Master's Thesis

TESTING FOR JUMPING POWER IN FIGURE SKATERS

A thesis presented to the School of Physical Education & Athletics
Lakehead University

In fulfilment of course P.E. 5901, Master's Thesis

Kelly L. Lockwood ©

November, 1993

National Library of Canada
Acquisitions and Bibliographic Services Branch
395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale du Canada
Direction des acquisitions et des services bibliographiques
395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

ISBN 0-315-86181-9

ABSTRACT

The purpose of the investigation was to contrast and compare tests of jumping power in figure skaters. Twenty two Canadian Figure Skating Association (C.F.S.A.) test stream figure skaters, qualified at a Senior Bronze Freeskate Test Level or above volunteered as subjects. The mean age and years of figure skating training was 13.9 and 7 years respectively.

Power measurements taken from the force platform were compared to estimates of power taken from laboratory jump tests and on-ice jumping performances. Correlations between empirical power measures and both laboratory and on-ice jumping power values were significant. In the past, the "gold standard" laboratory jump scores have been employed as measures of jumping ability in figure skaters. The results of the present research does not support the use of the jump scores from the vertical jump-and-reach test and the standing long jump to predict or estimate on-ice jumping ability. These two tests do not seem to be representative of the performance of on-ice jumping power. However, when the jump scores were used to calculate power, estimations of power from both on-ice performances and the laboratory jump tests correlated significantly with each other as well as with the empirical measure of power respectively.

In conclusion, based upon the results of this investigation, the reported on-ice analysis of jumping power offers the possibility of an alternative assessment of evaluating power in figure skaters. Optimally, a field test to assess power output, that could be administered by the coaches at the practice site may be established as a coaching tool to assist in establishing training loads and monitor the progress of the skater's jumping ability.

ACKNOWLEDGEMENTS

I would like to acknowledge the following people who assisted me in the completion of this thesis:

To my advisor, Dr. A. Bauer and members of my committee Dr. R. Thayer and Dr. D. Weeks, I would like to express my appreciation for their constructive suggestions and words of encouragement during the course of this study.

To the graduate coordinator, Dr. M. McPherson, I would like to extend a special thank you for your assistance and guidance.

To the laboratory technician, Carlos Zerpa for the hours of programming and technical assistance.

To the skaters who volunteered their time and efforts. Without their involvement, it would have not been possible to embark on this research project.

To my friends and confidants in Thunder Bay; Harold and Darciene Kish, Katie Peel and David Work. Sincere thanks for your support, understanding and encouragement.

To my brother Bill who graciously put up with an older sister embarking upon his university and university experiences. Bill, hopefully these are days we will never forget.

Finally, to my parents who provide me with a source of strength and have always contributed to my efforts in achieving the goals I set for myself.

TABLE OF CONTENTS

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

APPENDICES

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

Introduction

Figure skating can best be described as a successful union of athletic and aesthetic activity (Woch, 1977). According to the rules that govern the sport of figure skating, the athlete is required to perform technical feats that are both physically demanding and aesthetically pleasing. Technically, competitive figure skating has developed dramatically over the past decade. Evolution of the sport has been marked by revolution (T. Wilson, personal communication, January, 1992). Although freeskating programs include jumping, spinning, connective steps, and poses, jumping is probably the most progressive and important element in free skating performances today. Every year successively more difficult jumps of greater rotations are executed and mastered by competitive figure skaters.

Jumping is an action of power; a product of force and velocity. Maximum application of a force against the ground is required to produce an explosive take-off, converting horizontal speed to vertical lift (Koehane, 1978). Niinimaa, Woch & Shephard (1979) state that in the sport of figure skating, jumps are classified as brief bursts of maximal work, placing a premium demand on the explosive development of power. Therefore, it may be suggested that the ability of a skater to generate leg power impacts significantly upon on-ice jumping performances.

Numerous studies have investigated anaerobic power production on various athletes with different functional tests (Manning, Dooly-Manning & Perrin, 1988). Mechanical measures of external power output appear to be the most practical and accurate methods employed (Garhammer, 1993). The force platform, the vertical jump, and the standing long jump all assess the individual's capacity to generate anaerobic power and evaluate jumping ability. The vertical jump-and-reach test and the standing long jump are considered the "gold standard" laboratory tests for figure skating and are used routinely by many physical educators, coaches and researchers as a measure of muscular power (Adamson & Whitney, 1971; Glencross 1966; Gray, Start & Glencross, 1962). These tests are recognised as valid, reliable and objective measures of leg power.

Despite the wide acceptance of the vertical and standing long jump tests, it has been well documented that all tests of power do not measure similar qualities (Manning et al., 1988). Although it is recognised that the power output required by each performance is generated by the same metabolic reactions, each specific test requires different neurologic or skill components that may have the potential to cause variability in the test scores. Therefore, the question arises as to the usefulness and applicability of the "gold standard" power test results to predict on-ice jumping in the sport of figure skating. As well as measuring leg power as a standard component of a fitness test battery, do the results from the vertical and standing long jump tests have predictive value for performance capability in figure skaters? Furthermore, are these tests useful for estimating the training loads and performance potential of these athletes?

Extensive investigations by Harman, Rosenstein, Frykman, Rosenstein and Kraemer (1991), Manning et al. (1988), and Shephard (1978) all recommend that, anaerobic tests used to evaluate anaerobic power, be performed as specifically as the skill being tested. Shephard also claims that a sport-specific test generally gives a more accurate ranking of competitors than a non-specific evaluation. Therefore, it is suggested that the development of sport-specific tests, based on the qualities important to each individual sport, may allow construction of a more precise athlete profile that can be used by the coach to assess, monitor and modify training programs.

Due to the lack of sport-specific tests measuring leg power in figure skaters, the development of alternative tests may be required. In the present study, the current "gold standard" tests will be evaluated in comparison to possible alternative, skating-specific tests of jumping power.

Purpose of the Study

The purpose of the research was to contrast and compare tests of jumping power in figure skaters. Power measurements taken from the force platform were be compared to estimates of power taken from laboratory jump tests and on-ice jumping performances.

Significance

The heightened physical demands placed upon today's competitive skaters have promoted the growth and acceptance of figure skating as a physically demanding sport rather than an art form. Authors and coaches agree that it is no longer adequate to describe figure skating performance on the basis of artistry and technique alone. However, minimal research has been conducted to provide figure skating coaches with simple, reliable and objective on-ice measures of the physiological variables required by the free skater (Dainty, 1979).

In preparation for the present research, two preliminary investigations were conducted to establish a need for the study. Data was obtained from the physical fitness assessments conducted on the 1991-92 National Figure Skating Team members in July of 1991, conducted at York University. The protocol for laboratory tests currently used by the National figure skating team was developed by Dr. N. Gledhill (Appendix A). Measures of jumping power included the vertical jump-and-reach test (measured in centimetres) and the standing long jump (measured in centimetres). Correlations between these two physiological laboratory tests, and freeskating performance scores attained at the Canadian Championships were determined. This data was compiled with corresponding data obtained from the Canadian Figure Skating Association over the past five years. Of significance to the present research was the absence of a relation between anaerobic power tests and performance. No significant correlations between the vertical jump scores and performance scores or standing long jump and performance were revealed, even though jumping is an integral part of freeskating performances. These results indicate that the power tests employed are not significant predictors of competitive performance scores. Such conclusions stimulated a need to examine the physiological tests employed to evaluate figure skaters and more specifically assess the effectiveness and usefulness of the power tests currently used.

In August, 1991 a second investigation was conducted. A survey was distributed to one hundred and fifty Level III and twenty-five nationally certified figure skating coaches across Canada (Appendix B). One hundred percent (100%) of the respondents indicated that physiological testing was both valuable and necessary for all skaters participating in the Canadian Figure Skating Association test or competitive streams of figure skating. However, only twenty four percent (24%) of the coaches are currently using this type of testing. Expertise, accessibility, available facilities, cost, time, and equipment were all stipulated as reasons why testing was not routinely conducted. Similar restraints have also limited the funding provided by the Canadian Figure Skating Association and currently only the National team members are funded for testing. These results imply that the need for physiological testing is recognised by the coaches however, conducting this type of testing routinely does not appear to be a priority. If empirical evidence provided support for the use of sport-specific physiological testing as an accurate and reliable measurement tool to estimate training loads and predict performance capability, the use and effectiveness of testing may be valued as an essential component of training.

Based upon the results the these two investigations; lack of relationship between leg power test results and freeskate performance scores and a need to develop sport-specific testing procedures, this research was developed. The objective of this study is to investigate the appropriateness of the "gold standard" laboratory measures of leg power currently used by the Canadian Figure Skating Association. These measures will be compared to alternative power tests to determine the viability of on-ice measures of jumping power.

Limitations

This research will be conducted recognising the following limitations:

1. The sample of figure skaters used may not totally represent all levels of figure skaters.
2. The ability of this researcher to motivate the subjects to exert maximal effort during the tests.
3. Estimated error in the test protocols employed.
4. Measurement error in analyzing techniques employed:
    a) Measurement error related to camera optics and image clarity.
    b) The use of a 2D motion measurement system to analyze a 3D movement.
    c) The accuracy of the researcher in digitizing the anatomical endpoints of the body segments.
    d) Estimates of power are based upon the calculation of force with some degree of error depending on the test.

Delimitations

The scope of the analysis was delimited to:

1. A volunteer population twenty two local Canadian Figure Skating Association (C.F.S.A.) test stream figure skaters.
2. The video record of three trials of each subject performing the waltz jump and subsequent analysis of one filmed trial per subject.
3. The restrictions imposed by the video equipment in quantifying motion.
4. Nineteen estimated body segment parameter values were used in the determination of the centre of mass.
5. The analysis of power using the following methods:
    a) Force platform.
    b) Vertical jump.
    c) Power calculated from kinematic data.

Terminology

Field Test. A measurement that is conducted while the athlete is performing a simulated competitive situation.

Freeskating. A discipline in the sport of figure skating which consists of a well balanced program of free skating components, jumps, spins, steps, and other linking movements executed with a minimum of two-foot skating in harmony with music of the skater's choice. Freeskating allows the skater to show not only his/her skating ability and originality but also his/her interpretation of the music.

Jump. Any movement where the body springs from the ground as a result of its own muscular effort, travels freely in the air and lands back on the ground.

Power. The rate of doing work, or the work output of muscles at specific speeds of contraction: Power may also be expressed as a product of force (F) and velocity (v).

$$P\ (W) = F \times v$$

$$\text{Where: } P\ (\text{power}) = \frac{W\ (\text{work})}{T\ (\text{time})}$$

Waltz jump. A jump which is executed from a forward outside edge, is airborne for one half of a rotations and lands on a backward outside edge on the opposite foot. The takeoff foot, direction of rotation and the landing foot is determined by the direction of rotation which is "normal" for each individual skater.

CHAPTER 2

Review of Literature

Existing literature dealing specifically with the on-ice jumping power of figure skaters is limited, therefore a broader approach to reviewing related research was necessary. The following is a comprehensive account of the literature dealing with the scientific analysis of the sport of figure skating, the nature of jumping, and the measurement of leg power.

Figure Skating

Physiological Profile of a Figure Skater

Available literature dealing specifically with the scientific analysis of figure skating has focused primarily on the anthropometric and physiological characteristics of the elite figure skater. Investigations conducted by Niinimaa (1982) and Niinimaa, Woch & Shephard (1979) indicate that a skater tends to be significantly shorter, lighter and leaner than their sedentary counterparts. Small size is an advantage in sports requiring support and propulsion of one's own body, because a small person tends to have a higher relative strength (strength to weight ratio) (Niinimaa, 1982). Rielly, Secher, Snell and Williams (1990) have characterized the somatotype of female skaters as ecto-mesomorphic and male skaters as mesomorphic. Gailhaguet (1993) claims that skaters with long legs, narrow hips, waists and shoulders have a consider advantage in jumping and rotating rapidly. Body fat content in figure skaters is low (men 9.12 ± 2%, women 12.5 ± 4.6%) compared to the usually accepted values of 15-25% in college age sedentary populations (Niinimaa, 1982). Any fat not required for either physiological or aesthetic reasons reduces the skater's relative strength. As a consequence, it may decrease the height of jumps and time during which aerial manoeuvres can be performed.

Ross, Brown, Faulkner and Savage (1976) have demonstrated that both male and female figure skaters are late maturers. Peak growth and strength are reached approximately one year later than the general population and age of menarche of female skaters is delayed by more than one year (Ross et al., 1976). This extended period of leanness that coincides with prepubertal youth is advantageous in the performance of specific freeskating manoeuvres.

Podolsky (1988) states that figure skaters require both dynamic strength for jumping and static strength for balance and control. A study conducted by Niinimaa (1982) found that static strength measurements indicate extremely well developed leg strength, but less than average upper body strength. The prime muscles employed to perform figure skating elements are the hip extensors (gluteus maximus and hamstrings), knee extensors (quadriceps femoris), abductors (gluteus minimus and medius), and adductors (adductor magnus, longus, brevis) (Aleshinsky, 1988). Further investigations conducted by Podolsky, Kaufman, Cahalan, Aleshinsky & Choa (1990) concluded that both upper and lower extremity strength significantly contribute to the jumping ability of skaters. However during the traditional on-ice training method, in which jumping repetitions are performed to develop strength, the muscles of the lower extremities contract specifically with the load of the skater's body mass. In contrast, actions of the upper extremities are performed with no extra load, therefore are at a disadvantage in terms of progressive resistance or a training effect. As a result, if an alternative form of strength training is not employed, freeskaters typically have greatly developed lower extremity strength and relatively poor upper extremity strength development.

Niinimaa et al. (1979) have suggested that an aerobic power value of 47-52 $ml.kg^{-1}.min^{-1}$ is required for females to skate at an elite level. A review of aerobic power values of elite male and female figure skaters reported in the literature are outlined in Table 1. Although competitive freeskate performances are not long enough in duration to be considered purely aerobic in nature, the capacity to practice for extended periods of time to perfect the skills and techniques demand a moderate to high level of physical endurance from these athletes. Niinimaa and colleagues reported that skaters exercised at 75 -80% of VO_2 max during a freeskate session and reached maximal heart rates several times. However, these authors attributed the high heart rates in part to anticipation of difficult moments, emotional factors, breath holding and muscle tensing.

Table 1

Aerobic Power of Elite Male (M) and Female (F) Figure Skaters

Sex	VO_2max ($ml.kg^{-1}.min^{-1}$)	N	Exercise Mode	Reference
M	58.5	5	Treadmill	Niinimaa et al. (1979)
F	48.9	4	Treadmill	Niinimaa et al. (1979)
F	47.7		Cycle	Gordon et al. (1969)
F	52.5		Treadmill	McMaster et al. (1979)

Note. From Physiology of Sports (p.329) by T. Reilly, N. Secher, P. Snell & C. Williams, 1990.

A dearth in the literature exists with respect to investigating anaerobic power values in skaters. The requirement for high levels of power output is evident in the repetitive execution of jumps. Although authors agree that on-ice jumping performances are a display of anaerobic power and state that skaters achieve significantly higher power output values than noted in age-matched controls (Reilly et al., 1990), published studies fail to quantify power measurements.

Physiological Profile of Freeskating Perfomances

Athletic events are often classified by duration and the predominant source of energy being used (Shephard, 1978; Skinner & Morgan, 1985). Competitive figure skating requires the athlete to perform freeskate programs of two to four and a half minutes in duration. Each program consists of a minimum of seven technical feats choreographed artistically and performed to music. In the 1993 World championships, the men's and ladies senior competitors freeskating programs consisted of an average of 10 to 14 double and triple jumps and jump combinations in addition to other technical content within a four or four and a half minute program, respectively. Several of these elements (ie., jumps, combination jumps, flying spins) are performed in durations of less than ten seconds and require "all out" maximal efforts.

Several studies have investigated the energy systems employed during an entire freeskate performance (Niinimaa, 1982; Niinimaa et al., 1979; Patton, Pyke, Hahn, Telford & Tumilty, 1986; Reilly et al., 1991; Sharkey, 1986). Niinimaa et al. (1979) concluded that competitive figure skating places a demand on both the aerobic and anaerobic energy systems, superimposed by brief bursts of maximal and even "supramaximal" work. "Supramaximal" refers to power outputs greater than that necessary to elicit VO_2 max (Evans & Quinney, 1981). More recent studies by Sharkey (1986) and Patton et al. (1986) support the statements of previous researchers. Sharkey (1986) calculated the energy requirements to perform the sport of figure skating as being derived from 70% anaerobic and 30% aerobic processes. A summary by Reilly et al. (1990) describes freeskate programs as an interval type of activity; power movements (ie., jumps) requiring high energy expenditure and the glide phases only low metabolic output.

Jumping

As stated previously, jumps constitute a high percentage of the freeskating program in figure skating. Literature by Dainty (1979) and Koehane (1978) underscore the importance of jumping in the development of a successful skater. Although jumps are somewhat subjectively judged within the context of an entire program, authors and coaches agree that the success of a competitive skater is marked by the ability to perform both jumps in isolation and in combination. The concentration of research efforts dealing specifically with on-ice jumping has been directed primarily to technical "how to" articles. Limited attention has been devoted to empirical scientific investigations of the physiological parameters required for jumping performances in figure skating. Although, knowledge of on-ice jumping techniques is necessary to elucidate the relevance of leg power testing, the physical qualities required to perform the technical skills warrant scientific attention.

As defined by Koehane (1978) a jump is any movement where the body springs from the ground as a result of its own muscular effort, travels freely in the air and lands back on the ground. Figure skating jumps are classified on the basis of take-off; edge versus toe assisted take-offs, direction of rotation; normal or reverse, and number of revolutions while airborne; singles, doubles, triples, etc. On-ice jumps can be analyzed in three phases: take-off, flight and landing. As defined by McPherson & Bothwell-Meyers (1986), the take-off phase extends from when the skater transfers their weight over to the take-off foot, in preparation for a concentric thrust into the air, until the last instant of contact between the blade of the take-off skate and the ice. The flight phase commences the instant the blade of the take-off skate lifts off the ice, and extends throughout the airborne duration. During flight, the skater completes a specific number of revolutions. This is accomplished by "pulling in" the arms and the free lower extremity, ie., bringing limbs closer to the body or the vertical axis of rotation. This action decreases the skater's moment of inertia, in turn increasing the angular velocity or the speed of rotation. The landing phase is initiated the instant the landing skate makes contact with the ice surface and is concluded when the skater is in a balanced state of dynamic equilibrium with free limbs extended in an aesthetically pleasing manner. Equilibrium is facilitated by the skater "checking out" or opening the arms and free lower extremity, thus slowing down or decelerating the angular velocity during flight.

Dr. J. Dedic (1974) claims that the three variables that characterize correctly executed and powerful jumps are speed, height and length. Speed or velocity at take-off contributes to the height attained by the skater and the length of time the body is in flight. The number of revolutions completed while airborne is a function of the time of flight. Maximizing time spent in the air is accomplished by optimizing the velocity at take-off, the angle of take-off and producing a vertical force sufficient to project the skater as high as possible into the air. The velocity of the total body entering the jump combined with the vertical force produced during the take-off phase determines the vertical velocity imparted to the body. The force produced at take-off is the sum of the forces produced by the muscle action of the thigh, leg and foot and to some extent the part to whole transfer of momentum of the arms and free leg. As a result, greater flight or air time contributes to the skater's potential to complete multiple revolutions and ultimately achieve higher performance scores.

Podolsky et al. (1990) also emphasizes that the corner stones of a figure skating performance is the height of the skater's jumps. Although there are no objective measurements in figure skating as in speed skating or high jumping, it is recognised that a well performed jump of significant height attributes to the success of a skater's overall performance. Research conducted by Podolsky and colleagues focused on identifying the specific qualities needed for higher jumps in figure skating and specifically examined the relationship between strength and jump height. Skaters were assessed for strength of the shoulder, knees, and hips at multiple angular velocities using a Cybex II system. The results of that study show that the height of the jumps significantly correlate with muscle strength of the shoulder in abduction and adduction, the knee in extension and the hip in extension and flexion. Knee extension and shoulder abduction were shown to be the most important strength parameters in determining the height of the jump.

The figure skating jump identified for the purpose of the present research is the waltz jump. The waltz jump is one of the most fundamental jumps in freeskating. It is extremely important as it requires all the basic skills necessary for the execution of more powerful jumps (McPherson, unpublished thesis, 1983). The skater begins the jump with a one foot take-off from the forward outside edge, rotates 180 degrees while airborne and lands on the backward outside edge of the opposite foot. As previously described the take-off, flight and landing phases of this particular jump are characteristic of all edge jumps, including jumps of greater difficulty and additional rotations.

McPherson (unpublished thesis, 1983) conducted a biomechanical analysis of the waltz jump performed by 14 highly skilled figure skaters. This qualitative analysis was done to enhance the understanding and description of the jump as well as provide scientific information regarding the factors which mechanically limit the jump. McPherson concluded that a successful waltz jump demands good physical efficiency and take-off power at a low skill requirement. This allows the researcher to more effectively parcel out the skill component of the jump and analyze the mechanical and physiological power component of the jump.

Power

Manning et al. (1988) state that power output is extremely vital to sports which require explosive movements. The explosive nature of jumping is described frequently in the literature in terms of power (Ayalon, Inbar & Bar-Or., 1974; Dainty, 1988; Garhammer, 1993; Harman et al., 1991; Manning et al., 1988). The term explosive power has been used to define the type of activity that requires short, "all-out" muscular effort such as jumping (Ayalon et al., 1974). Insights into the characteristics associated with power output and methods used to evaluate power can be of value to sport scientists, coaches and athletes in enhancing and predicting performances that require an expression of power.

Power can be examined physiologically, biomechanically and technically with regard to both on-ice and other related jumping activities. Metabolically, performances which principally involve short bursts of heavy exercise, depend on high energy phosphate stores in the muscle (Manning et al., 1988). Metabolic work is the energy used and released by the body during the chemical breakdown of substrates such as glucose and fats (Garhammer, 1993). The capability of the muscle to utilize these stores generating maximum force in the shortest possible time is defined as metabolic or anaerobic power. Therefore, power may also be expressed as metabolic work performed per unit of time. According to Shephard (1978) the physiological variables associated with generating power for jumping include: (a) explosive force - the total number of muscle fibres that can be recruited, the proportion of fast twitch muscle fibres, the activity of the enzyme ATPase and the resultant rate of transfer of energy from phosphate stores to the bonding of the muscle proteins actin and myosin, (b) resistive forces - the viscosity of the muscles, the degree of relaxation of the antagonists, the inertia of the body and of its individual parts, and (c) coordination - timing, skill and agility. Sargeant (1990) summarizes that muscular power delivered for physical activity of short-term duration is a result of a proportionate contribution of energy pathways, efficiency of energy transformation, muscle architecture and size, and patterns of recruitment and coordination.

It has been well established by Margaria, Aghemo & Rovelli (1966) that the power developed in very short exercise of no more than 4-5 seconds duration may only be indicative of the phosphagen splitting mechanism of work production alone. Sport-specific studies by Tharpe, Newhouse, Uffelman, Thorland & Johnson (1985) also suggest that the sudden release of a large amount of energy demanded during on-ice jumping in a freeskate performances can only be provided by anaerobic energy pathways involving phosphagen breakdown and glycolysis. Niinimaa et al. (1982) reported that maximal lactate values of 11.9 ± 3.6 mM for male and female skaters, respectively, following the completion of a 4 minute freeskate performance were recorded indicating a significant anaerobic metabolic requirement is demanded during these performances. McArdle, Katch and Katch (1986) agree that any performance, involving all-out exercise of 4-6 seconds in duration, can be considered indicative of the persons capacity for immediate power from the high energy phosphates in the specific muscle activated.

Within the scope of this research, power will be limited to the biomechanical measurement of lower extremity power output. With specific reference to skaters, Gledhill (1976) describes power as the capacity to release maximal force through an optimal range of motion in the fastest possible time. He states that the more powerful the legs, the easier it is to perform the jumps required in figure skating performances. Aleshinsky (1988) agrees that better jumpers have the ability to maximize power output and therefore execute more explosive takeoffs and technically superior jumps.

Biomechanically, power is a product of force and velocity (Reilly et al., 1990). As a result of manipulating either of these two variables, power production would increase. Investigations conducted by Aleshinsky (1988) on the biomechanics of figure skating, indicate that superior technique was observed by skaters executing jumps at higher take-off velocities. Aleshinsky therefore postulates that, if a skater can increase absolute velocity from 5 to 8 m/s, the reward would be an additional jump height of approximately .5 meters and additional length of approximately .3 meters. Height of the jump increases flight time and consequently time to complete multiple revolutions. As a result the higher speed of approach, power output is increased, height is achieved and as previously described in the section on jumping these factors all contribute to enhance both the artistic and technical aspects of performance.

Predicting Power

Due to the highly invasive techniques required to estimate the interaction of the physiological factors involved in jumping, numerous mechanical tests of jumping power have been developed (Ayalon et al., 1974; Bosco, Luhtanen & Komi, 1983a; Gray et al., 1962; Glencross, 1966; Margaria et al., 1966). The prediction of anaerobic power from functional tests conducted both in the laboratory and in the field is promoted by the literature. Laboratory tests are defined on the basis of being conducted in a controlled laboratory setting, they are precise, reliable and objective measures, and measure actual physical capacities (NCCP, 1990). However, they tend to lack sport-specificity, involve extensive equipment and are often expensive. In contrast, field tests or lab-like tests are conducted in the sport environment, result in actual sport performance measures and are often more accessible for coaches and athletes in sport.

Although numerous studies have investigated anaerobic power tests in several other sports (Adamson et al., 1971; Coggan & Costill, 1984; Gray et al., 1962; Glencross et al., 1966; Manning et al., 1988; Vandewalle, Peres & Monod, 1987) to the knowledge of this researcher, no single test or anthropometric measure exists which can specifically predict anaerobic power during on-ice jumping in figure skaters. The Canadian Figure Skating Association currently employs the "gold standard" laboratory jump-and-reach test and standing long jump to determine jumping power and jumping ability in figure skaters. Research conducted by Dainty (1979) claims that the vertical jump characterized the skater's ability to produce forces on the ground to obtain height. Dainty cautioned, however, that jumps performed during a skating routine are quite different than those performed in the laboratory. Nevertheless he felt that they are indicative of what can happen on ice. Recommendations made by Dainty included further investigations using film as well as force platform data on larger samples of athletes to investigate the critical factors inherent in the skill of jumping as it relates to skaters.

The relevance and relative importance of power to performance can be established by correlating the results and specific tests of power to sport performance (MacDougall et al., 1991). If this process is conducted successfully, the coach then acquires information that allows him or her to establish the priority that should be placed on duration and type of training for power. During a preliminary investigation in July, 1991, a statistical analysis was performed on the physiological variables assessed by Gledhill (1991) measuring jumping power and the performance scores attained at the Canadian Championships among members of the Senior National Single Figure Skating Team. No significant correlations existed between the vertical jump and performance or standing long jump and performance. If jumping is an essential element in the freeskating performance and the vertical and standing long jump are determinations of jumping ability, this non relation warrants further scientific investigation.

Description of Jumping Power Tests

Anaerobic power tests reflect an individual's capacity to do maximal or supramaximal work in a brief period of time (Evans & Quinney, 1981). The tests selected for this review are easily administered and generally well accepted by the subjects due to their short duration and non-exhaustive nature (Margaria et al., 1966). Other power tests, such as the Margaria stair test and the Wingate ergometer test, do not relate as well biomechanically to jumping movements, therefore were not selected as comparative measures. In the section to follow, a description of the tests employed for the purpose of estimating power in the present investigation are presented.

Force Platform Power Measures

A force platform is a device designed to measure the forces exerted by a body on an external surface (Dainty & Norman, 1987). A flat plate is supported by four strain gauges as transducers and allows the simultaneous measurements of the three components of a force in three planes about three orthogonal axes (X, Y, Z) of the platform (Dainty & Norman, 1987). For the purpose of the present research, an AMTI-component biomechanical platform interfaced with AMTI Power Analysis Software (Appendix C) was used to measure take-off or peak power.

The use of a force platform has enabled the most accurate measurement of the power produced during a vertical jump (Davies, 1971; Davies & Rennie, 1968; Offenbacher, 1970) Harman et al. (1991) states that the force platform technique is the method of choice for precise jumping-power measures in the laboratory. Power output of the jumper is calculated as a product of force and velocity. Force exerted by the jumper's muscles results in a vertical ground reaction force at the feet, which could be considered to act at the total body centre of mass accelerating the body upwards (Harman et al., 1991). In jumping, the power value is a product of the vertical ground reaction force (VGRF) and the total body centre of mass vertical velocity (TBCMVV).

Jumping power (W) = VGRF (N) x TBCMVV (m.s-1)

From the data collected both instantaneous and average power values can be determined. Instantaneous power is calculated throughout the jumping movements as a product of VGRF and the calculated TBCMVV. Whereas, average power is calculated over the time period between initiation of the jump movement and takeoff.

Vertical Jump Power Measure

The vertical jump test was presented by D.A. Sargent (1921) as the "physical test of man" and a measure of general muscular power. Sargent as cited by Adamson et al. (1971) refers to the work done by causing the body to rise above the ground is the excess work done over that required merely to raise it from the squatting to the standing position. This excess work consists of building up velocity, an accomplishment possible only when the rate of doing work (power) is above a certain minimum (Adamson et al., 1971).

The Sargent jump-and-reach test is scored as the difference between a persons standing reach height and the maximum jump-and-reach height. The height of a vertical jump can depend on the protocol used. The jump begins either in a crouch position, with knees bent about 90 degrees or in a standing position followed by a fast knee bending movement just before jumping (counter-movement). The displacement of different parts of the body (preferred hand, waist, head) is measured. MacDougall, Wenger & Green (1991) recommend that during the jump-and-reach test in which jump height is measured directly from a jump-and-reach board, standardization of positioning and range of movement or depth of the countermovements is essential.

McCloy (1932) as cited by Adamson et al. (1971) stated that the Sargent jump test, when combined with an appropriate formula containing factors of age and weight, predicts a 'power' type of athletic ability that is probably the best single measure of predicting explosive energy (Adamson et al., 1971). The Lewis formula (Power (kg-m/s) = Body mass (kg) x $[4.9 \text{ x Jump height (m)}]^{0.5}$) and the nomogram first published in 1974 by Fox and Mathews has become widely used among coaches, physical educators and researchers to estimate power output during the vertical jump-and-reach test. Several other investigators (Garhammer, 1993; Harman et al., 1991; Manning et al., 1988 & Vandewalle et al., 1987, Davies & Young, 1984) have questioned the validity of the Lewis formula. As cited by Garhammer (1993), the power value calculated by this formula must be multiplied by the acceleration of gravity (9.8 m/s^2) to obtain the standard power unit of watts. Garhammer also claims that this formula assumes that work done during the jump equals the work done in lifting body mass a height equal to the jump height. The time factor to determine power is set equal to the time it would take a point mass to fall from rest a distance equal to the jump height and as a result is not generally related to the actual time of propulsion to generate the take-off velocity for the jump. Vandewalle et al. (1987) state that the validity of the Lewis formula is dubious because the power given by the formula is equivalent to the quotient of the potential energy change divided by the duration of the ascending phase of the flight, instead of the thrust duration. Moreover, Lewis's formula does not take into account the work performed before the take-off (Vandewalle et al., 1987).

These researchers advocate that it may be simpler to consider only the value of the height of the vertical jump because there is a high correlation (r=0.92) between the height of a vertical jump and the peak power output calculated from the data of the force platform. Literature indicates that test-retest reliability of the vertical jump-and-reach test is high. For example, Bosco et al. (1983a), and Gray, Start, and Glencross (1962) reported reliability coefficients of .95 and .98, respectively. According to these authors, the values support the use of raw jump scores as an alternative method of estimating jumping power.

In 1991, Harman and colleagues proposed an alternative formula to calculate power from the vertical-jump and reach test results. This formula was derived as a result of a theoretical analysis by Harman et al. that also disputed the validity of the Lewis formula. According to that investigation, they conclude that the Lewis formula does not provide accurate estimates of either peak or average power produced by the muscles. Harman et al. states that initially, power should be measured in watts, which are newton.meters.per second (n.m.s.$^{-1}$) and secondly, the power calculated from the Lewis formula is that exerted by gravity on the jumper's body as it falls back to the ground from the jump's high point. It was confirmed that the formula provides only the average power of the falling jumper and not the power exerted by the jumper while taking off. It was suggested that a method to determine the power produced during the jumping take-off phase be established. From this investigation, Harman et al. proposed the following formulae for estimating both average and peak power from the jump-and-reach distance and body mass.

Peak Power (W) = 61.9 x jump height (cm) + 36.0 x body mass (kg) - 1,822

Average Power (W) = 21.2 x jump height (cm) + 23.0 x body mass (kg) - 1,393

Standing Long Jump

Available literature regarding the nature of the standing broad jump is limited. As cited by Glencross (1966) this jump test was proposed as a measure of muscular power, leg power, dynamic strength, coordination and jumping ability. However, has also been included in test batteries devised to measure physical fitness, motor and athletic abilities. Norms for the standing broad jump have been presented by the Canadian Association for Health, Physical Education and Recreation, Ottawa, Fitness Canada (1969) with regard to age of the subject and distance jumped, however were not used in the present investigation.

Video Analysis

Video analysis systems allow an athlete's videotaped performance to be displayed on a computer screen as a series of graphic images and stored in digital form. The system imports a video image recorded on VHS format videotape into a computer, where it is split into two pictures (fields), enhanced, and presented to the operator to be digitized. The researcher can then extract quantitative data on the position and movement of the subject being studied. Associated software can then condition and scale raw displacement data as well as calculate segmental centres of mass and both linear and angular velocities, accelerations, and displacements.

A study conducted by Cole, Meixel, Morris & Stoner, (1984) claims that computer analysis of figure skating jumps can identify opportunities for improving skater performance by utilizing the kinematic description of jumping dynamics derived from film analysis in an attempt to optimize jumping technique. In addition, this type of analysis provides the freedom to explore alternatives in body position, speed, thrust and timing by simulation and provides the coach with a tool for systematic assessments of jumping technique. Computer analysis also provides the opportunity to visually contrast different skaters both through an examination of differences in position, velocity and timing and through an exploration of the different forces that are exerted. As stated by Cole et al. world class skaters could be compared with national contenders to provide insights into the subtle differences. Used as a teaching and training tool, feedback provided from the analysis could be used by the national level skater to improve jumping techniques.

Field Tests

For non-laboratory test situations, the constraints imposed by available facilities, equipment, time, and expertise all limit the variables that may be measured. Consequently, it is the purpose of a field test to provide a reliable estimate of the selected fitness scores from a few simple variables. For the purpose of the present study, an on-ice field measure of power has been selected from unpublished literature. The protocol employed for this assessment has been provided by A. Reed (1991) and is being used to assess on-ice leg power in figure skaters. According to Reed (personal communication, November, 1991) this test has not been validated and therefore limits the test results.

Inter-Relations among Power Tests

It is argued that if the various power tests measure the same metabolic capacity, then the individuals ranking high on one test should rank correspondingly high on a second or third test. Although information on this topic is incomplete, the data collected by McArdle et al. (1986) indicate that those who do well on one power performance test tend to do well on another, but the correlation is at best moderate. Most relations among power tests range from poor to good, indicating some in commonality between tests and suggesting that each may be measuring a similar metabolic quality. McArdle et al. explain the difference between power scores as due to human performance being highly task specific. Even though energy to power each performance is generated by the same metabolic reactions, the reactions are isolated within the specific muscles activated by the exercise. McArdle et al. emphasize that each specific test requires different neurologic or skill components that tend to cause variability in the scores.

A factor analysis of various anaerobic power tests was conducted by Manning et al. (1988). All anaerobic power tests utilized in that study involved a quick explosive movement for a short period of time. The tests included: the vertical jump using the Lewis formula, the Margaria-Kalamen stair climb test, the Wingate maximum anaerobic capacity and peak power test, the Cybex II Isokinetic measures for knee extension, the 40 yard dash and the standing long jump. Results showed that no one common factor emerged in the analysis. The authors suggested that factor analysis, when applied to numerous field and laboratory anaerobic power tests, shows that unrelated aspects exist among the tests and that they are not measuring similar qualities.

The study previously outlined by Harman et al. (1991) compared force plate and Lewis formula methods of power output determination for vertical jumps. They reported considerable differences in the values obtained by the two methods and as a result generated the equation as previously stated. Most recently, a study by Garhammer (1993) compared vertical jump as an estimate of power output to performance measures in the sport of power and weight lifting. His results suggested less than a 10% differences in power output between these activities. However, cautions that using a maximal vertical jump test to predict an athlete's state of readiness for competition or continued heavy training is questionable when at least a 10% fluctuation up or down in calculated power output is possible due to measurement uncertainties.

These findings agree with other research suggesting that there is no one single anaerobic power test that can be used to measure anaerobic power as compared to maximum oxygen uptake which is used to obtain aerobic power (Vandewalle et al., 1987). Although, a comparison of force plate and film or video methods for measuring power output during jumping performance has not been found in the literature, it would seem appropriate that the most empirical method of measuring power output be compared to the actual performance, to accurately estimate and validate performance measures.

Test Specificity

Anaerobic tests employed to evaluate anaerobic power must be performed as specifically as the skill being tested (Manning et al., 1988). In sport, a specific test generally gives a more accurate ranking of competitors than a non specific evaluation (Shephard, 1978). Manning et al. (1988) recommended that if a performance skill is to be tested then the time of event, the body size, the speed of movement, the direction of the task (ie., vertical or horizontal), and whether the task is weight bearing or non-weight bearing must be accounted for when attempting to assess the specific anaerobic power of an individual. MacDougall et al. (1991) also states that the more closely a test can simulate the movement pattern, velocity of movement, and pattern of resistance of a sport performance, the more valuable it will be.

A study conducted by Stromme, Ingjer and Meen (1977) on maximal aerobic power of specifically trained athletes, compared the attainment of maximal aerobic capacity in a heterogeneous group of athletes, during a standard treadmill procedure and during maximal performance of their specific sport activity. The results revealed that nearly all subjects reached higher levels of oxygen uptake when tested in the real training situation. The study concluded that the type of test is an important factor that must be considered when evaluating maximal aerobic power in specifically trained athletes (Stromme et al., 1977). As indicated by their investigation, it becomes important to select an appropriate test activity which tests the optimal use of the specifically trained muscles (Stromme et al., 1977).

Taylor, Burkirk & Henschel (1955) and Skinner & Morgan (1985) agree that the type of activity should be specific to the type of performance being studied as anaerobic capacity can be influenced by the mass of muscle employed to perform the work. The type of activity should also be specific to the individual; for example, runners should be tested on a treadmill, cyclists on a bike and skaters on the ice. To be useful, Harman et al. (1991) proposes that a power test should measure power output during a type of movement of interest to the evaluator, such as one similar to an activity the subject must perform in sport. It may be reasonable to assume that the more sport-specific the mode of testing, the better the result predicts an actual sport performance. In the present study, sport-specific power testing for figure skaters is a significant factor in the research process.

Summary

In summary, jumping is an inherent action of many sporting activities and is a prime performance component in the sport of figure skating. As most authors agree that jumping is an action of power, it is assumed that leg power is a critical component in the performance of on-ice jumping. Numerous studies have investigated anaerobic power production on various athletes with different functional tests. However, a review of the literature suggests a void in scientific investigations dealing specifically with the measurement of on-ice jumping power in figure skaters. Although comparative measures of power have been investigated in the laboratory, their application to measuring on-ice jumping power has received little scientific attention.

Determinations of power from non-sport specific, functional power and jumping tests have presented confounding and often contradictory results. A question to be addressed by the present study is whether or not the tests of jumping ability currently employed by figure skaters are accurate measures of on-ice jumping power. Furthermore, would a sport-specific test of on-ice jumping power be a more accurate predictor of the skater's on-ice jumping ability? It was the focus of the present research to investigate power measures determined by both the traditional and sport- specific methods of anaerobic power testing in figure skaters.

CHAPTER 3

Methods & Procedures

The purpose of the present study was to examine methods of measuring jumping power of Canadian Figure Skating Association (C.F.S.A.) test stream figure skaters. Both empirical and estimated power measures were determined to provide an indication of the suitability of laboratory versus on-ice anaerobic power tests for jumping in figure skating. Both one foot and two foot take off jumps were used in the test protocol to enhance test specificity for figure skating.

All skaters participating in this study were asked to complete anthropometric measures and three types of power testing: empirical, laboratory and on-ice jump measures. The empirical and laboratory testing was held in the auxiliary gym of the C.J. Saunders Field House at Lakehead University. The location for on-ice performances was the Port Arthur Arena, Thunder Bay, Ontario. Both conditions of testing were conducted during the same time frame on two separate days to control for diurnal effects.

Prior to testing, all subjects were well informed of testing methods and procedures, however in an attempt not to influence their efforts, the subjects were not informed of the experimenter's hypothesis. An informed written consent was obtained from the parents of the subjects as well as the individual subjects as required by the Ethics Advisory Committee of the institution. Upon completion of the experiment, the skaters were debriefed and given a copy of their individual results.

Subjects

Twenty two local Canadian Figure Skating Association (C.F.S.A.) test stream figure skaters volunteered as subjects. All participants were qualified at a Senior Bronze Freeskate Test Level or above and constituted a homogeneous group in terms of figure skating skill and proficiency. The mean age and years of figure skating training of the skaters was 13.9 and 7 years respectively. Mean subject characteristics are reported in Table 2. A complete list of individual subject characteristics can be found in Appendix J.

Table 2

Subject Characteristics

Variables	Mean	Std. Dev. (±)	Range
Age (yr)	13.91	± 2.02	11.0 - 18
Height (cm)	157.55	± 9.45	141.5 - 185
Estimated Height of Centre of Mass (cm)	105.95	± 5.57	95.0 - 116
Weight (kg)	50.22	± 11.18	32.6 - 67.5
Weight with Skates (kg)	52.41	± 11.78	34.5 - 70.2

N of cases: 22

Anthropometric Measures

Anthropometric measures included: standing height (measured in cm), total body weight (measured in kg), height from the waist to the floor with skates on (measured in cm), and weight of subjects with skates on (measured in kg) as illustrated in Table 2.

Testing Procedures

Prior to testing, all subjects participated in a five minute group warm-up. As illustrated in Figure 1, the battery of tests included two tests of empirical power; measured during a vertical jump administered on the force platform executed from one and two foot take-offs (measured in watts), three laboratory jump tests; the vertical jump-and-reach test using the jump-and-reach apparatus executed from both one and two foot take-offs (measured in cm), and the standing long jump (measured in cm) and two on-ice tests of on-ice jumping performances; a video analysis measuring height and range, and the Reed Field Test analysis. Power measures were derived from all three sources; empirical, laboratory and on-ice tests.

Each subject was given three practice trials of each jump test to familiarize themselves with the required technique. Practice was followed by a short rest period. All subjects attempted three consecutive test trials of each jump test. Verbal encouragement was provided equally throughout all trials and for all subjects.

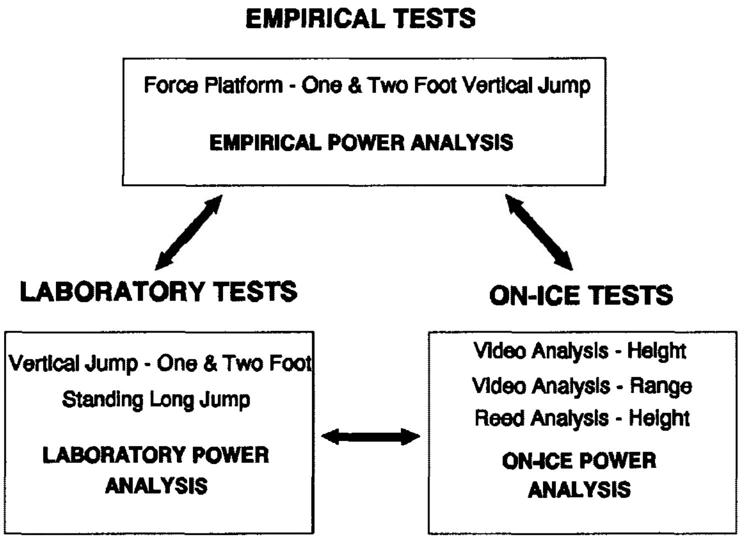

Figure 1. Experimental Design.

Empirical Tests

a) Force Platform Test. The vertical jump was performed on the AMTI force platform interfaced with a personal computer, so that power measures could be ascertained simultaneously to the vertical jump-and-reach test and power measures analyzed. The procedure for administering this test was identical to the vertical jump (Appendix D). Power measures were determined using a Power Software Package (Appendix C).

Laboratory Tests

a) Vertical Jump Test. The vertical jump was administered according to a modified protocol described by Fox and Mathews, (1981) (Appendix D). Modifications included standardizing: (a) the starting position on one and two foot take-offs, (b) the amount of pre-stretch prior to the jump, and (c) the arm swing. A jump-and-reach apparatus was used to measure height jumped to the nearest centimetre. The formula proposed by Harman et al. (1990) was used to determine peak power (measured in watts) (Appendix G).

b) Standing Long Jump. The standing long jump was administered according to the protocol outlined by the Canadian Standard Tests of Fitness as cited by Banister and Mekjavic (1986) (Appendix E). Distance was recorded to the nearest centimetre from the toes of the take-off to the heel of the landing.

On-Ice Tests

Skaters were instructed to dress in black spandex skating dresses, tights and figure skates. One inch florescent hockey tape was used to mark body segment end points to aid in ease of digitizing. Prior to video taping, the subjects were given the opportunity to become familiar with the experimental design and procedures. Three practice trials of the waltz jump were attempted by each subject. Following the practice trials, each subject performed three successive trials of a waltz jump. All attempts were video taped and analyzed but only the best trial as defined by technique was used for statistical analysis. Skaters were verbally encouraged to perform each trial to the best of their ability.

a) Video Taping Procedures

In February, 1992 on-ice video taping was practised. The investigation was undertaken to determine: (a) physical requirements for camera placement, (b) lighting conditions, (c) field width required, (d) average duration of the skill, and (e) photographic parameters. Additionally, raw data taken from the preliminary investigation was used to conduct a trial video analysis to measure digitizing reliability and determine cut off frequency.

On-ice video taping was conducted in accordance with the videotaping procedures outlined in the Peak 2D Motion Measurement Systems Manual (Appendix F). A Panasonic S-VHS camera was used allowing a film rate of 30 frames per second at an exposure time of 1/1000 second. The on-ice site was set up as determined by preliminary investigations, outlined in Figure 2.

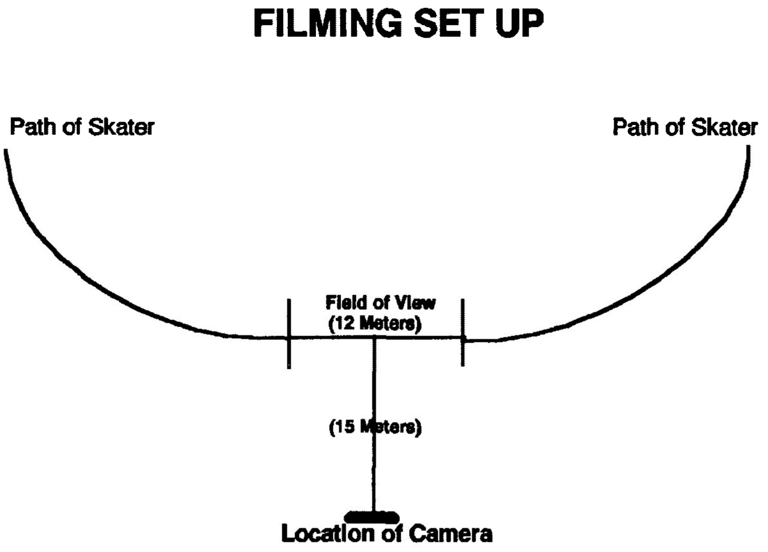

Figure 2. Diagram of video site: camera set up with respect to the skater's path of motion and jump location.

b) Power Analysis Procedures

Two methods of analysis were employed to determine on-ice indices of jumping power. Taped trials of each skater performing a waltz jump were analyzed by both video analysis and the

Reed Field Test for leg power. The video analysis determined height of centre of mass (measured in meters), range of centre of mass (measured in meters), and take-off velocity of centre of mass (measured in meters/second). A nineteen member, linked, segmental model was constructed for each frame of tape to be analyzed. Power was calculated from the kinematic data in combination with additional custom software developed in the Biomechanics Laboratory at Lakehead University (Appendix G). This approach utilized video analysis velocities to produce force and power curves for each filmed trial. The software program produced velocity, force and power curve relationships to provide a peak power output for each jump at take-off.

The Reed Field Test determined height of centre of mass (measured in cm) during jumping performances. The protocol recognises the jump score (height) as a measure of leg power (Reed, 1991).

c) Measurement Reliability

Prior to analyzing the data, two preliminary assessments of reliability on the video analysis procedures were conducted. First, measurement reliability was estimated by computing reliability coefficients for the mean X and Y coordinates from 5 repeated measures of nineteen segmental endpoints of a randomly selected film frame. The correlation values presented in Appendix H indicate that the investigator was consistent in estimating the spatial coordinates of endpoints used in the calculation of the centre of mass and selected kinematic variables.

As a result of further assessment, a cut off frequency of 6 Hertz was selected to filter the data. The velocity and acceleration curves for the jumps of three randomly selected subjects were analyzed at cut off frequencies of 0 - 24. Filtering of any signal is aimed at the selective rejection, or attenuation, of certain frequencies. The video system uses a Butterworth-type low pass filter, of the fourth order which is designed to cut off at 6 Hz, using film data taken at 60 Hz (60 frames /sec).

Velocity and acceleration curves filtered at cut off frequencies of 4, 6, and 8 Hz illustrate the influence of the selected cut off frequency as shown in Appendix I. Supported by Winter (1979), the cut off frequency of 6 Hz was selected.

Statistical Analysis

Pearson product moment correlations were performed to determine significant relationships between the force platform measures of power and the calculated power measures from the laboratory tests and the on-ice video analysis. Correlations were also performed among all the indices of power and the jump scores attained by the jumper in both the laboratory and on-ice tests. Level of significance was set at $p \leq 0.05$.

CHAPTER 4

Results

Estimates of jumping power taken from the force platform, laboratory jump tests and on-ice video analysis of twenty-two Senior Bronze Freeskate Test figure skaters performing waltz jumps were contrasted and compared. Pearson product moment correlations were computed to examine the relations among ten variables as illustrated in the experimental protocol (Figure 1). A correlation coefficient equal to .423 was required for significance at the 0.05 level of confidence. Although several correlations exist only those significant at $p \leq 0.05$ will be discussed. The significant correlations among the selected variables are presented in Table 6. A complete listing of measures on all variables for each subject can be found in Appendices J, K, and L.

Means, standard deviations, and range values for all variables were generated to enhance the description among comparative power measures. These results for the empirical power measures are presented in Table 5.

Table 5

Summary of Empirical Power Measures

Power (watts)	Mean	Std. Dev. (±)	Range
Force Platform			
One Foot	1747.89	± 557.48	926.4 - 2876.1
Two Feet	2479.05	± 652.65	1262.7 - 3519.1

N of cases: 22

Table 6

Correlation Matrix of Power Measures and Jump Scores

Variables	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Empirical Power Measures										
1. Force Platform Power 1 ft. (w)	1.000									
2. Force Platform Power 2 ft. (w)	.7881*	1.000								
Laboratory Jump Scores										
3. Vertical Jump - 1 ft. (cm)	.6027*	.6262*	1.000							
4. Vertical Jump - 2 ft. (cm)	.5905*	.5302*	.6568*	1.000						
5. Standing Long Jump (cm)	.3379	.7296*	.2802	.3384	1.000					
On-Ice Jump Scores										
6. Video - Height (m)	.2578	.1586	.2360	.3854	.0808	1.000				
7. Video - Range (m)	.4310*	.2981	.1816	.2030	.1680	.5720*	1.000			
8. Reed Analysis - Ht. (cm)	.1929	.0686	.1240	-.0457	.1453	.0632	.5059*	1.000		
Laboratory Power Measure										
9. Harman Peak Power (w)	.8458*	.8536*	.7021*	.5590*	.5370*	.3929	.4434*	.1532	1.000	
On-Ice Video Analysis Power										
10. Video - Power (w)	.6599*	.6525*	.4110	.2938	.3232	.1516	.5060*	.2381	.6641*	1.000

N of cases: 22 2-tailed Signif: * - 0.05

Table 7 presents the mean, standard deviation and range values for jump scores recorded from both the laboratory and on-ice video analysis.

Table 7

Summary of Jump Scores

Jump Scores	Mean	Std.Dev. (±)	Range
Laboratory Jump Scores			
Vertical Jump - 1 ft. (cm)	25.14	± 5.80	15.8 - 35.8
Vertical Jump - 2 ft. (cm)	31.0	± 4.07	25.0 - 37.5
Standing Long Jump (cm)	87.18	± 17.04	60.0 - 125.0
On-Ice Jump Scores			
Video - Height (m)	0.22	± 0.10	0 - 0.4
Video - Range (m)	2.26	± 0.52	1.0 - 3.1
Reed Analysis - Height (cm)	54.78	± 12.53	34.2 - 81.9

N of cases: 22

Laboratory and on-ice power measures were calculated from the respective jump scores presented in Table 7. Table 8 shows the mean, standard deviation and range values for estimated power measures based on the jump scores. A complete list of all individual jump scores and power measures can be found in Appendix K and Appendix L respectively.

Table 8

Summary of Estimated Power Measures from Laboratory and On-ice Jump Scores

Power (watts)	Mean	Std. Dev. (±)	Range
Harman Peak Power (w)	1930.95	± 545.19	1115.8 - 2908.4
Video Peak Power (w)	7277.96	±3251.82	2228.5 -14902.9

N of cases: 22

CHAPTER 5

Discussion

The purpose of this investigation was to examine three methods of determining jumping power in figure skaters. Empirical measures of power were taken from the force platform and estimates of power were calculated from laboratory jump tests and on-ice video analyses of jumping performances. It was assumed that the force platform is currently the most accurate system for measuring jumping power. Based on a review of the current literature, a comparison between the force platform and film or video methods for measuring power output during jumping has not been found. Although several researchers advocate the use of laboratory as opposed to sport-specific evaluations, no data has been found to support laboratory versus sport-specific or on-ice power tests in figure skating. Furthermore, laboratory tests of jumping power have not been previously correlated with on-ice jumping performances. Therefore, the primary objective of this study was to compare and evaluate the use of sport-specific methods of estimating power in figure skating.

The correlation matrix presented in Table 6 will be discussed under the following three headings: (i) Empirical power measures versus laboratory and on-ice video power determinations (Figure 3), (ii) Empirical power measures versus jump scores from the laboratory and on-ice tests (Figure 4), and (iii) Power measures versus jump scores from all sources (Figure 5).

(i) Empirical power measures versus laboratory and on-ice power determinations.

Jump scores from both the vertical jump-and-reach test and the on-ice video analysis were used to calculate peak power measures relative to body weight on all subjects. As illustrated in Figure 3, the laboratory and on-ice determinations of power were then compared to the empirical power measure and to each other respectively.

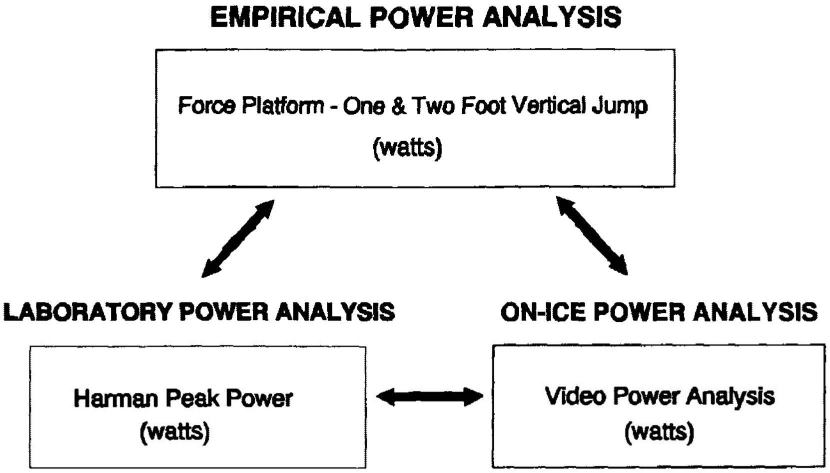

Figure 3. Empirical power measures versus laboratory and on-ice power determinations.

The data in Table 5 and Table 8 indicates that the power values from all three sources vary considerably. Empirical power measures and laboratory power measures appear to be significantly lower than the on-ice power values. It is suggested that task specificity, measurement technology, and error associated with measurement could be major contributors to the inter-test differences in the current study. Task specificity refers to the type of activity and specific movement patterns from which the measurements were derived. The activity used to obtain power measures from both the force platform and the laboratory power measure involved a two foot vertical jump performed from a stationary position. Whereas, the on-ice jumping power values were estimated from the kinematic data extracted from a one foot jump performed while in motion. Technological differences, such as the methods used to obtain the variables that calculate power, may also partially explain for inter-test differences. Coggan and Costill (1984) estimate that 10% - 30% of inter-test variability can be attributed to technology. Power output, derived from the force plate, utilizes the velocity of the centre of mass of the subject, a direct measure of vertical force and time. Although the variables used to calculate on-ice power were similar to the empirical power measure, kinematic data, as opposed to direct measures, were utilized to formulate on-ice power measures. Direct measures of force can only be obtained on the force plate and not feasible to obtain while performing on-ice. Therefore, on-ice power measures were determined from a predicted measure using changes in centre of mass velocities to predict force (Appendix G).

Another difference which may partially account for the magnitude of the on-ice power values in comparison to empirical or laboratory measures may be due to the velocity at take-off. On-ice take-off velocity is considerably higher due to horizontal velocity during the preparatory gliding phase being transferred to vertical velocity to initiate the jump. As suggested by Aleshinsky (1986), it can be observed that skater's with superior technique execute jumps with higher velocity at take-off. In both the empirical and laboratory methods, the vertical jump starts from a stationary position.

The potential for measurement error would appear to be greatest in the on-ice power tests. Video analysis initially requires the video of the subject to be digitized. The digitized data is used as input for the segmental method determination of the centre of mass. Accuracy of digitizing determines the accuracy of the calculation of centre of mass. This variable is then used in further calculations. Error in digitizing has the potential to magnify further potential for error in calculations.

Despite the variability in power values, correlations among all three power measures were significant (refer to Table 6). Significant relations were revealed between the empirical power measures and both the laboratory and on-ice determinations of power. Furthermore, Harman peak power (measured in watts) (Harman et al., 1991) significantly correlated with the on-ice video power measurement (measured in watts) ($r(21) = .6641, p \leq 0.05$). The strongest correlation among 3X watts) power (Harman et al., 1 scores was between the empirical power measure (two foot - force platform power) and the laboratory power measure (Harman peak power) ($r(21) = .8536, p \leq 0.05$). Although, the technology used by these two sources to determine power is different, it was expected that there would be a relation due to the common jump technique. Instantaneous power determined by both the empirical and laboratory power measures are products of the vertical jump-and-reach test. The positive correlation shown is in agreement with other published data (Harman et al., 1991) and would indicate further support for the validation of the Harman formula. In contrast, when comparing the techniques employed to determine the empirical power measure versus the on-ice power measure, jumping techniques differed significantly, however, a significant relation was still revealed between the resultant power measures ($r(21) = .6525$, $p \leq 0.05$).

Of significance to the present study is the strength of the relationships between 'like' tests. Results reveal that correlations are higher between tests employing similar technique regardless of the method of determining power values. For example, even though the on-ice power measure correlated positively to both the one and two foot - force platform power measures, a higher correlation exists between the one foot - force platform power measure and the on-ice power measure ($r(21) = .6599$, $p \leq 0.05$). Likewise, the laboratory power values taken from the two foot vertical jump score correlated highest with the two foot - force platform power measure ($r(21) = .8536$, $p \leq 0.05$). These results further support the use of sport-specific methods of testing to accurately predict performance measures of power output.

In conclusion, determinations of power from all three sources correlate significantly. Both the laboratory and on-ice analysis correlate significantly with the empirical power measures as well as with each other. The relations that exist demonstrate a commonality among all three power measures. In other words, the force platform power measure, the Harman power formula and power values derived from on-ice video analysis may all give an indication of the power the skater is capable of producing. One obvious similarity among all methods employed is that, all three tests required the subjects to perform all-out muscular efforts to measure explosive power. Secondly, the degree to which the tests are similar influences the strength of the relationship. 'Like' tests of similar activity correlate higher than dissimilar tests. The relationship among these test results support the validity of all three methods to estimate jumping power. However, it is suggested that the more similar the testing activity is to the actual sport activity, the stronger the prediction and consequently, sport-specific tests may related better to actual performance measures. The mode of testing and movement patterns tested are therefore recommended to be as specific as possible to sport activity. Although comparative research is not available, this finding may provide support for further investigating the validity and effectiveness of sport-specific, on-ice power determinations.

(ii) Empirical power values versus jump scores from the laboratory tests and on-ice tests.

As stated by several researches, the use of jump scores as opposed to power values has been adopted as a field estimate of performance (Garhammer, 1993). Figure 4 illustrates the comparison between the empirical power values and jumps scores from both the laboratory and on-ice tests.

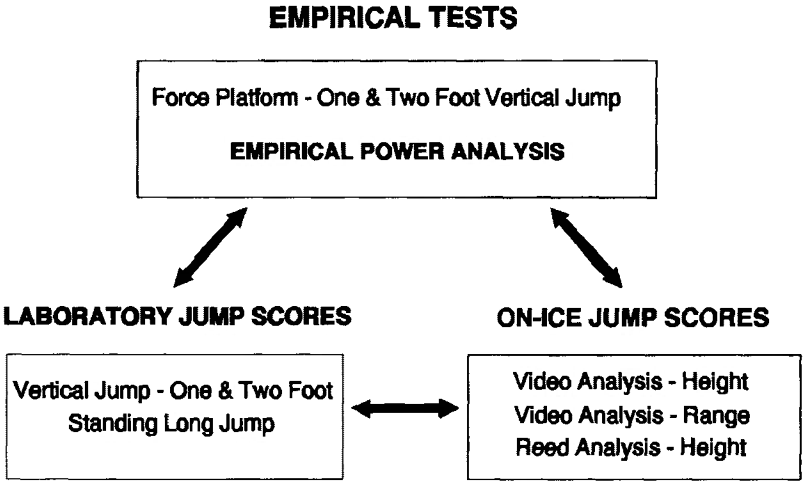

Figure 4. Empirical power measures versus jump scores from laboratory and on-ice tests.

Currently, the Canadian Figure Skating Association uses the jump scores from the "gold standard" laboratory vertical jump-and-reach tests and the standing long jump to evaluate jumping power in figure skaters. Previous research (Glencross, 1966) has promoted the use of the height score from the vertical jump-and-reach test as a estimate of jumping power. The findings of the present study are in agreement with Davies and Young (1984) and Vandewalle et al. (1987) in that the height of the vertical jump positively correlates with the peak power output as determined by the force platform. As shown in Table 6, both the one and two foot vertical jump scores are positively related to both empirical power measures. This correlation can be considered as an additional validation of the vertical jump score as being an effective field evaluation of muscular power (Davis & Young, 1984; Vandewalle et al., 1987).

Unlike the vertical jump, the standing long jump has received much less recognition as a measure of muscular power. However, in this investigation, when comparing the empirical power measures to the laboratory jump scores, the strongest correlation exists between the standing long jump and two foot - force platform power measure ($r(21) = .7296$, $p \leq 0.05$). Distance jumped from a two foot take-off in the laboratory, correlated positively with power produced by a two foot take-off measure by the force platform. A similar relation exists when the empirical power measure was compared to the on-ice video jump scores; on-ice analysis - range correlated positively with the one foot - force platform power ($r(21) = .4310$, $p \leq 0.05$). Unlike the laboratory jump scores, no other on-ice jump scores correlated significantly with the force platform power measures. These results suggest that a stronger relationship exists between the range (distance) value and empirical power measure than between the vertical height scores and empirical power measures. Dr. J. Dedic (1974) in his book Single Figure Skating for Beginners and Champions postulates that, height as well as length are two variables which characterize correctly executed powerful jumps. Results from this study reveal that in the laboratory, both height and distance scores indicate positive correlations with power, however on-ice, only the distance score correlates with the empirical power measure.

When contrasting the jump measures obtained from the laboratory tests and the jump measures determined from the on-ice jumping analysis, the results of the present study reveal no significant relations. Possible explanations for this finding may be the differences in jumping technique, the mechanical efficiency of lower extremity muscle contraction in each of the jumping techniques and the velocity at which the jump is executed. As mentioned previously, the "gold standard" laboratory jump tests requires the individual to execute a two foot jump from a stationary position. Whereas, the waltz jump which is representative of all figure skating edge jumps is executed from a one foot take-off which follows a preparation phase of increasing velocity. In addition, the take-off of the on-ice jump is assisted by the upperward swing of the freeleg and arms to propel the body into the air.

Another possible explanation could be due to the inherent difficulties faced when comparing laboratory versus field or sport-specific evaluations. Supporting literature suggests that tests which are used to evaluate performance should be performed as specifically as the skill being tested (MacDougall et al., 1991; Manning et al., 1988; Shephard, 1978). Laboratory jump tests are typically non-sport-specific evaluations. Jump scores from the laboratory tests were proposed to predict jumping ability. Although the validity of laboratory power tests have been proven in the laboratory, the findings of the present study do not indicate a strong relationship between the laboratory jump scores and on-ice jump scores. The results presented would not support the use of laboratory jump scores to accurately predict on-ice jump scores in figure skating.

(iii) Power measures versus jump scores from all sources.

As illustrated in Figure 5, absolute jump scores and power calculations from all three sources were also contrasted with the empirical measure of power. The results demonstrated a close relationship between laboratory jump scores produced by the vertical and standing long jump and both the laboratory power score and the empirical power measure. The correlations observed among these three tests indicate that all are reasonable estimates of jumping power off ice.

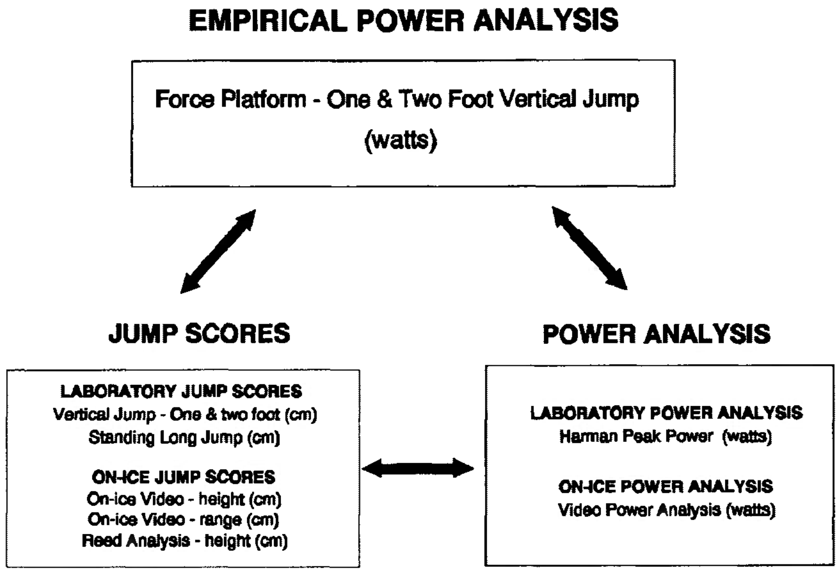

Figure 5. Power measures versus jump scores from all sources.

In contrast, the on-ice jump scores do not demonstrate similar relationships. The video - range (distance) is the only on-ice measure which consistently correlated with both the empirical power and the on-ice power measurements.

When contrasting jump scores and power measures, none of the laboratory jump scores correlated with the on-ice power measurement and as previously described video - range was the only on-ice jump score which correlated positively with the laboratory power ($r(21) = .4434$, $p \leq 0.05$). Two foot vertical jump scores and the standing long jump scores, both of which are used by the Canadian Figure Skating Association as a measure of jumping ability for skaters do not correlate to either the on-ice jump scores or on-ice power measures. This result raises questions concerning the use of the two foot vertical jump and standing long jump as a measure of jumping ability in figure skaters.

It was expected that if the "gold standard" laboratory jump scores (vertical jump and standing long jump) correlate with the force platform power measure and the on-ice jump scores also correlate with the force platform measure, then the laboratory tests may be predictors of on-ice jumping ability. However, this was not the case. Although both laboratory jump scores (vertical jump score and standing long jump score) correlate with the empirical measure, as cited previously only on-ice range correlates positively with the force platform measure of power. Furthermore, neither the vertical jump nor the standing long jump scores significantly correlated with either the on-ice measures jump scores or the on-ice power calculation. Therefore, the results presented in this investigation seem to indicate that the "gold standard" jump scores are not an accurate estimation of on-ice jumping ability in figure skaters. Since authors in the area agree that sport-specific evaluations are more accurate predictors of the athletes potential to perform a specific event (Shephard, 1978; Manning et al., 1988; MacDougall et al., 1991), findings of the present study would further support the use of an alternative sport-specific method of testing rather than the "gold standard" laboratory methods presently employed.

As no significant relations were found among the Reed field test and all other variables measured with the exception of video - range, the results of the present study do not seem to support or provide validation for the Reed on-ice field test as a test of jumping power in figure skaters.

CHAPTER 6

Conclusions

Recent trends in the sport of figure skating have focused on developing the athletic, as opposed to the aesthetic, qualities of the sport. As a result of a decision made by the International Figure Skating Association to eliminate compulsory figures in competition, the sport of figure skating has experienced rapid growth in both the technical and physiological demands placed on the freeskating performers. Although free skating programs include jumping, spinning, connective steps, and poses, jumping has been identified as probably the most important element in contemporary freeskate performances. The ability of the skaters to generate sufficient leg power to successfully complete multi-rotation jumps is imperative.

The majority of on-ice tests currently conducted on figure skaters are concerned with skills rather than physiological determinants such as leg power. Results from a preliminary investigation revealed that although coaches across Canada feel it is necessary to conduct physiological testing on competitive figure skaters, only a select population of skaters are actually being evaluated. Inasmuch as laboratory determinations may be impractical, notable efforts have not been made to develop sport specific tests that correlates well with laboratory tests.

Peak power determined from the force platform has been cited as the best indicator of jumping power (Davies, 1971; Davies & Rennie, 1968: Offenbacher, 1970). However, the lack of specificity may limit the use of this method for accurately predicting sport specific performances. It is argued that explosive power as measured by sport specific methods may be a more effective measure of on-ice jumping capacity than the "gold standard" jump scores presently used. The purpose of the present study was to assess relationships between measures of jumping power using three methods. A field test for estimating on-ice jumping power was also compared.

All jump tests employed for the purpose of the present investigation were estimates of instantaneous power, reflecting the ability to transform ATP splitting into external power. No objective criteria to enable the investigator to confirm maximal efforts is available. However, the investigator consistently motivated subjects to perform maximally. In addition, the extent to which power output is influenced by learning depends on the type of test chosen and the definition of learning (Sargeant, 1990). The tests employed for the purpose of the present investigation involved very common activities such as two foot jumping. In addition, the waltz jump is classified as a simple, over-learned skill given the calibre of the subjects used for testing. It is assumed that little margin exists for further learning of this jumping skill.

In the current research, power was derived from three sources; the force platform, laboratory jump tests and on-ice analysis of jumping performances. Correlations between empirical power measures and both laboratory and on-ice jumping power values were significant. In the past, the "gold standard" laboratory jump scores have been employed as measures of jumping ability in figure skaters. The results of the present research does not support the use of the jump scores from the vertical jump-and-reach test and the standing long jump to estimate on-ice jumping ability. These two tests do not seem to be representative of the performance of on-ice jumping power. However, when the jump scores were used to calculate power, estimations of power from both the laboratory and on-ice performances correlated significantly with each other as well as with the empirical measure of power respectively.

The power software developed as an extension of the video analysis kinematics provided an estimation of on-ice jumping power which is a more sport specific measure of assessing on-ice jumping ability than the currently used laboratory jump tests. Although, this method of power measurement is still in the developing stages, validation testing had demonstrated strong relationships with force platform measures ($r(8) = .93$, $p \leq 0.05$) (Appendix G).

Paralleling the increasing physical demands of the sport, in skating, as well as other sporting events, there is a world wide trend for children to begin serious athletic training at progressively younger ages. Zauner, Maksud & Melichna (1989) claim that the coaching philosophy appears to be based on the supposition that early training facilitates later performance. However the effects of intensive jump training on young athletes in the sport of figure skating has not been thoroughly investigated. As a result of the present study, the power output required by the skater to perform specific on-ice jumps can be estimated. From a practical point of view, it would be a distinct advantage for the coach to have access to information that would allow assessment of the training and performance loading of the athlete. This information will help to prevent or reduce potential overloading that can be caused by repetitive jumping that might affect the short or long term health of the athlete (Nigg, 1982).

Recommendations for further study may include addressing the questions: what power outputs are required of skaters to execute single, double, and triple revolution jumps? What are the strength requirements of these technical feats? Is it safe to encourage young athletes to participate in intensive jump training and what are the potential short and long term effects of repetitive jumping on the development of muscle and bone based upon the power output required. Furthermore, studies examining the impact of landing as a result of power generated at take off should be investigated.

In conclusion, based upon the results of this investigation, the reported on-ice analysis of jumping power offers the possibility of an alternative assessment of evaluating power in figure skaters. The proposed method of estimating power from video analysis may also be applied to measuring power in a variety of other sport specific environments. To further validate the use of video analysis in determining power during on-ice jumping in figure skaters, it is recommended that (i) a larger sample size be used to attempt to generalize findings, (ii) an analysis of alternative jumps requiring varying power outputs be conducted, and (iii) the use of a 3D analysis system be employed to more accurately assess the action of jumping. Optimally, a field test to assess power output, that could be administered by the coaches at the practice site may be established as a coaching tool to assist in establishing training loads and monitor the progress of the skater's jumping ability.

References

Adamson, G., & Whitney, R. (1971). Critical appraisal of jumping as a measure of human power. Medicine and Sport, 6: Biomechanics II, 208-211.

Aleshinsky, S. (1988). Strength and conditioning program for figure skating. NSCA Journal, 10(4), 26-30.

Ayalon, A., Inbar, O., & Bar-Or, O. (1974). Relationships among measurements of explosive strength and anaerobic power. Biomechanics IV, Proceedings from the 4th International Seminar on Biomechanics, 574-577.

Banister, E. & Mekjavic, I. (1986). Experiments in Human Performance. Canada: Holt, Rinehart and Winston of Canada, Ltd.

Bosco, C., Luhtanen, P., & Komi, P. (1983). A simple method for measuring power in jumping. European Journal of Applied Physiology, 50: 273-282.

Canadian Figure Skating Association (1991). Official Rulebook. 1991 Revised Edition, Ottawa.

Coggan, A. & Costill, D. (1984). Biological and technical variability of three anaerobic ergometer tests. International Journal of Sports Medicine, 5, 142-145.

Cole, L., Meixel, G., Morris, T. & Stoner, L. (1984). Figure skating jump optimization through computer simulation. In Terauds, J. (ed.) et al., Sports Biomechanics. Proceedings of ISBS, Del Mar, California., Research Centre for Sports, 207-216.

Dainty, D. (1979). Impulse production in jumping. The Circle, 11 (10), 7-8.

Dainty, D. & Norman, R. (1987). Standardizing Biomechanical Testing in Sport. New York: Human Kinetics Publishing Inc.

Davis, C. (1971). Human power output of short duration in relation to body size and composition. Ergonomics, 14 (2), 245-256.

Davis, C. & Rennie, R. (1968). Human power output. Nature, 217, 770.

Davis, C. & Young, K. (1984). Effects of external loading on short term power output in children and young male adults. European Journal of Applied Physiology, 52, 351-354.

Dedic, J. (1974). Single Figure Skating For Beginners and Champions. Prague: Olympia.

Evans, J., & Quinney, H. (1981). Determination of resistance setting for anaerobic power testing. Canadian Journal of Applied Sport Sciences, 6:2, 53-56.

Fox E. & Mathews, D. (1981). The Physiological Basis of Physical Education and Athletics (3rd ed.). Philadelphia, PA: Saunders College.

Gailhaguet, D. (1993). Jumps. Patinage Magazine, May-June, 26, 62-63.

Garhammer, J. (1993). A review of power output studies of Olympic and powerlifting: methodology, performance, prediction and evaluation tests. Journal of Strength and Conditioning Research, 7(2), 76-90.

Gledhill, N. (1976). Fitness testing and training prescription for figure skaters. Professional Circle, 10(3), 9-12.

Gray, R., Start, K., & Glencross, D. (1962). A test of leg power. The Research Quarterly, 33(1), 44-50.

Glencross, D. (1966). The nature of the vertical jump test and the standing broad jump. The Research Quarterly, 37(3), 353-359.

Harman, E., Rosenstein, M., Frykman, P., Rosenstein, R., & Kraemer, W. (1991). Estimation of human power output from vertical jump. Journal of Applied Sports Science Research, 5(3), 116-120.

Koehane, A. (1978, February-April). Perfecting your jumps. Canadian Skater, 35-41.

Komi, P., Rusko, J., & Vihko, V. (1977). Anaerobic performance capacity in athletes. Acta Physiology Scandinavia, 100, 107-114.

Manning, J., Dooly-Manning, C., & Perrin, D. (1988). Factor analysis of various anaerobic power tests. Journal of Sports Medicine, 28, 138-44.

MacDougall, J., Wenger, H., & Green, H. (1991). Physiological Testing of the High-Performance Athlete. Champaign, Illinois: Human Kinetics Publishers Inc.

Margaria, R., Aghemo, P., & Rovelli, E. (1966). Measurement of muscular power (anaerobic) in man. Journal of Applied Physiology, 21(5), 1662-1664.

McArdle, W., Katch, F., & Katch V. (1986). Exercise Physiology (2nd ed.). Philadelphia: Lea & Febiger.

McPherson, M. (1981). Factors effecting mechanical efficiency in the waltz jump. Unpublished master's thesis, University of New Brunswick, New Brunswick.

McPherson, M. & Bothwell-Meyers, C. (1986). The waltz jump. Coaching Review, 55, 56-57.

Nigg, B. (1982). Biomechanical testing in sport. Science Periodical On Research and Technology in Sport, Biomechanics, W-3.

Niinimaa, V. (1982). Figure skating: What do we know about it? The Physician and Sports Medicine, 10(1), 51-56.

Niinimaa, V., Woch, Z. T., & Shephard R. J. (1979). Intensity of physical effort during a free figure skating programme. *The Journal of Sports Medicine and Physical Fitness*, *9*, 75-81.

Offenbacher, E. (1970). Physics and the vertical jump. *American Journal of Physics*, *38*, 7.

Patton, S. G., Pyke, F. S., Hahn A. G., Telford, R. D., & Tumilty, R. D. (1986). A physiological study of competitive figure skaters. *Sports Coach*, *10*(1), 30-34.

Podolsky, S. (1988). Strength and conditioning program for figure skating. *NSCA Journal*, *10*(4), 26-30.

Podolsky, S., Kaufman, K., Cahalan, T., Aleshinsky, S. & Chao, E. (1990). The relationship of strength and jump height in figure skaters. *The American Journal of Sports Medicine*, 18(4), 400-405.

Reilly, T., Sechner, N., Snell, P., & Williams, C. (1990). *Physiology of Sports*. New York: E & FN Spon.

Ross, W. D., Brown, S. R., Faulkner, R. A., & Savage, M. V. (1976). Age of menarche of elite Canadian skaters and skiers. *Canadian Journal of Applied Sport Sciences*, *1*, 192-193.

Sargeant, A. (1990). Short-term muscle power in children and adolescents. *Advances in Pediatric Sport Sciences*, 3, 41-59.

Sargent, D.A. (1921). The physical test of man. *American Physic Education Review*, *26*, 188-194.

Sharkey, (1986). *Coaches Guide to Sport Physiology*. Champaign, Illinois: Human Kinetics Publishers Inc.

Shephard, R. (1978). Aerobic versus anaerobic training for success in various athletic events. *Canadian Journal of Applied Sport Sciences*, *3*(1), 9-15.

Skinner, J. & Morgan, D. (1985). Aspects of anaerobic performance. *Limits of Human Performance: American Academy of Physical Education Papers*, *18*, 31-43.

Stromme, S. B., Ingjer, F., & Meen, H. D. (1977). Assessment of maximal aerobic power in specifically trained athletes. *Journal of Applied Physiology: Respirat. Environ. & Exercise Physiology*, *42* (6), 833-837.

Taylor, H.L., Buskirk, E., & Henschel, A. (1955). Maximal oxygen intake as an objective measure of cardio-respiratory performance. *Journal of Applied Physiology*, *8*, 73-80.

Tharp, G., Newhouse, R., Uffelman, L., Thorland, W., & Johnson, G. (1985). Comparison of sprint and run times with performance on the Wingate anaerobic test. *Research Quarterly for Exercise and Sport*, *56*(1), 73-76.

Vandewalle, H., Peres, G., & Monod, H. (1987). Standard anaerobic exercise tests. Sports Medicine, 4, 268-289.

Winter, D. (1979). Biomechanics of Human Movement. Toronto: John Wiley & Sons.

Woch, Z. T. (1977). Heart rate changes during figure skating manoeuvres. Professional Circle, 11(4), 11-30.

Woch, Z. T., Niinimaa, V., & Shephard, R. J. (1977). Heart rate responses during free figure skating manoeuvres. Canadian Journal of Applied Sport Science, 12, 274-276.

Zauner, C., Maksud, M. & Melichna, J. (1989). Physiological considerations in training young a athletes. Sports Medicine , 8(1), 15-31.

Appendix A

Fitness Assessment Protocol for Figure Skaters

1. Anthropometry
    - Standing Height (measured in centimetres)
    - Body Weight (measured in kilograms)
    - Fat Measurement - seven site estimation of percent body fat (measured in millimetres)

2. Flexibility Measurements

    - Trunk Flexibility (measured in centimetres)
    - Hip Extension (measured in degrees)
    - Hip Flexion (measured in degrees)
    - Trunk Rotation (measured in centimetres)

3. Maximal Aerobic Power Measurement (treadmill)

4. Jumping Power

    - Vertical Jump (measured in centimetres)
    - Standing Long Jump (measured in centimetres)

5. Anaerobic Power

    - Sixty Second Wingate - (measured in watts/kg)

6. Haematology

Appendix B

Coaches Questionnaire

Please circle your response and add additional comments and opinions where you feel it necessary.

1. **Do you feel that physiological testing (fitness testing) is a necessary part of the training of all figure skaters?**

   Somewhat necessary   Necessary   Necessary & Valuable

   For Competitive or elite skaters only

2. **Which of the following measures do you find most useful in predicting skating performance?**

   Anthropometric measurements (ie. height, weight, etc.)
   Percent body fat
   Aerobic capacity - endurance tests (ie. treadmill, bike, 12 min run)
   Anaerobic tests - short sprints
   Strength tests
   Power tests (ie. vertical jump)
   Other, please specify:

3. **Do you feel that any of the above tests are inappropriate and not applicable to figure skating? If so, which ones? and why do you feel this way?**

4. **How often, if ever are your skaters tested on their physical fitness abilities?**

   Monthly   Annually   Occasionally
   Seasonally (ie. spring, summer, fall, winter)

5. **At what level or calibre of skater do you feel it is important to conduct physical assessments?**

   All levels   None   Canskate

   CFSA test skaters   Competitive skaters

   Specific test level

6. **Do you conduct the testing yourself?** Yes No
If not, who does your testing?

7. **If you don't presently use these tests, why?**

No available testers or facilities
Don't feel they are valuable
Time restraints
Other reasons, please specify?

8. **Are the skaters provided with the results and recommendations for training as a result of their evaluations?** Yes No

9. **What impact does these test results have on your training plan for each skater?**

10. **With the present structure of the CFSA, do you feel that physical evaluations are:**

Necessary
Repetitious of other testing
Not required/optional
Only for the elite or highly competitive skaters

11. **Do your skaters participate in off ice conditioning?** Yes No
If not, why?

12. **At what level do you feel off ice conditioning is an important part of the skaters training?**

All levels
None
Canskate
Junior (Preliminary and first test)
Intermediate (Second, third and fourth test)
Senior (fifth test and up)
Competitive skaters only

13. **If an evaluation package was prepared that could be administered and interpreted by you the coach with minimal time demands, would you consider evaluating your skaters?**

Yes No

14. **Would you be interested in participating with your skaters in a research project, testing the physical fitness level of your skaters?**

Yes No

15. **Approximately how many skaters do you teach at each of the various levels?**

Junior (Preliminary & First test) ________________________
Intermediate (Second, Third & fourth test)________________
Senior (Fifth test to eighth test)________________________

16. **What percentage of your skaters would you categorize as recreational versus competitive athletes and approximately how many hours do they train per week?**

Recreational ________________ Hours/wk __________________
Competitive _________________ Hours/wk __________________

17. **Does your club or school participate in team coaching?**

Yes No

If yes, how many coaches per team? _______________________

How many coaches are on your club's staff? _______________

18. **Other than professional coaches, do you have any other support staff assisting in the training of your skaters? Please name their positions ie., choreographer, etc.**

19. **Do you use any equipment to assist you with your teaching? ie., jump harness, video, etc. Please list the equipment you use.**

20. **Please make any further comments expressing your thoughts and your opinions with regard to the administration and application of physiological tests for figure skaters.**

THANK YOU FOR YOUR COOPERATION IN COMPLETING THIS QUESTIONNAIRE.

Appendix C

AMTI Force Platform System - Power Analysis Software Package

The Power Program (PWR) analyses data from one force platform as if the data were acquired during a lifting action. The program computes the power and work done during the lift, and reports on the maximum, minimum, and average values of vertical force, velocity, power, and work.

The only signal used during this computation is Fz (channel 3). The weight of the subject and weight to be lifted must have been acquired before the test. If channel 3 data is not present or the subject's weight is not available the calculation will not be performed and an explanatory message is displayed.

Power Analysis Results:

The power analysis software is based on reaction forces. It uses the weight of the subject, weight of the apparatus and the measurements of Fz during the lift to compute, as a function of time, the vertical velocity of the centre of mass of the subject plus apparatus. From this function the program computes the power output and work functions. The following are the formulas used in the computations.

Let: g = acceleration due to gravity
dT = sampling interval
Wt weight of the subject plus apparatus
Fj = the jth Fz datum during the test
NFj = net (unbalance) force acting on centre of mass of subject plus apparatus, at the time of the jth datum

Vj vertical velocity (positive upward) of centre of mass of subject plus apparatus, at the time of the jth datum

Pj : power associated with Fj

Wj = cumulative work done by Fz through the jth datum

Then: NFj = Fj - Wt

$$V_j \quad \sum_{i=1}^{j} \frac{NF_i}{Wt/g} \cdot dT$$

$$P_j \quad F_j * V_j$$

$$W_j \;:\; \sum_{i=1}^{j} p_i \cdot dT$$

Power Plots:

The power plot is available under the "graph" option of the analysis menu. When the analysis results are on the screen, type "G" (for graph) and the "S" (for screen) to view the plot.

The graph shows Net force, Velocity, Power, and Work plotted on a single set of axis.

Appendix D

Vertical Jump Test Protocol (Sargent Jump Test)

Procedure: (Fox & Mathews, 1981)

1) Weigh the subject
2) Have the subject warm-up. Some leg flexibility exercises may be recommended.
3) The subject should be positioned sideways as close to the marking pole as is practical.
4) The preferred hand should be raised vertically and held steadily against the side of the head.
5) The non-preferred hand should be positioned behind the back and should be allowed to move during the jump.
6) While standing in this position, a measurement is taken of standing height (H1).
7) The subject is instructed to jump vertically as high as possible (H2).
8) The difference between the initial heights is measured in centimetres to give the score.
9) Each subject should be allowed three trials and the best trail allowed as the measured score.

Analysis: Power Score = H2 - H1

This power score will be used in the Lewis nomogram to estimate Average Power in (N.m.sec).

Appendix E

Standing Long Jump Protocol

Procedure: (Banister & Mekjavic, 1986)

1) Warm-up with gentle stretch and bends for 2-3 minutes before test.

2) The subject assumes a position with feet slightly apart and toes behind the take-off line.

3) The hips, knees and ankles should be bent enough so that the subject can push vigorously with his legs, swinging his arms to jump as far forward as possible.

4) Measurement is in terms of centimetres to the nearest centimetre from the take-off line to the heel of the foot nearest the take-off line.

5) The suggested take-off angle should be between 30-40 degrees. Three valid trials are allowed, the better trail recorded. If any part of the body touches behind the heels, the jump will be considered invalid.

Appendix F

Videotaping Procedures

If videotaping is to be used for the purpose of analysis, these guidelines should be followed:

1. The camera should be perpendicular to the plane of motion of the object being videotaped.
2. The camera should be level in both the fore-aft and the lateral directions. A circular bubble level can be used for this purpose.
3. The camera should be as far away from the subject as possible.
4. The image size of the subject should be as large as possible in proportion to the field of view. This should be done by using the zoom lens (using the largest focal length possible), and not by bringing the camera closer to the subject.
5. Once the system is ready to go, the camera and the VCR should be allowed to record for at least three minutes before any actual trials are videotaped.
6. A scaling rod should be videotaped before and after the video session.
7. The camera should not be moved during the filming procedure. Any change in the cameral position will require the reference measure to be re-taped.
8. If the VCR must be paused or stopped during the taping session, PAUSE/STOP the tape at least five seconds after the trail is completed and PLAY at least five seconds prior to the next trial.
9. Make sure the subject is well illuminated and there is a good contrast between the subject and the background.
10. At the completion of the video session, run at least one minute of excess videotape.
11. Use a log book or a large sign that is videotaped before the trial to keep subject records.

Appendix G

Power Calculations

1. Empirical Power Measure

Force Platform Power (AMTI Power Software) - The AMTI software takes into consideration the weight of the subject plus the apparatus and the measurement of the vertical reaction force during the vertical jump. The software then computes, as a function of time, the vertical velocity of the center of mass of the subject. It utilizes velocity, vertical force and time to calculate power output and work (refer to Appendix C for calculations).

2. Laboratory Power Measure

Harman Peak Power Formula (Harman et al., 1991). - The formula proposed by Harman et al. (1991) provides a reasonable alternative to the Lewis formula for estimating jumping power output. The equation estimates peak jumping power from body mass and the jump height score from the vertical jump-and-reach test.

$$\textbf{Peak Power (W)} = 61.9 \times \text{jump height (cm)} + 36.0 \times \text{body mass (kg)} - 1{,}822$$

3. On-Ice Analysis Power Measure

Peak 2D Power - (Biomechanics Laboratory, Lakehead University).

Additional custom software was developed to calculate peak power from the velocity data derived from the video analysis. The calculations take into consideration the instantaneous velocity of the center of mass at takeoff, the mass of the subject and the apparatus (skates) and the vertical reaction force at the jump's takeoff.

The following formulae are used in the computations:

Impulse Formula :

$$\mathbf{F \times T = M \times \Delta V}$$

Force x Time = Mass x Change in Velocity

Where:	F	force during test
	T	sampling time of test (0.17 sec)
	M	mass of the subject
	ΔV	change in velocity between sampling times

Then: **Power Formula:**

$$\mathbf{P = Ft\,(Rf + wt) \times Vi}$$

Power = Total Force x Instantaneous Velocity

Where:	P	Instantaneous power
	Ft	Total force = reaction force + weight
	Let:	Weight (w) = mass x gravity
		Total Mass (mt) = mass of subject + mass of skates
		Total weight (wt) = total mass x gravity
	Vi	Instantaneous velocity = velocity at takeoff

This calculation has been validated to some degree by correlating power measures for the vertical jump performed on an AMTI force platform to results provided by the video analysis data and the power software ($r(8) = 9.3$, $p \leq 0.05$).

Appendix H

Measurement Reliability

Correlation Matrix for X Coordinates

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Trial 1	1.0000				
Trial 2	.9995	1.0000			
Trial 3	.9991	.9992	1.0000		
Trial 4	.8581	.8597	.8555	1.0000	
Trial 5	.9996	.9997	.9993	.8580	1.0000

Reliability Coefficient for 5 trials: Alpha = .9827

Correlation Matrix for Y Coordinates

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Trial 1	1.0000				
Trial 2	.9996	1.0000			
Trial 3	.9992	.9993	1.0000		
Trial 4	.7630	.7639	.7686	1.0000	
Trial 5	.9993	.9995	.9998	.7684	1.0000

Reliability Coefficient for 5 trials: Alpha = .9763

Appendix I

Cut Off Frequency Investigation

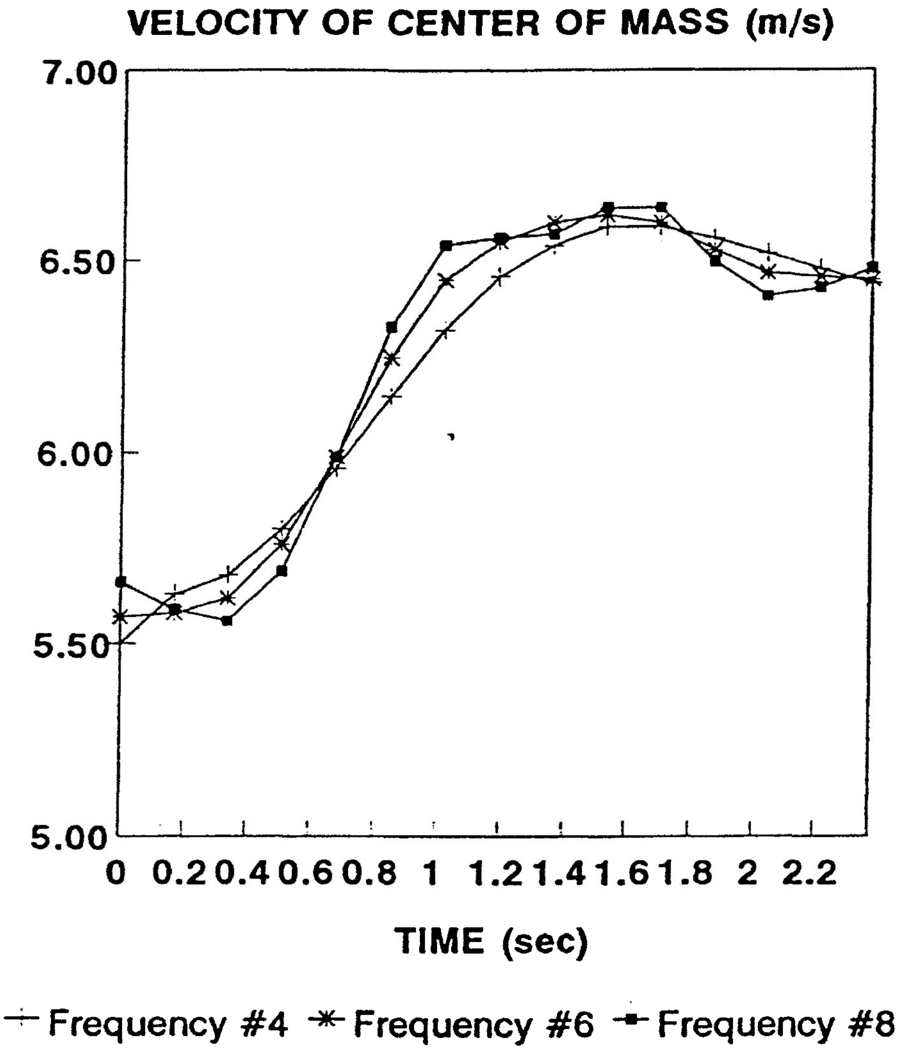

Figure 3. Velocity curves of the center of mass during the performance of a waltz jump sampled at selected cut off frequencies of 4, 6, and 8 Hz.

Appendix I

Cut Off Frequency Investigation

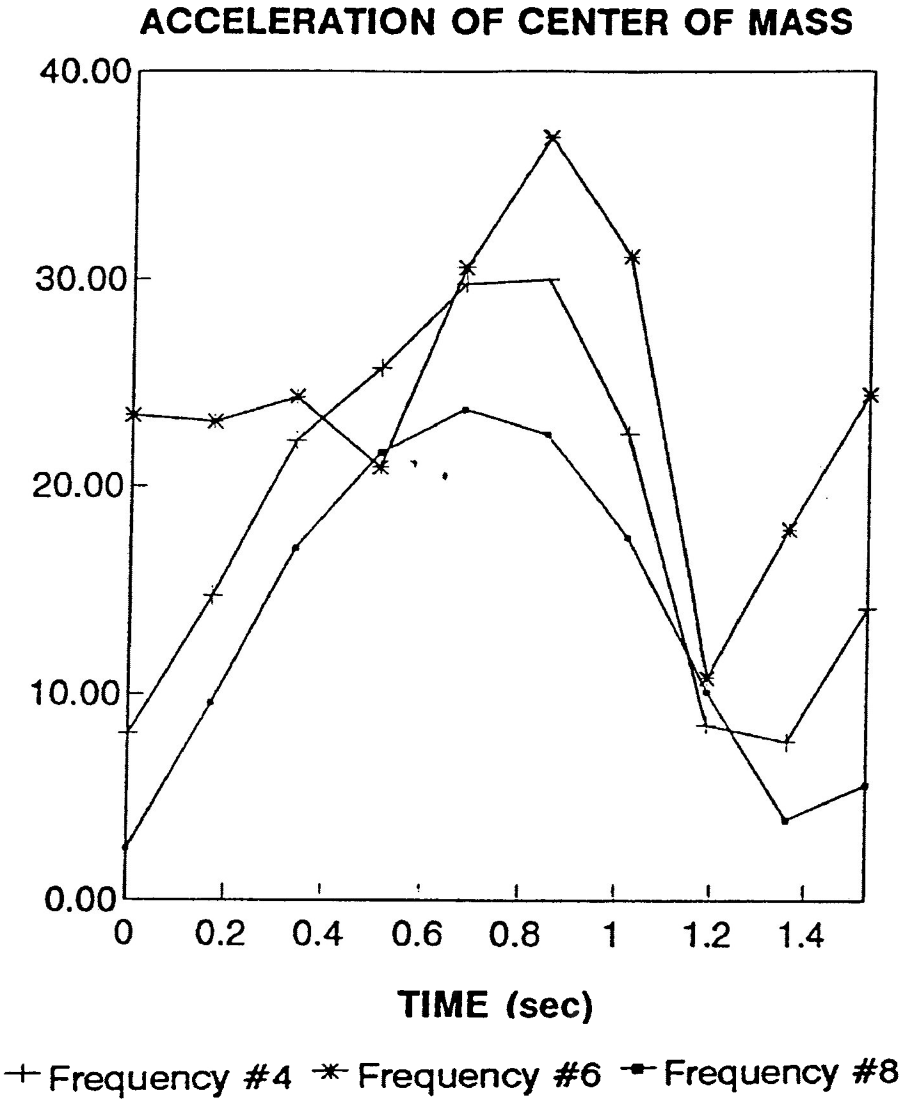

Figure 4. Acceleration curves of the center of mass during the performance of a waltz jump sampled at selected cut off frequencies of 4, 6, and 8 Hz.

Appendix J

Individual Subject Characteristics

Subjects	Age (yrs)	Height (cm)	Weight (kg)	Estimated Height of Center of Mass (cm)	Weight with skates (kg)
1	13	141.5	38.5	99	40.4
2	12	154	48.5	107	51
3	13	158	45.5	108	47.6
4	12	144	39.6	95	41.5
5	13	145	35.5	98	34.5
6	17	157	47.3	105	49.5
7	13	171	53.3	116	56.1
8	11	151	41.5	103	43
9	14	175	61.7	107	63.8
10	13	161.5	44.6	101	47.2
11	14	168	65	113	67.5
12	15	156	39	106	40.6
13	18	167	65.7	114	68.5
14	17	154	60.7	106	63
15	11	145	32.6	100	34.5
16	14	170	67.5	115	70.2
17	15	164	57.5	109	59.7
18	11	146	38.2	102	40.2
19	15	160	64.7	110	69.5
20	14	159	61.2	106	63.5
21	17	161	43.9	107	46.2
22	14	158	52.8	104	55

N cases = 22

Appendix K
Individual Jump Scores

Subjects	Standing Long Jump (cm)	Vertical Jump Two Feet (cm)	Vertical Jump One Foot (cm)	Reed Height (cm)	Video Range (m)	Video Height (m)
1	66	28.6	21.1	42.42	2.512	0.227
2	101	25	22.2	48.32	1.859	0.0163
3	68	29.5	22.2	66.19	2.618	0.174
4	77	33.4	25.7	61.07	2.98	0.378
5	60	27.1	17.7	54.06	1.954	0.165
6	89	30.9	20.6	60.96	2.153	0.0258
7	125	37.7	33.7	81.88	2.637	0.165
8	75	25.4	23.4	68.66	2.037	0.163
9	108	30.9	26.9	47.55	2.098	0.193
10	102	32.1	20.2	52.76	3.126	0.383
11	83	35.2	32	45.19	2.269	0.247
12	89	31.2	25.5	34.19	1.03	0.09
13	86	29	35.1	80.47	2.959	0.274
14	94	37.6	35.8	54.6	2.565	0.33
15	70	28.5	17.7	68.96	1.737	0.239
16	97	26.9	26.9	52.57	2.408	0.334
17	72	33.4	26.1	44.88	2.134	0.246
18	74	36.3	33.1	37.4	1.676	0.187
19	110	36.4	24.5	56.71	2.91	0.349
20	103	26.1	15.8	51.29	2.002	0.189
21	98	34.3	26.3	45.39	1.62	0.325
22	71	26.6	20.5	49.6	2.34	0.203

N cases = 22

Appendix L

Individual Power Measures

Subjects	Force Plate Power (w) Two Feet	Force Plate Power (w) One Foot	Lewis Power (w)	Harman Peak Power (w)	Harman Avg. Power (w)	Video Power (w)
1	1476	1003.7	4439.07	1334.34	98.82	4998.44
2	2921.5	1580	5228.3	1471.5	250.5	9691.21
3	2021.1	1877.5	5328.08	1642.05	278.9	9875.15
4	2246.8	1971.4	4941.58	1671.06	225.88	6508.79
5	1586.5	962.3	3984.38	1133.49	46.8	4221.55
6	2364.7	1735.9	5668.77	1793.51	405.6	5893.84
7	3473.5	2390	7055.8	2430.43	632.14	8452.53
8	1857.6	1163.3	4509.35	1244.26	145.7	7449.29
9	2999.3	1604.2	7394.57	2311.91	681.18	6969.84
10	2341.8	1392.3	5447.98	1770.59	313.32	6712.81
11	3363.3	2590.6	8314.44	2696.88	848.24	14902.93
12	2494.4	1387.2	4696.67	1513.28	165.44	2228.46
13	2820.4	2413.2	7628.04	2908.4	723.9	10090.21
14	3466.9	2223	8024.74	2690.64	800.22	10513.32
15	1262.7	926.4	3752.22	1115.75	-39	3292.54
16	2780.3	1592	7547.94	2273.11	729.78	6693.26
17	2718.5	2876.1	7164.56	2315.46	637.58	6371.31
18	1916.3	1466.6	4962.09	1800.17	255.16	6604.33
19	3519.1	2587.2	8415.96	2760.36	866.78	13296.47
20	2286.3	1559.9	6740.93	1996.79	567.92	8773.86
21	2385.1	1564.7	5543.19	1881.57	343.86	2655.42
22	2237.1	1586.1	5871.2	1725.34	385.32	3919.49

N cases = 22