static muscular endurance was determined as the length of time the subject, with his knees at a 90 degree angle, could keep a resistance comparable to his own body weight elevated. These tests were all done using the Universal gym as the testing device.

The ranking of the competitors was done by the varsity ski coach (the author) at the university of Montana after observing them in races and training throughout the season. The number of years racing experience was obtained on the personal questionnaire. The subjects were tested for aerobic capacity by means of a test developed for the U. S. Forest Service by the Missoula Equipment Development Center and the Human Performance Laboratory at the University of Montana (11).

The subjects were the top twenty skiers on the 1969 University of Montana Varsity Ski Team. The subjects had all used the testing apparatus during the Fall training program. After becoming refamiliarized with the testing device, the subjects were tested on the various measures.

The relationships between the various test results were determined by using Spearman's Rank Order Correlation (Rho).

## CONCLUSIONS

On the basis of the findings in this study, the following conclusions were made:

1. As separate measures maximum phasic strength, phasic muscular endurance and static muscular endurance were not related to ranked skiing performance.
2. There was a strong positive relationship between ranked performance and ski racing experience indicating that experience may be an accumulation of many variables.
3. There was no relationship between ranked performance and aerobic capacity.
4. There was no relationship between phasic muscular endurance and aerobic capacity.
5. There was a significant correlation between maximum phasic strength and phasic muscular endurance.
6. Neither maximum phasic strength nor phasic muscular endurance were related to static muscular endurance.

## RECOMMENDATIONS

In view of the findings and conclusions from this study, the following recommendations have been made.

1. The same basic tests should be administered to another group of ski racers who are more equal in ability and experience in order to determine if the findings of this study would apply to all competitors.
2. A study should be conducted which would relate more measures such as agility, coordination, reaction, speed, anaerobic power, and personality type to racing performance.
3. A strength and endurance study consisting of a pre-season pre-test and a post-season post-test should be conducted to measure strength and endurance changes and their relationships to alpine skiing performance.
4. A study similar to this study should be conducted with a group of beginning skiers. After one season of practice, their strength and endurance scores could be related to their ability ranking.
5. Using multiple regression procedures, a variety of physical and psychological variables could be related to skiing performance. The resulting prediction equations would help the coach or teacher to define those factors associated with success in alpine ski racing.

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## SELECTED BIBLIOGRAPHY


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# APPENDIX

## DATA SHEET - APPENDIX A

| SUBJ. | ABILITY RANK | AGE | HT. | WGT. | SKI EXP. | RACE EXP. | STRENGTH $T_1$ | STRENGTH $T_2$ | STATIC ENDURANCE TIME | STATIC ENDURANCE WGT. | PHASIC END. REPS. | PHASIC END. WGT. | AEROBIC CAPACITY ml/kg/min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R.G. | 1 | 21 | 72" | 167 | 12 | 8 | 420 | 450 | 4 min. 51 sec. | 180 | 50 | 330 | 46.6 |
| J.W. | 2 | 25 | 67" | 140 | 23 | 15 | 660 | 660 | 4 min. 20 sec. | 150 | 300 | 270 | 71.9 |
| R.L. | 3 | 21 | 69" | 141 | 15 | 9 | 390 | 450 | 3 min. 20 sec. | 150 | 50 | 270 | 45.3 |
| K.H. | 4 | 18 | 68" | 151 | 7 | 4 | 450 | 510 | 4 min. 03 sec. | 150 | 51 | 300 | 51.0 |
| C.M. | 5 | 18 | 68" | 151 | 11 | 3 | | 540 | 5 min. 40 sec. | 150 | 51 | 300 | |
| M.H. | 6 | 19 | 72" | 172 | 8 | 6 | | 540 | 4 min. 56 sec. | 180 | 50 | 330 | |
| M.D. | 7 | 19 | 71" | 161 | 6 | 3 | | 480 | 9 min. 18 sec. | 150 | 43 | 330 | |
| A.W. | 8 | 19 | 72" | 165 | 11 | 3 | 450 | 480 | 3 min. 46 sec. | 150 | 66 | 330 | 48.6 |
| G.K. | 9 | 19 | 68" | 147 | 13 | 13 | | 510 | 2 min. 29 sec. | 150 | 51 | 300 | |
| J.M. | 10 | 20 | 68" | 159 | 14 | 4 | | 600 | 8 min. 14 sec. | 150 | 60 | 330 | |
| D.C. | 11 | 20 | 70" | 140 | 7 | 3 | | 420 | 1 min. 05 sec. | 150 | 34 | 270 | |
| R.H. | 12 | 19 | 64" | 135 | 9 | 6 | | 510 | 1 min. 49 sec. | 150 | 50 | 270 | |
| P.T. | 13 | 18 | 69" | 139 | 14 | 6 | | 420 | 5 min. 05 sec. | 150 | 50 | 270 | |
| D.C. | 14 | 19 | 67" | 149 | 14 | 1 | | 660 | 4 min. 00 sec. | 150 | 125 | 300 | |
| O.S. | 15 | 20 | 66" | 126 | 8 | 3 | | 510 | 7 min. 45 sec. | 120 | 43 | 240 | |
| D.H. | 16 | 18 | 73" | 198 | 3 | 2 | | 510 | 3 min. 10 sec. | 210 | 50 | 390 | |
| M.R. | 17 | 19 | 68" | 152 | 6 | 4 | | 570 | 4 min. 20 sec. | 150 | 80 | 300 | |
| G.G. | 18 | 18 | 69" | 145 | 12 | 3 | | 390 | 7 min. 47 sec. | 150 | 90 | 300 | |
| J.M. | 19 | 18 | 72" | 192 | 9 | 1 | | 450 | 4 min. 35 sec. | 180 | 31 | 390 | |
| D.T. | 20 | 22 | 74" | 181 | 7 | 1 | 480 | 510 | 7 min. 50 sec. | 180 | 32 | 360 | 48.4 |
| R.F. | 5* | 20 | 67" | 145 | 9 | 6 | | | | | 115 | 300 | 40.7* |
| J.S. | 7* | 18 | 68" | 157 | 3 | 1 | | | | | 52 | 300 | 55.7* |

*Results used only in Aerobic Capacity Statistics

# APPENDIX B

## STATISTICAL RESULTS

| | Relationships | t | P | N |
|---|---|---|---|---|
| 1. | Phasic Strength--Ranked Ability | .55 | .1274 | 20 |
| 2. | Phasic Endurance--Ranked Ability | 1.02 | .2399 | 20 |
| 3. | Static Endurance--Ranked Ability | .55 | -.1297 | 20 |
| 4. | Aerobic Capacity--Ranked Ability | .17 | -.0714 | 8 |
| 5. | Ranked Ability--Racing Experience | 3.816 | .6733 | 20 |
| 6. | Phasic Strength--Phasic Endurance | 2.42 | .4936 | 20 |
| 7. | Phasic Strength--Static Endurance | .297 | .0694 | 20 |
| 8. | Phasic Endurance--Static Endurance | -.297 | -.0726 | 20 |
| 9. | Phasic Endurance--Aerobic Capacity | .86 | .3274 | 8 |
| 10. | Body Weight--Phasic Strength | .424 | .1000 | 20 |
| 11. | Body Weight--Phasic Endurance | -.72 | -.1741 | 20 |
| 12. | Body Weight--Static Endurance | .97 | .2267 | 20 |
| 13. | Phasic Strength Test - Retest | 14.02 | .94 | 6 |
| 14. | Percent of Maximum Strength at 1 Body Weight 31.58 Percent | | | |
| 15. | Percent of Maximum Strength at 2 Body Weights 62.2 Percent | | | |
| 16. | Average Contraction Time - Isometric 4 minutes, 55 Seconds | | | |
| 17. | Average Contraction Time - Isometric 2 Minutes, 16 Seconds | | | |

# APPENDIX C

These findings may have substantiated some theories that perhaps the best downhill racers were very athletic and aggressive while the best slalom racers were very precise and self-sufficient. It is the experience of the author that this is most generally true. Often, you find that the individual that excels in downhill racing also performed well in other sports such as football or soccer, whereas the individual that does extremely well in slalom racing may be one that participates in very few, if any, other sports, and these sports most often tend to be individual rather than team sports.

It is the author's contention that in most cases exposure to an aggressive athletic situation would be very beneficial to the introverted athletes. Skiing is a good example. For the most part skiers compete only against a clock. The skier never beats the clock, he only beats his previous time, or doesn't; at any rate, in normal ski racing he is never placed into a one-on-one situation where he must defeat another individual. Dual slalom races have altered this situation a great deal. In a dual slalom, competitors race against each other on identical courses without regard to elapsed time. Quite simply, the first racer to successfully negotiate the course is the winner. This type of race tends to make the racer ski more aggressively, sometimes sacrificing style and technique for speed, but nevertheless, reducing the amount of time required to complete the course.

# APPENDIX D

## AEROBIC CAPACITY MEASURING DEVICE

## APPENDIX E

## ON-SNOW TRAINING - COMMENTS

On-Snow training sessions must be carefully supervised by the Coach. Skiing is like any other sport in many ways; bad habits are often more easily developed than are good ones. The Coach must be aware of the progress of each individual and must be alert to recognize any tendencies to develop bad habits. In a concentrated training program, a Coach's inattentiveness could be disastrous.

Another note of caution pertains to the "burning-out" of competitors. The conscientious Coach must also be able to recognize signs of boredom or apathy in his charges. Fortunately, skiing is a sport in which this is not too common of an occurence. However, because of too long a conditioning period or just too much skiing, this may sometimes occur. It will generally happen to individuals and not to an entire team. If this should happen, it is advisable to reduce the amount of required training time for the individual. It is the contention of the author that the competitor should put in as much time in actual race course work as is practical, because every run through a slalom course is, or should be, a learning experience. Too much of a workout fails to simulate an actual competitive situation and bad habits, injuries, and apathy may result from overtired muscles or minds. It also must be remembered that an actual ski race will generally require only about 35 seconds to three minutes of actual skiing, so it is easy to see that the fourth hour of a training session is probably not too constructive.