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Design and Validation of a Multi-Stage Skating Specific Test to Predict Aerobic Power in Competitive Figure Skaters

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ABSTRACT

The goal of this study was the design and validation of a progressive skating test (PST) for competitive figure skaters. This consisted of two phases: design and validation of the on-ice protocol and an investigation of the validity and reliability of the Cosmed K4 collection instrument used to measure ventilatory data during the on-ice test. Two groups of subjects, one in California (n = 20) and one in Calgary (n = 7) completed two on-ice trials of the prospective PST and one cycle ergometer trial. The validation study used two additional groups of subjects (n = 9, n = 10, respectively) that completed four maximal cycle ergometer tests: two on the K4 instrument and two on the Horizon MMC metabolic cart. All of the tests were to exhaustion.

There was a linear increase in $\dot{V}O_2$ with skating speed and no significant difference in test-retest outcomes in repeated trials of the PST. However, a composite regression model was not determined because there was a significant difference in relative $\dot{V}O_2$ values ($ml \cdot kg^{-1} \cdot min^{-1}$) determined for the California test subjects compared to the Calgary test subjects. This difference may have been due to a combination of effects including that the K4 1 instrument used in California gave significantly higher results relative to the instruments used in Calgary, and differences in ice quality, skating equipment used by the subjects, and individual skills of the skaters which caused differences in skating efficiency.

Despite the differences between the groups, the $\dot{V}O_2$ max scores within each group were not different using the same instrument for the PST and maximal cycle ergometer tests. This finding suggests the PST is a reliable sport-specific test of $\dot{V}O_2$ max.

The Cosmed K4 instruments validated in this study gave varying results. The K4 2 and 3 units were not significantly different from each other nor were they different from the "gold-standard" Horizon MMC metabolic cart. The $\dot{V}O_2$ values obtained from the K4 1 unit may not be valid since it gave higher absolute $\dot{V}O_2$ at most power outputs evaluated. All of the units were reliable in test-retest experiments. Based on this study, the Cosmed K4 2 and 3 units were both valid and reliable.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

MET	Metabolic Equivalent
mm:ss	Minutes:seconds
MSE	Mean standard error
MST	Multi-staged test
N	Number of subjects
PST	Progressive Skating Test
PAR-Q	Physical Activity Readiness Questionnaire
RER	Respiratory exchange ratio
SD	Standard deviation
UMTT	University of Montreal Track Test
$\dot{V}E$	Minute ventilation
$\dot{V}O_2$ max	Maximal oxygen uptake
Wmax	Maximal workload

CHAPTER 1: INTRODUCTION

Overview

The task of accurately assessing the aerobic power of an athletic population can, in practice, be prohibitive in terms of both time and expense. However, applied field tests can provide quantitative physiological information for the coach and athlete while simultaneously avoiding large investments of resources. Furthermore, many field tests offer a higher degree of sport specificity than what is typically available in the exercise physiology laboratory. Sport specificity, in fact, may be the primary reason for selecting a particular exercise test.

Figure skating competition is comprised of two major phases: a 2:30 (mm:ss) short program requiring clearly defined elements, and a 4:30 (mm:ss) minute free program composed of elements of the skater's choosing. Skaters receive a technical and presentation mark for each program as determined by a panel of judges. Each phase is respectively weighted and the cumulative weighted ordinal placement (first, second, third, etc.) determines the final result. In addition to short and long programs, larger competitions may include a qualifying round in which the skaters perform their long programs that counts for up to 20% of the final mark. Each phase of the competition is typically separated by at least one day, with the entire event completed within the time span of five days at most. At elite levels, competitive figure skating programs require six or more difficult triple and/or quadruple rotation jumps distributed throughout a four-and-a-half minute program. While non-aerobic energy sources are likely the power supplies for executing the jumps themselves, the aerobic system is probably the primary generator of the energy used to maintain speed and intensity throughout the program.

Although several well-established field protocols exist for predicting aerobic power (Astrand et al., 1954, Léger et al., 1982) no test specific to on-ice figure skating performance is currently available. It is well known that being well conditioned aerobically is important not only for endurance sports (Costill and Winrow, 1970), such as distance running and cross-country skiing but also for sport activities where brief periods of high bursts of energy are interspersed with intervals of lower intensity. Having a strong aerobic base allows the athlete to recover more rapidly in the periods of lesser activity to allow them to complete subsequent bursts of high intensity exercise more easily.

The development of a skating-specific field test to predict aerobic power would be useful for competitive skaters and coaches by providing an activity-specific method to assess the athlete's on-ice aerobic ability. This testing method is important for the direct and intuitive application of the test results to the skater's actual ability to sustain intensity in competitive performance.

Introduction

Field tests are useful for the coach and athlete because they return applicable, quantitative information but require relatively minimal investment of time and specialized equipment. Predictive tests have been developed to measure specific physiological parameters such as strength (Fox et al., 1973), anaerobic power (Margaria, 1966 and Kalamen, 1968) and aerobic power (Astrand, 1954). The most popular aerobic predictive tests use familiar physical activities like cycling, walking, or running to estimate oxygen uptake based on a known power output or velocity. Using activities familiar to test subjects is advantageous because it may minimize a learning effect and/or local fatigue due to using muscle groups atypical to a particular athlete.

There are a few established conceptual methods useful for constructing and developing new field tests for aerobic power. Typically these methods fall into two broad categories: 1) telemetric measures: the remote monitoring of physiological parameters via transmission, such as the use a heart rate monitor; 2) non-telemetric measures conducted in the laboratory and/or the field. Non-telemetric lab tests would typically take measures during a simulation of the field test. Non-telemetric measures in the field would use observations of parameters peripheral to the actual test, such as the use of backward extrapolation of the O_2 recovery curve to estimate oxygen uptake during exercise (Léger et al., 1980).

Of particular interest is how these field tests reflect or correlate with direct measure and these protocols' reliability in instances of test-retest. Predictive tests such as the Léger 20 m shuttle (Léger et al., 1982), the Astrand-Rhyming cycling test (Astrand et al., 1954), Cooper walk-run (Cooper, 1968), and 12 minute field performance test (Balke, 1963) have been validated and are well discussed in the literature.

The choice of a particular predictive test protocol should consider the accuracy of the test, the applicability to the activity of interest, and the population being tested (Ward et al., 1995). Therefore, when evaluating a specific sport population, such as figure skating, the physiological demands of the sport should be known. While a figure skating competition is evaluated subjectively, judging criteria includes speed, technical difficulty of the skating routine, and the perceived ease with which an athlete can execute these elements when performing in competition. The physiology underlying these criteria includes anaerobic power for jumping and aerobic conditioning for maintenance of speed and recovery from anaerobic bouts.

Competitive skaters typically train five or more days per week for 45-50 weeks of the year. The training routine involves two or more free skating sessions a day (45-60 minutes each) during which the athlete practices various jumps, spins, and other skating technique under the supervision of a coach. Skaters also practice their competitive programs ("run-throughs") at least once a day during these free skating sessions. Other elements typically found in a competitive training program include powerstroking sessions which emphasize basic skating technique and speed; ice dance sessions; and off-ice work including aerobic conditioning, resistance training, and flexibility training. Total training time can range from two to six hours per day and may be broken up with rest between individual sessions (Zapalo and Smith, pilot work, 1997). Thus, aerobic conditioning becomes further important to figure skaters not only for competition but also to meet the demands of training volume and intensity.

Despite the obvious performance benefits of a strong aerobic base, figure skaters typically have only average aerobic power (Mannix et al., 1996, Zapalo and Smith, pilot work, 1997) and do not devote a significant or adequate amount of time to off-ice aerobic training relative to total training time. Some coaches have taken steps to integrate aerobic power training into their athletes' daily training, particularly in light of physiological evaluations demonstrating aerobic weaknesses in the skating population.

Based on the length of competition programs, aerobic power underlies the sustained intensity capabilities of competitive skaters. It is desirable to use a maximal test to predict $\dot{V}O_2$ max because maximal protocols typically provide a more accurate prediction of the real value (as measured by the gold standard metabolic cart) relative to submaximal predictive protocols. Because competitive figure skating performance is maximal (Zapalo and Smith, pilot work, 1997) a maximal test would be a closer approximation to the actual sport activity. Although using a maximal test places more of a cardiovascular stress on the subject, competitive figure skaters are typically young so the risk of complications during the test due to heart disease is small (Ward et al., 1995).

Little evidence in the literature addresses specific contributions of physiological energy systems to performance ability during a competitive figure skating program. An examination of current trends in world-class skaters reveals that the ability to sustain intensity, maintaining skating speed and the capacity to perform all jumps throughout a competitive program, is essential to success at elite levels.

Statement of the Problem

Laboratory testing is relatively inaccessible to the skating coach because of prohibitive expense and lack of interest by older elite coaches. At the more established competitive levels where such testing is available through funding by sport governing bodies, it is frequently ignored, partly because of the unclear application of test results to on-ice performance. At lower levels, where coaches and athletes need high quality feedback such tests would provide, adequate funding and education is commonly unavailable.

No on-ice protocol exists to quantify a skater's ability to sustain intensity throughout a performance. Although the skating coach may subjectively evaluate an athlete's consistency and intensity by observing program practices, such observations are qualitative. While validated methods for evaluating aerobic power and sustained intensity in athletic performance exist in the exercise physiology laboratory, these tests are not skating-specific and direct application of these measurements to field performance is unclear.

Goals

The goal of this investigation was the design and validation of a progressive skating-specific field test to quantify sustainable intensity of skating. Specifically, the goal was to develop a tool coaches may use to assess on-ice sustained intensity as it relates to aerobic fitness of the athlete. The key points for the ultimate application of the test include:

1. The test may be administered cheaply and easily in a training setting;
2. Test results are quantitative and accessible to the coach and athlete;
3. The protocol may be used as a training exercise as well as a diagnostic tool.

Purpose

Using telemetric methods to record the O_2 uptake of competitive figure skaters throughout a progressive on-ice multistage test, it was the purpose of this study to derive a regression model relating oxygen uptake (aerobic power) to skating speed. In addition, the validity and reliability of the Cosmed K4 portable oxygen uptake instrument used in the field was assessed.

CHAPTER 2: REVIEW OF LITERATURE

Measurement of Physical Work Capacity

Besides directly measuring the athlete during a specific exercise activity of interest, a main method of physiological work assessment is the measurement of metabolic response to exercise in the laboratory. Direct measure is typically obtained with standardized performed during running or cycling. Besides the convenience of these activities, which are easily available via treadmill or cycle ergometers, respectively, they require the use of large muscle groups. Bicycling typically results in a slightly lower maximal O_2 uptake versus treadmill running during a maximal test (Astrand and Rodahl, 1986). This may be related to local fatigue, where during running a larger muscle mass is typically used.

Methods Used to Predict Maximum Oxygen Uptake

Direct measure of oxygen uptake during exercise requires expensive and technical equipment. Measuring $\dot{V}O_2$ max can place the subject at risk in some specific populations because of heart disease or other medical condition. Additionally, direct measure may be prohibitive in terms of expense or time needed to assess large numbers of subjects. Therefore, indirect, predictive measures have been developed to measure $\dot{V}O_2$ max.

Many studies have examined the validity and reliability of methods of predicting $\dot{V}O_2$ max. Grant et al., (1995) compared results from the Cooper walk run test, a maximal multistage progressive shuttle test, submaximal cycle test, and direct measurement of $\dot{V}O_2$ on a treadmill as assessed by the gold standard metabolic cart. The Cooper test had the highest correlation with the direct measure whereas the multistage shuttle test and cycle test underpredicted $\dot{V}O_2$ max.

The Léger 20 m shuttle run (Léger et al., 1982) is a widely used validated maximal protocol, that predicts $\dot{V}O_2$ max based on the oxygen cost of running. Subjects shuttle between two lines placed 20 meters apart in time with audio cues emitted by a calibrated recording. The running speed is therefore standardized in each stage. The test becomes more difficult as the running speed is increased by the distance the subjects must cover in each stage. The test concludes when a subject arrives late (off time with the beeps) on two consecutive shuttles. The $\dot{V}O_2$ max is then estimated from the subject's chronological age and stage reached as related by a regression developed by Léger et al., (1988). Léger et al. (1980) used backward extrapolation of $\dot{V}O_2$ max values from the O_2 recovery curve as a method for estimating $\dot{V}O_2$ max at the conclusion of a maximal predictive test. To validate this method $\dot{V}O_2$ max values obtained by backward extrapolation of the O_2 recovery curve at time zero of recovery (corrected for the three-second lag in breath collection) were compared with $\dot{V}O_2$ max measured directly at the end of a continuous multistage test. The authors reported that this protocol was useful in tests where carrying a bag of expiratory air could become cumbersome because of wind resistance. They also cited that wearing a gas-collection face mask may be annoying and could affect performance in shuttle run and skating applications.

The comparison of values obtained using backward extrapolation with direct measure of $\dot{V}O_2$ max showed no significant differences as long as the initiation of post-exercise gas collection occurred within a few seconds following the completion of exercise. It was concluded that backward extrapolation of the O_2 recovery curve was a valid method to measure $\dot{V}O_2$ max and that this method was particularly useful when obtaining expired gasses during an exercise test would affect the results.

Léger and Lambert (1982) used this method of backward extrapolation to validate a maximal multistage 20-m shuttle run test (20 MST) to predict $\dot{V}O_2$ max. The 20 MST started at 8 $km \cdot h^{-1}$ and increased by 0.5 $km \cdot h^{-1}$ every two minutes and terminated at the subject's point of volitional fatigue. The $\dot{V}O_2$ max of 91 subjects was assessed at the point of fatigue using backward extrapolation. The least squares line was fit relating running speed and $\dot{V}O_2$ max to construct a mathematical model for predicting $\dot{V}O_2$ max in the field.

Protocols have been adapted and validated specifically for use with pediatric populations. Mechelen et al. (1986) studied 82 children aged 12-14 who completed Léger's 20 MST and compared the estimated $\dot{V}O_2$ max values with direct measure assessed on the treadmill. The values predicted by the field test were not significantly different than those from direct measure of $\dot{V}O_2$ max, demonstrating the usefulness of the 20 MST in a young population.

Indirect Continuous Field Tests

Léger and Boucher (1980) validated the University of Montreal Track Test (UMTT) by comparing test results obtained in the field to an analog of the field protocol in the laboratory. This test is similar to Léger's 20m shuttle test in that it is progressive. However, rather than shuttling back and forth the subjects run in one direction on the track for the duration of the test. The test was designed to be continuous, indirect, and maximal and was based on the energy cost of walking and running. The energy cost calculated is equal to the aerobic power output necessary (expressed as gross energy cost) to run at a given speed expressed in $ml \cdot kg^{-1} \cdot min^{-1}$ of oxygen consumed by the subject. The UMTT validation was conducted on a 166.7 m indoor track with inclined curves. Red pylons were used to divide the course into quarters and the subjects were paced throughout the test by audio tones from a pre-recorded tape. The starting speed for the test is 6.0 $km \cdot h^{-1}$. The starting speed is equal to 5 metabolic equivalents (MET's) where 1 MET is defined as a standard quantity of oxygen needed to sustain life in a resting state per kilogram of body mass (ACSM, 1991). The speed increases every 2 minutes by 2 METs to 9 METs and by 1 MET each 2 minute stage thereafter (see Table 2-1).

To test the validity of the UMTT, the predicted $\dot{V}O_2$ max obtained for the group of subjects tested in the field was compared with 1) the $\dot{V}O_2$ max assessed directly with the metabolic cart for treadmill running using a speed protocol identical to that used in the field, and 2) with a modified Balke test. The protocol for the modified Balke test started at 0% grade and 4.8 $km \cdot h^{-1}$ and the slope increased every two minutes by 2.5% to a maximum of 20%. The speed was increased by 0.4 $km \cdot h^{-1}$ every two minutes thereafter. $\dot{V}O_2$ for the treadmill tests was analyzed with a metabolic cart that measured O_2 and CO_2 with an infrared CO_2 analyzer and an paramagnetic O_2 analyzer which were calibrated against gasses of known concentration. Additionally, $\dot{V}O_2$ max was estimated by backward extrapolation using the O_2 recovery curve.

Table 2-1. The University of Montreal Track Test Protocol.

Stage	$\dot{V}O_2$	Time	Speed	Split Times		
MET	($ml \cdot kg^{-1} \cdot min^{-1}$)	(min)	($km \cdot h^{-1}$)	166.7m (s)	200m (s)	1 km (min)
WALK						
5	17.5	2	6.00	100.00	120.00	10:00
7	24.5	4	7.10	84.51	101.41	8:27
RUN						
9	31.5	6	7.16	83.80	100.55	8:22
10	35.0	8	8.48	70.75	84.90	7:04
11	38.5	10	9.76	61.47	73.76	6:08
12	42.0	12	11.00	54.53	65.43	5:27
13	45.5	14	12.21	49.13	58.96	4:54
14	49.0	16	13.39	44.81	53.77	4:29
15	52.5	18	14.54	41.27	49.53	4:07
16	56.0	20	15.66	38.32	45.98	3:50
17	59.5	22	16.75	35.81	42.98	3:35
18	63.0	24	17.83	33.66	40.38	3:22
19	66.5	26	18.88	31.79	38.14	3:10
20	70.5	28	19.91	30.14	36.17	3:01
21	73.5	30	20.91	28.69	34.43	2:52
22	77.0	32	21.91	27.39	32.87	2:44
23	80.5	34	22.88	26.22	31.47	2:37

The $\dot{V}O_2$ max predicted by the UMTT was similar to the $\dot{V}O_2$ max values measured on the treadmill using the UMTT protocol. $\dot{V}O_2$ max estimated with the backward extrapolation was also similar to $\dot{V}O_2$ max predicted by the UMTT. Overall the difference between predicted and directly measured values was not significant.

Use of the K2/K4 for Telemetric Data Collection

The Cosmed K2 and K4 instruments are telemetric pulmonary gas analyzers used for real-time measurement of expired gasses. The K2 system consists of a face mask with a turbine flow meter, a transmitter unit worn by the subject which also contains the O_2 analyzer, and a receiver. A full description and illustration of the K4 is given in Chapter 3. The main difference between the K2 and K4 devices is that the K4 has both O_2 and CO_2 sensors whereas the K2 has only an O_2 detector. The O_2 detector is an electrochemical disposable unit; this has been found valid in measuring standard gas of known concentration and has also been shown to be valid in varying conditions of temperature and pressure (Bigard and Guezennec et al., 1995).

The Cosmed K2 and K4 instruments have been validated for data collection during exercise (Hausswirth et al., 1997, Bigard and Guezennec, 1995, Lucia et al., 1993). The K2 is limited because it contains no CO_2 sensor and pulmonary calculations are therefore based on an assumption of an RER of 1.00. The K2 significantly underestimates $\dot{V}O_2$ at lower submaximal workloads as compared to the standard metabolic cart (Peel et al., 1993).

Hausswirth et al., (1997) tested subjects at rest and at submaximal power outputs equivalent to 25, 50, and 75% of the maximal work rate and measured $\dot{V}O_2$ with both the Cosmed and a CPX Medical Graphics metabolic cart. The subjects (n=7) were trained males, including endurance trained triathletes (n=2) and crosstraining endurance athletes (n=5) who all exercised at least three times per week. Subjects abstained from strenuous exercise for 48 hours before the start of the study and subsequently completed both exercise tests separated by a 3-day rest period. Subjects were measured while at rest and exercise on an electronically braked cycle ergometer. Expired gas was measured at 15 s intervals by both devices, respectively, for each test.

Heart rate values for the subjects in each test were found to be comparable for exercise at equivalent workloads, regardless of instrument used for gas collection (183 ± 13.8 vs. 184 ± 14.3, for the K4 and CPX, respectively). Similarly, $\dot{V}O_2$ max values were not significantly different ($p = 0.89$) at each of the workloads between the Cosmed and the cart (see Table 2). No significant differences were found for VCO_2, $\dot{V}E$, respiratory rate, nor RER at maximum workloads ($p = 0.84$, $p = 0.68$, $p = 0.91$, $p = 0.75$, respectively). Likewise, a correlation of $\dot{V}O_2$ values reported by both devices was significant ($r^2 = 0.95$, $p < 0.001$).

Table 2-2. Mean (± SD) $\dot{V}O_2$ values found at rest, 25, 50, and 75% of max workload (Wmax), and maximum, as assessed by K4 and CPX devices, respectively (compiled from Hausswirth, et al, 1997).

W_{max} (%)	Mean $\dot{V}O_2$ K4 ± SD ($ml \cdot kg^{-1} \cdot min^{-1}$)	Mean $\dot{V}O_2$ CPX ($ml \cdot kg^{-1} \cdot min^{-1}$)
Rest	4.40 ± 0.83	4.16 ± 0.58
25%	20.97 ± 1.31	21.32 ± 2.54
50%	33.32 ± 3.92	33.50 ± 3.51
75%	47.01 ± 7.51	47.49 ± 7.11
Max	62.07 ± 8.48	62.84 ± 11.31

The authors concluded that K4 device was valid for all oxygen uptake measurements at intensities ranging from rest to maximal exercise.

Previously, Bigard et al., 1995, had evaluated the K2 Cosmed device in exercise applications at moderate altitude. The aim of their study was to test the linearity and validity of the K2 system at sea level and moderate altitude. Subjects were measured with the K2 at rest and at three levels of submaximal exercise lasting 12 min each, at 25%, 50%, and 75% of the peak workload. The measurements obtained from the K2 were compared with those obtained with a metabolic cart. The authors found that the K2 system was a reliable system for $\dot{V}O_2$ measurements at sea level and at moderate altitude; however, the K2 system significantly overestimated and underestimated the $\dot{V}O_2$ computations at rest and 25% of the peak workloads, respectively at moderate altitude. The K2 unit was found to be accurate at sea level. The authors concluded that the K2 system was an accurate system for $\dot{V}O_2$ measurements during submaximal exercises (at 50% and 75% of the peak workloads) under laboratory conditions up to 2,000 m.

Lucia et al. (1993), also evaluated the validity and reliability of the Cosmed K2 for measurement of oxygen consumption in the laboratory at submaximal and maximal intensities. Twenty subjects completed three sets of submaximal and maximal treadmill tests in three consecutive days. $\dot{V}O_2$ was analyzed with the Douglas bag method on one of the test days and with the K2 on the other two days. The order of testing apparatus was randomized. The investigators concluded that the Cosmed K2 instrument is reliable and valid ($p > 0.05$) for measurement of $\dot{V}O_2$ ($l \cdot min^{-1}$) at submaximal and maximal exercise intensities.

Physiology of Competitive Figure Skaters

Few studies of figure skater physiology have been published; additionally the physiological traits specific to competitive skating performance have not been well characterized.

The fact that figure skaters have only average aerobic power is corroborated by several studies (Delistraty et al., 1992, Mannix et al., 1996, McMaster et al., 1979). Mean $\dot{V}O_2$ max values reported in these studies for adolescent competitive figure skaters were from approximately 40-50 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}. Delistraty et al., (1992) attempted to develop a physiological profile of young competitive figure skaters. Subjects (n = 13, age 9-17 years) completed tests of aerobic power and other performance-related parameters. Aerobic power was predicted from a submaximal cycle ergometer test. The mean $\dot{V}O_2$ max was average based on the age range for the subject population (48.7 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) and subjects had a higher percent body fat than found in competitive skaters in previous studies. Additionally the skaters profiled spent less time training both on- and off-ice than those participating in previous studies.

Mannix et al. (1996) studied 15 figure skaters enrolled in traditional competitive ice skating instruction. Subjects were randomly placed into two study groups: one group which maintained typical on-ice training and a second which completed identical on-ice training as Group 1 plus off-ice cycle ergometer interval training for 33 min four days per week. The on-ice routine is summarized in Table 2-3.

Table 2-3. Summary of daily on-ice training (adapted from Mannix et al., 1996).

Activity	**Time** (min)	**Average Heart Rate** ($b \cdot min^{-1}$)
Stretching	2 x 10	n/a
Patch (compulsory school figures)	2 x 45	105-120
Freestyle	2 x 45	120-200
Power stroking	2 x 10	185-205

Subjects completed exercise testing at the beginning and the end of the training period. Each subject performed a $\dot{V}O_2$ max test on a cycle ergometer and a supramaximal test on the cycle ergometer to examine lactate accumulation and supramaximal exercise time.

No significant differences were found between the groups before the training period in the following parameters: $\dot{V}O_2$ peak (mean = 47.2 $ml \cdot kg^{-1} \cdot min^{-1}$), work rate at $\dot{V}O_2$ peak, supramaximal exercise time, and lactate response to exercise. On-ice training alone failed to modify any physiological parameters measured and there was no change in these variables from pre- to post-testing in Group 1. Subjects who completed the cycling program exhibited significant training effects in all variables. Mean $\dot{V}O_2$ peak increased from 50.7 to 55.9 $ml \cdot kg^{-1} \cdot min^{-1}$ in the subjects who cycled. Lactate and heart rate response to exercise was decreased in both groups following the training period although the cycling group had a greater decrease in these variables.

The most significant finding of this study was that on-ice training alone failed to improve aerobic power as measured on the cycle ergometer. Although there were improvements in aerobic power in the cycle training groups because this was not activity-specific to figure skating the authors did not claim that the increase was beneficial to on-ice performance. The authors further observe that even if improvements in skating speed and quality of jumps were shown this does not guarantee better success in competition.

This study agreed with the findings of McMaster et al., (1979) who implemented a three-month training period to study the effect of interval training on figure skating performance. Subjects were measured pre- and post-training via a direct measure of $\dot{V}O_2$ max on the treadmill and a half- mile skate effort. Participants completed a three month program of 3 x 30 min/week interval training, 3 x 30 min/week strength training on alternate days, and an unsupervised stretching program each training day.

Subjects showed a 9% overall increase in mean $\dot{V}O_2$ max from 44.7 to 55.5 ml $\cdot$ $kg^{-1} \cdot min^{-1}$) and a 10 second reduction in half-mile mean skate time following the training period. Skaters were also subjectively observed to have a greater consistency, particularly in the last minute of their competitive skating programs.

Neither study claimed to have developed an optimal off-ice supplemental training routine to enhance on-ice performance. Albright (1979), an Olympic Champion in figure skating and a physician, commented that the best training for figure skating is skating. She cited the typical use of trial-and-error rather than a systematic testing approach by most skating coaches to develop a program with optimal volume and intensity of on- and off-ice training for competitive skaters. She also concurred that figure skaters have only average cardiovascular conditioning.

Considering the length of a competitive long program (4:00 - 4:30), both anaerobic and aerobic energy systems contribute to on-ice performance (Zapalo and

Smith, pilot work, 1997, Mannix et al., 1996). Jumps, which require short, intense bursts of power are likely fueled by the ATP-CP and anaerobic systems, whereas the physical skating of the program, including stroking, steps, most spins, and the regeneration of anaerobic jumping systems would be more aerobic-anaerobic.

One mark of world-caliber skaters is the relatively fast overall skating speed they can maintain throughout the entire program, as well as the ability to execute difficult jumping elements at the end of the program. At advanced competitive proficiency levels the impact of stroking technique is probably minimal relative to the aerobic capacity of the skater. This suggests that having a high level of aerobic conditioning would be favorable for increased sustained intensity throughout a skating routine.

Sub-elite and elite competitive skaters from the U.S. and Canada were physiologically profiled by Zapalo and Smith (pilot work, 1997) over the course of a week-long testing camp at the University of Calgary March 20-27, 1997. Camp participants (n=24) were divided into three groups: males (n = 7, mean age = 17.7), females 13 and under (n = 8, mean age = 12.3), and females 14 and older (n = 9, mean age = 16.7). The purpose of the camp was to measure performance-specific indicators of fitness and to compare physiological abilities of current competitive skaters to both those previously tested at the University of Calgary and to what had been reported in the literature.

Aerobic power of the camp participants measured directly on the cycle ergometer was not significantly greater than those reported in the literature, although it should be noted that the camp was conducted a few weeks following the conclusion of the main competitive season. The mean $\dot{V}O_2$ max values for the three test groups (expressed in ml · kg^{-1} · min^{-1}) were 50.4 for females 13 and under, 46.9 for females 14 and older, and 54.0 for males.

Besides assessing aerobic and anaerobic power of the camp participants, cardiovascular response was measured 1) in maximal cycle ergometer tests; 2) on-ice during competitive short and long programs; 3) on-ice in the prospective PST. Camp skaters reached maximum heart rate in all three tests. Because skaters reach maximal heart rate during both short and long programs the PST was designed to also elicit a maximal response to be a good simulation of typical on-ice performance. It was shown that once the skaters' heart rates reached a maximum during a program it remained there throughout the program despite changes in skating pace. This reflects previous findings by Mannix et al., (1996) that heart rate reaches 100% within the first minute of the program and remains there for the program duration.

From this review of literature, it is clear that there is little physiological data complied on figure skaters and no on-ice testing has been developed. Albright (1979) made the comment that the best training for figure skating is skating; thus the need for our on-ice test which can be used not only for testing but also for training.

CHAPTER 3: METHODS

This chapter details the two major aspects of this study: the design and validation of the prospective Progressive Skating Test and the validation and reliability of the Cosmed K4 portable oxygen uptake instrument.

Design and Validation of the Progressive Skating Test

Subjects

High caliber subjects were desired for the development of the on-ice test to minimize the effect of forward and backward technique on the outcome of the test protocol. It was a clear limitation of the prospective protocol (Zapalo and Smith, pilot work, 1997) that skaters with less proficient technique may experience difficulty skating the test pattern (see below) at more advanced stages and speeds. Therefore, by using elite caliber subjects whose basic skating skills were of exceptional proficiency, it was more likely that the stage reached on the test were a result of cardiovascular performance parameters.

Subjects for the development of the regression model were solicited from a population of national and international competitors currently training in Oakland, California, San Jose, California, and Calgary, Alberta. Subject demographics are summarized in Table 3-1. Skaters were of Intermediate (equivalent to Pre-Novice under the CFSA) to Senior proficiency levels. Subjects were required to be national competitors in at least one of the two previous competitive seasons and free of serious illness or injury. Recruitment of subjects was conducted via verbal solicitation in person and through their coaches and supported by endorsement from the Canadian and United States Figure Skating Associations, the competitive governing bodies of the sport in Canada and the U.S., respectively, and the Professional Skaters' Association, a national coaching association.

Table 3-1. Summary of on-ice subject demographics.

	California (K4 1) Subjects			Calgary (K4 3) Subjects		
	Males	**Females**	**Combined**	**Males**	**Females**	**Combined**
N	7	13	20	n/a	7	7
Mean Age (years)	19.9 ± 4.8	16.1 ± 4.6	17.4 ± 4.9	n/a	17.4 ± 5.7	17.4 ± 5.7
Mean Weight (kg)	74.9 ± 5.8	51.9 ± 8.6	60.0 ± 13.5	n/a	51.6 ± 11.4	51.6 ± 11.4
Mean Skate Weight (kg)	3.9 ± 1.2	2.7± 1.0	3.0 ± 1.0	n/a	2.7 ± 0.7	2.7 ± 0.7
Proficiency Level	Novice = 3 Junior = 1 Senior = 3	Int. = 1 Novice = 5 Junior = 2 Senior = 5	Int. = 1 Novice = 8 Junior = 3 Senior = 8	n/a	Novice = 3 Junior = 2 Senior = 2	Novice = 3 Junior = 2 Senior = 2
Primary Discipline	Singles = 5 Pairs = 1 Dance = 1	Singles = 11 Pairs = 1 Dance = 1	Singles = 16 Pairs = 2 Dance = 2	n/a	Singles = 7	Singles = 7

Subjects were fully informed about the aim and potential risks of the investigation. The study was approved by the Faculty of Kinesiology Ethics Committee of the University of Calgary. All subjects were screened for major health problems using the standard PAR-Q form. Parental consent was given in person for subjects under the age of 18.

Testing Environment

On-ice testing was conducted at the following locations: Oakland Ice Arena, Oakland, California; San Jose Ice Arena, San Jose, California; Norma Bush Arena, Calgary, Alberta. Cycle ergometer testing of the California subjects took place in the respective ice arenas in off-ice areas used by the athletes for strength and conditioning work. Calgary subjects completed the cycle testing in the Human Performance Laboratory at the University of Calgary. Local environmental temperature and pressure was recorded during the testing and included in the calculations of ventilatory measurements. Ice depth and temperature was recorded daily and following resurfacing at all testing venues. Subjects wore relatively similar hand-made custom leather skating boots fitted with steel figure skating blades. They were instructed to have a recent and comfortable degree of sharpening prior to the test days.

Progressive Skating Test Protocol Design

The Progressive Skating Test (PST) course was marked using seven pylons on a standard-sized NHL hockey ice rink. The rinks used to prototype this design were the North and South surfaces at the Olympic Oval, University of Calgary.

The pylons were placed as shown in Figure 3-1: one at center ice on the red face-off dot; one each at the outer edges of the face-off circles at either end of the rink; one each centered on the hockey goal crease. Orange plastic pylons were used for both visibility and safety. Lightweight pylons were used in case skaters hit them with their blades during the test, particularly at the higher speeds of later stages.

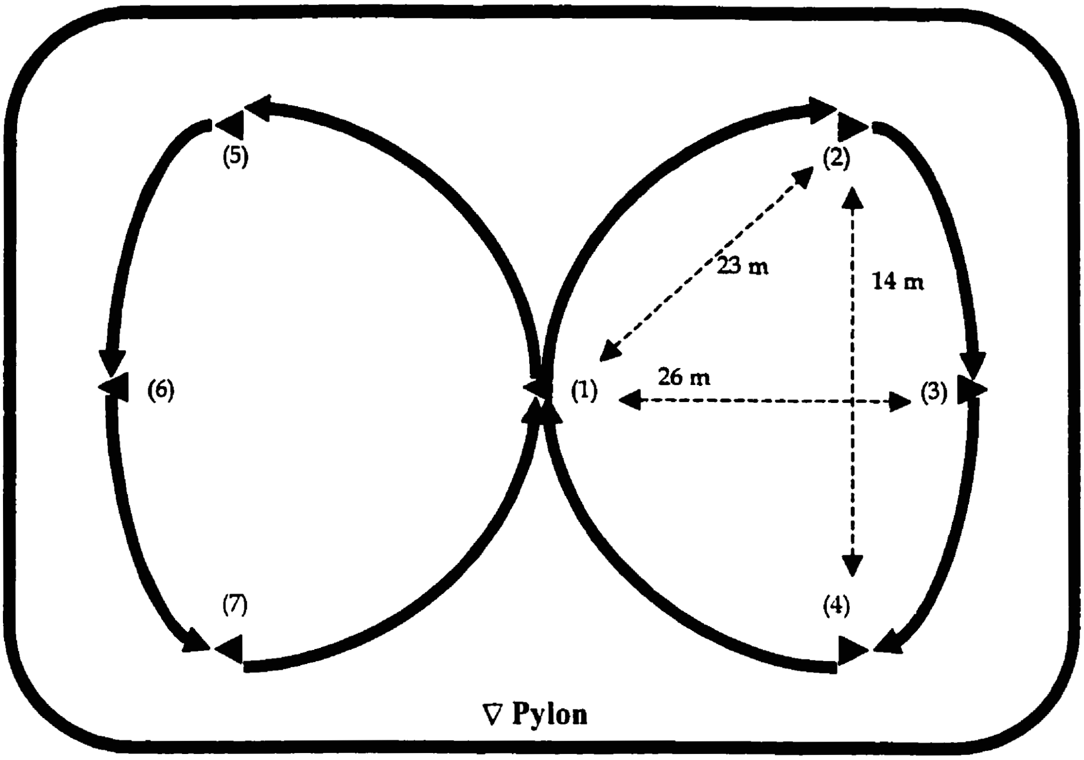

Figure 3-1. Schematic of the Progressive Skating Test.

One course lobe (half lap) was equal to approx. 44 m; each lap is 88 m. The test protocol was designed to increase the skating speed of the skater by increasing the number of lobes completed in each 90 second stage. The distance covered was modulated during the test by cueing the subjects with audio beeps clearly played on the arena sound system.

A sample test was skated as follows (refer to Figure 3-1). Note: this protocol is described as would be executed by a right-handed subject. It is normal for a skater to have a stronger or native side for rotation and skating direction. Right-handed skaters typically perform stronger technique to their left when skating forward (left forward outside), to their right when skating backwards (right back outside), and rotate and spin counterclockwise. Left-handed skaters typically are stronger skating forward to their right, backwards to their left, and rotate and spin clockwise. To allow each subject to use his/her strongest skating skills, the test pattern as described here was reversed for left-handed skaters.

The audio recording used to set the skating pace was engineered on a Macintosh OS compatible computer using built-in audio hardware and Macromedia Sound Design Pro 1.0. The audio pace recording was written in digital format directly to audio CD to prevent variation due to temperature that occurs with analog record formats.

The timing for the test stages is detailed in Table 3-2.

When cued by the audio recording, the subject started from a standing position at the center marker (1, refer to Figure 3-1). The subject performed forward outside crossovers to his/her left following the pattern around the second marker (2), and reached the third marker (3) precisely on cue with the next audio tone. Continuing forward skating around the next course marker (4) the skater reached the center marker (1) with the next tone and simultaneously executed a backwards turn of the skater's choice. The skater then performed backwards crossovers to the left. Passing around the next marker (5) the subject reached the next marker (6) with the next audio cue, continued at the set pace around the next marker (7) and returned to the starting point (1) with the next cue.

Starting at a standardized pace as outlined below (Table 3-2), the skating speed was increased in each stage by instructing the subject to follow the audio cues played during the test. As the test was skated, the subjects were verbally encouraged by an investigator who trailed the skater on the ice, as well as by assistants and bystanders off-ice. The audio recording periodically announced the current stage, by 30 s interval, as well as alerted the subject to prepare for the next stage just prior to the speed increase.

These announcements were designed to make the skater aware of time elapsed and to warn when they needed to increase their skating speed to avoid falling behind at the beginning of the next stage.

Table 3-2. The Progressive Skating Test protocol.

Stage	Time	Speed	Lap 1 Split Times (Pylon Number)			
	(min)	($m \cdot s^{-1}$)	22 m (3) (s)	44 m (1) (s)	66 m (6) (s)	88 m (1) (s)
Warm-up						
1	1:30	2.20	10.00	20.00	30.00	40.00
2	3:00	2.57	8.57	17.14	25.71	34.28
Test						
3	4:30	2.93	7.50	15.00	22.50	30.00
4	6:00	3.30	6.66	13.33	19.99	26.65
5	7:30	3.67	6.00	12.00	18.00	24.00
6	9:00	4.03	5.45	10.90	16.35	21.80
7	10:30	4.40	5.00	10.00	15.00	20.00
8	12:00	4.77	4.62	9.24	13.86	18.48
9	13:30	5.13	4.29	8.57	12.86	17.24
10	15:00	5.50	4.00	8.00	12.00	16.00
11	16:30	5.87	3.75	7.50	11.25	15.00

Note: the number in parentheses following the split distances corresponds to the pylons in Figure 3-1.

The skating pattern was repeated identically with the distance completed in each stage increasing continuously (by stage) until the skater could no longer maintain the skating speed. This was judged by the subject being greater than 2 m behind the audio cue on two consecutive markers, as judged by the test administrators, at which point the test was terminated by verbally notifying the subject. The final stage completed on the PST was recorded as the subject's score for the test.

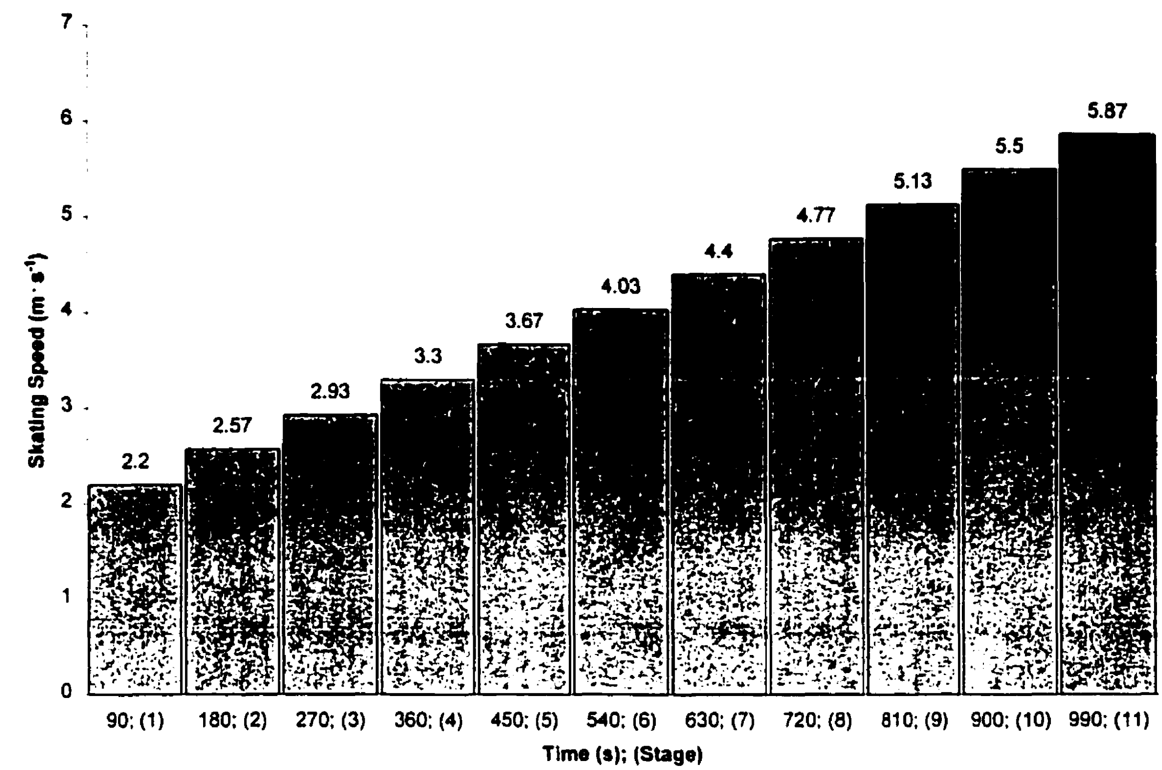

Figure 3-2. Progressive Skating Test skating speeds vs. time and stage.

At later stages of the test, centripetal force resulting from the subject's movement around the arc of the test course increased the distance traveled slightly in each lap. This variation was allowed for in the test protocol design by having pilot subjects skate the test course at various stages of the PST and then manually measuring the tracings on the ice. These measurements were averaged to arrive at a mean distance skated per lap. This distance was used to calculate skating speeds for the regression.

On-Ice Testing

Prior to the actual testing days, all subjects were oriented on an individual basis to the PST protocol via a standard format administered by the principle investigator. After the course layout was demonstrated and the execution explained, each subject completed several supervised rehearsals of the test were completed to demonstrate orientation to the timing and course pattern. The subject was verbally corrected as s/he completed the practice tests when errors were made in pacing or skating direction.

Subject Preparation

Subjects completed the series of three tests (two on-ice PST's, one cycle ergometer $\dot{V}O_2$ max test) in randomized sequence to limit variations due to training effect. On the testing day(s), subjects reported to the testing venue (ice arena or physiology laboratory) 15-30 minutes before the test began to allow time for preparation. Subjects were weighed (with and without skates, where applicable), given an adequate warm-up on the ergometer or ice, and fitted with the K4 collection instrument. These procedures were carried out at rink-side for the ice testing and were expedited to minimize discomfort for the athletes.

The Cosmed K4 instrument was used to record metabolic parameters during the testing. Primary parameters were recorded on a breath-by-breath basis including heart rate, $\dot{V}O_2$, VE, and various calculated ratios.

The K4 was worn as shown in Figure 3-3.

Figure 3-3. The K4 pulmonary gas exchange device worn by a subject.

In addition to the K4 apparatus, the subject wore a Polar heart rate monitor strapped around the center of the chest under clothing typical to what they would during routine training. The K4 was attached to an adjustable harness worn over the subjects' clothing. The portable unit was worn over the abdomen and attached to the collection mask via a Permapure sampling line, to the turbine via a rubberized wire, the temperature probe/heart rate receiver, and to the battery and antenna via standard BNC connectors.

The battery and antenna attached to the back of the harness. All lines were secured with Velcro straps. The rubber mask was held tightly to the face by a nylon mesh headpiece that attached to the sides of the mask with plastic clips over the molded fittings and was adjusted with Velcro straps.

Care was taken to check for leaks from the mask. This was done by blocking the outflow holes on the front of the mask and asking the subjects to exhale forcefully to pinpoint any escaping air. In some cases where the straps alone proved insufficient to form an airtight seal, a disposable moist sticky gel provided by Cosmed for use with the K4 was manually carved to custom-fit the subject's face and placed where necessary to plug leaks. This odorless, inert gel was placed directly onto the respective subject's skin and the mask was placed over it. Subjects were instructed to immediately alert the investigators of leaks that developed during the test.

While prepping the subject, the K4 unit was calibrated using a known reference gas consisting of 16% O_2, 4% CO_2, with N_2 balance. Additionally, the portable unit automatically performs a room air check against the known partial pressures of 20.93% O_2, 0.03% CO_2 and accordingly adjusts the baseline and gain of the respective sensors. This feature of the K4 unit is regarded as a limitation of the apparatus, because there was no independent analysis of arena air available to corroborate ambient partial pressures.

On-Ice Test Execution

Following the calibration, the subject skated to the center ice marker and waited for the audio cue to start the test. The recording announced a standardized countdown and then beeped to start the test. Simultaneously with this tone, the "Enter" button on the K4 portable unit was depressed to initiate data collection. The subject proceeded through the test stages as directed by the audio recording and was followed on-ice by the principal investigator for the purpose of immediately correcting any errors made by the subjects in the test execution. Also, the principal investigator, other investigators, coaches, and other subjects present verbally encouraged the skater to reach maximal effort. The test protocol terminated at the discretion of the principle investigator based on the subject's failure to make two consecutive markers on time with the audio cues (as outlined above). An electronic time marker was inserted into the breath-by-breath data via the laptop computer at the exact conclusion of the test. As the subject cooled down on-ice, data collection was terminated telemetrically with the K4 software. Immediately following the subject reported to rink-side where a post-calibration of the O_2 and CO_2 sensors was completed by sampling the known reference gasses used to initially calibrate the device. These values were recorded and subsequently used, where applicable, to correct error due to sensor linear drift.

Figure 3-4. A subject executes the PST wearing the K4.

Each test was recorded, in its entirety, on videotape with two 8mm Sony camcorders mounted on tripods. The field of view of each camera was directed to capture as much of the ice surface as possible and all markers were viewed at all times by at least one camera. The recordings were started immediately prior to the test start and ran unattended throughout the test trial. This was done for a manual reference; the K4 software also recorded the test termination and elapsed time.

Cycle Ergometer Testing (Ice Subjects)

Using a Sensormedics electronically braked cycle ergometer, each of the on-ice subjects was tested individually with the K4 during a progressive multi-staged maximal exercise test to the point of volitional fatigue. These tests were primarily conducted to provide a reference using the K4 for the maximal oxygen uptakes observed in the on-ice test.

Test Protocol

The ergometer seat height and handlebars were adjusted for the subject's comfort and the subjects were fitted with the apparatus; the K4 was then calibrated using the reference gasses (as outlined above). Subjects warmed up for each test on the cycle ergometer with nominal resistance. Each subject, respectively, selected a pedaling cadence ranging from approximately 70-90 revolutions per minute. Subjects were instructed to maintain a constant pedaling rate throughout the test and were verbally encouraged by the investigators. The starting power output for each test was set at 50-150 W based on the individual characteristics of the subject (weight, estimated fitness level, etc.). The Sensormedics ergometer automatically maintained a constant workload by modulating the resistance based on the cycling cadence. From the starting resistance, workload was increased by constant intervals of 35 W every two minutes until the anaerobic threshold was detected as indicated by metabolic characteristics (McLellan, 1985). Subsequently the resistance increased by 20 W each minute to the point of volitional fatigue of the subject. Post calibration of the K4 was executed as outlined above.

Data Recording

For the duration of the test, the metabolic parameters measured by the K4 sensors were recorded by the portable unit's flash RAM as well as transmitted in real-time to a laptop computer running Cosmed $K4b^2$ software and attached to a proprietary receiver. In certain instances where real-time data was not received by the computer because the subject traveled outside the transmitter range, data was manually downloaded following the test from the portable unit to the hard drive of the computer via a tethered RS-232 cable.

Data was exported from the K4 software directly to Microsoft Excel 97 for further post-processing and analysis.

Validation of the Cosmed K4 Instrument

To investigate the validity and reliability of the Cosmed K4 within the context of the applications of this study, the unit was compared to the Horizon MMC metabolic cart (see Appendix for technical specifications on the Horizon apparatus). An independent population was used for this part of the study. This experimental design was similar to the Hausswirth et al., (1997) investigation; however, the number of subjects used was greater and each subject completed two trials on each device. The incremental exercise protocol the subjects completed in each test was designed to elicit a range of workloads to demonstrate the validity and reliability of the K4 at various stages of exercise.

Overview

The study consisted of two subject groups: the first group completed K4 testing alone and the second group completed both K4 and MMC tests. Group 1 was tested in November, 1998, and Group 2 in March, 1999.

Subjects

Subjects were verbally solicited from the University of Calgary Cycling Club, which trained several times weekly at the Olympic Oval, Calgary. Subjects were selected from interested volunteers based on perceived fitness and availability to attend the four testing sessions.

Subjects were fully informed about the aim of the study and potential risks of participating. This study was approved by the Faculty of Kinesiology Ethics Committee of the University of Calgary. All subjects were screened for major health problems using the standard PAR-Q form. All participants were over the age of consent.

A summary of subject demographics is listed in Table 3-3 below.

Table 3-3. Summary of validation subject demographics.

	Study 1 (November 1998)			Study 2 (March 1999)		
	Males	Females	Combined	Males	Females	Combined
N	5	5	10	7	2	9
Age (years) Mean ± SD	26.0 ± 6.6	25.6 ± 3.3	25.8 ± 4.9	30.0 ± 8.2	28.0 ± 2.8	29.6 ± 7.3
Weight (kg) Mean ± SD	79.2 ± 20.2	63.2 ± 10.1	71.2 ± 17.3	76.1 ± 7.2	67.0 ± 4.8	74.1 ± 7.6

Cycle Ergometer Test Protocol

The ergometer seat height and handlebars were adjusted for the subject's comfort and the subjects were fitted with the respective apparatus. Reference gasses of 16% O_2 and 4% CO_2 with N_2 for balance were used for calibration. The metabolic cart was calibrated for volume, temperature, and gas, using the proprietary routine built into the Horizon's software. The K4 was calibrated as outlined above. Subjects warmed up for each test on the cycle ergometer with nominal resistance. Each subject, respectively, selected a pedaling cadence ranging from 70-90 revolutions per minute. Subjects were instructed to maintain a constant pedaling rate throughout the test and were verbally encouraged by the investigators. Starting resistance for each test began at 100-205 W based on individual characteristics of the subjects (weight, estimated fitness level, etc.). The Sensormedics ergometer automatically maintained a constant workload by modulating the resistance based on the cycling cadence.

From the initial resistance, the power output was increased by intervals of 35 W every two minutes to the point of volitional fatigue. Subjects were verbally encouraged throughout each test. Post-calibration of the metabolic cart was conducted by running the cart in manual mode and reading the reference gasses. Post calibration of the K4 was executed as outlined above. Sensor reading were recorded and, where applicable, used to correct for linear sensor drift during the test. For the duration of each K4 test, the metabolic parameters were recorded by the portable unit's flash RAM as well as downloaded in real-time to a laptop computer running Cosmed $K4b^2$ software and attached via a RS-232 cable.

Group I Study

A series of two maximal exercise tests was completed by each subject. The subject was measured by the K4 for both tests. Subjects started at 100 W and increased by 35 W intervals every two minutes.

Group 2 Study

Each subject completed a series of four maximal exercise tests. The subject was measured by the K4 for two of these tests and by the Horizon MMC metabolic cart for the other two. Tests were completed in random order to control for learning and/or fatigue effects. Workloads were standardized at 35 W intervals every two minutes across the group of subjects to allow for one-to-one comparisons of absolute $\dot{V}O_2$ by workload for the group. Additionally, following the initial test, subsequent trials for the same subject used the same starting workload and protocol.

Statistical Analysis

Results were analyzed post-hoc using parametric means for evaluating the California group (where there was sufficient *n* to do so) and non-parametric methods for the Calgary group and the validation studies where the number of subjects was insufficient to give the required normal distribution needed to use parametric methods.

Parametrically, the 2-tailed Student's t-test was used with a significance level set at $P \leq 0.05$. For the non-parametric tests, the Wilcoxon Paired Means Test was used for paired population samples (such as the K4 3 PST vs. K4 3 cycle ergometer tests) and the Mann-Whitney Test was used for independent populations (such as comparing the K4 2 validation subjects to the K4 3 validation subjects). Again the significance level was set at $P \leq 0.05$.

To compare the difference in the regressions developed between power output and $\dot{V}O_2$ for example, the 95% confidence interval for the regression was calculated. Where the confidence intervals of two independent regressions did not overlap, it represented a significant difference at the $P \leq 0.05$ level for that range of the regression.

Post-correction of K4 was done using Microsoft Excel 97 (Microsoft Corporation, Seattle, WA). Statistical analysis was performed using SPSS versions 8 and 9 (SPSS, CA), and Statistica '98 Edition Release 5.1 (StatSoft, OK).

CHAPTER 4: RESULTS

The results are presented in the following sections: the PST results, divided into the results of the California (K4 1) testing, the results of the Calgary (K4 3) testing, and a summary of the PST results; and the validation and reliability of the Cosmed instrument.

The results presented in this chapter have been corrected from the raw data reported by the K4 units where warranted by the post-calibration readings of the O_2 and CO_2 sensors, respectively, unless otherwise noted.

Results of the PST

California (K4 1) Subjects

The California subjects completed two on-ice and one off-ice tests, using the PST and cycle ergometer protocols, respectively. All tests were to exhaustion (volitional fatigue). The range of stage completion on the PST was from 4.3 – 7.1. A representative $\dot{V}O_2$ response of a subject to the PST is shown in Figure 4-1. The $\dot{V}O_2$ of the subject increased linearly with time/PST stage as shown. The aerobic responses of the skaters to the PST during the test were meaned, where applicable, and a summary of the absolute $\dot{V}O_2$ means by stage of the PST is shown in Table 4-1.

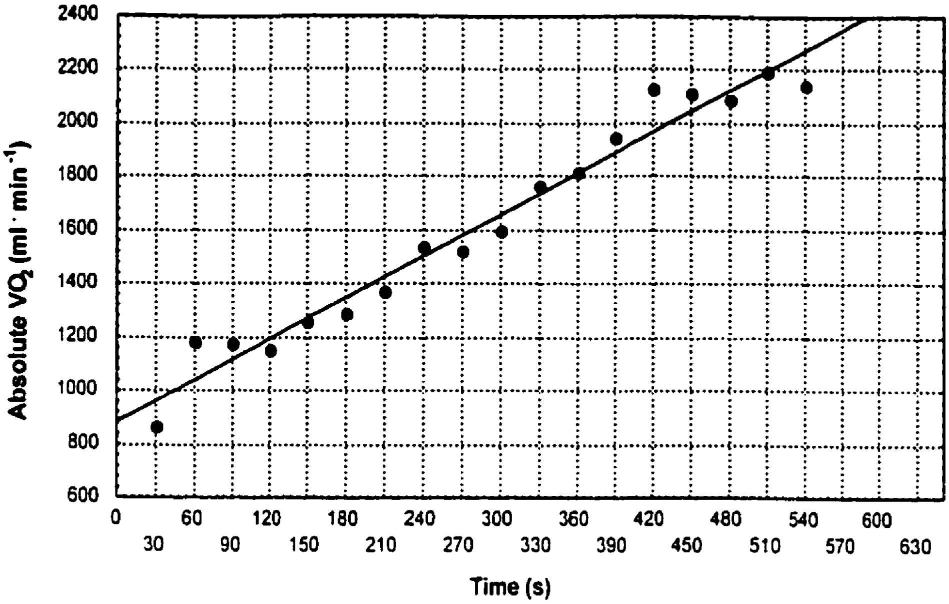

Figure 4-1. Absolute $\dot{V}O_2$ vs. time during the PST, (representative trial: Subject 9, Trial 1).

Table 4-1. Mean ± SD absolute $\dot{V}O_2$ by PST stage for California (K4 1) subjects.

	K4 1 (California)	
PST Stage	*N*	Mean $\dot{V}O_2$ (ml)
1	20	1421 ± 351
2	20	1628 ± 389
3	20	1898 ± 434
4	20	2259 ± 522
5	18	2602 ± 623
6	4	3137 ± 962

N = number of subjects completing stage.

The criteria for completing the PST were decided by the investigators; the test was terminated when the subject failed to be within 2 m of two consecutive distance markers on time, as indicated by the audio time cues. Subjects typically ended the test 10-30 seconds into a new stage when the required skating speed increased and the subjects were unable, because of fatigue, to increase or maintain the skating speed to make the markers on time. Each 90-second stage was divided into thirds by 30-second intervals and was denoted .1, .2, and .3, respectively. Therefore, the first 30-second interval of stage 1 was designated 1.1, the second 30-second interval was 1.2 and the last interval 1.3. PST termination was marked to the nearest .1 stage.

A summary of stage completion is presented in Table 4-2.

Table 4-2. PST stage completion by subject for trials 1 and 2, respectively, for California subjects.

Subject	Trial 1	Trial 2	Difference
1	5.3	/	n/a
2	6.2	7.1	+ .2
3	5.3	/	n/a
4	5.3	/	n/a
5	5.2	/	n/a
6	5.2	5.3	+ .1
7	6.1	5.3	- .1
8	5.3	5.2	- .1
9	6.1	6.3	+ .2
10	6.1	/	n/a
11	6.1	/	n/a
12	6.1	6.2	+ .1
13	5.2	5.1	- .1
14	5.3	5.2	- .1
15	6.2	7.1	+ .2
16	6.1	6.1	0
17	5.3	/	n/a
18	6.2	/	n/a
19	5.1	/	n/a
20	6.2	/	n/a

The time range represented by the PST stage completion was 390 s (stage 5.1) to 570 s (stage 7.1). The mean time at exhaustion was 450 s ± 75 s (stage 5.3).

The mean $\dot{V}O_2$ at each stage was regressed against skating speed by stage as presented in Figure 4-2. Also shown is the calculated 95% confidence interval.

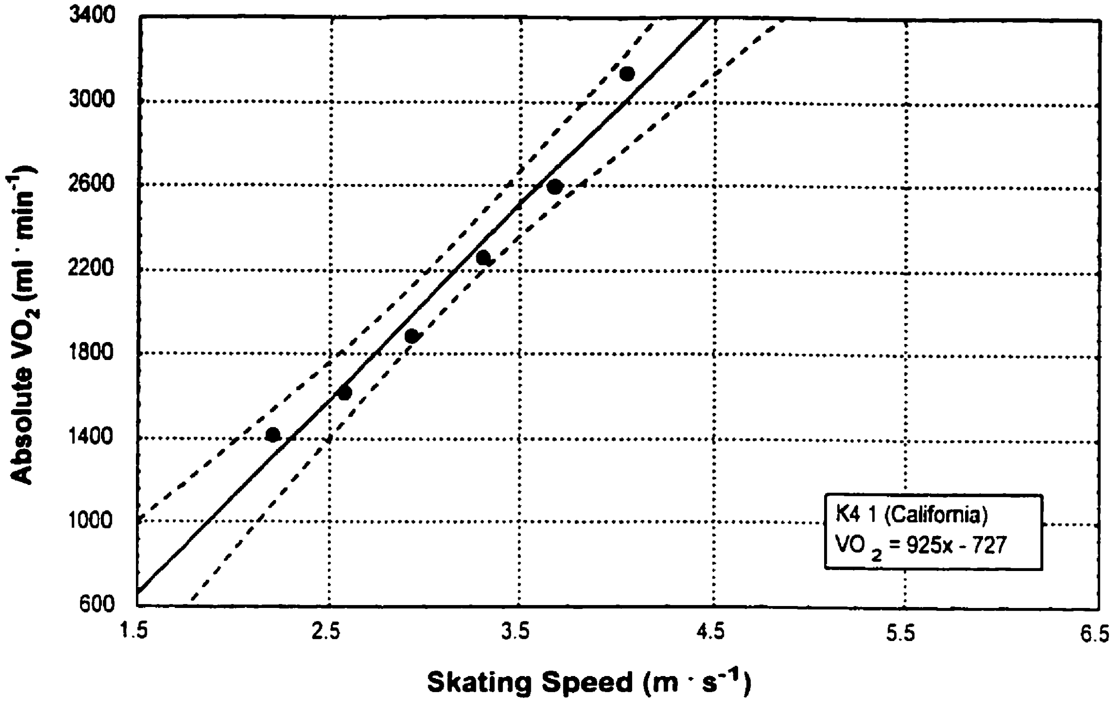

Figure 4-2. Mean absolute $\dot{V}O_2$ vs. skating speed (California subjects).

Test-Retest Repeatability (California PST)

The repeatability of the subjects' absolute $\dot{V}O_2$, by PST stage completion, was examined. The difference between the mean $\dot{V}O_2$ values calculated for trials 1 and 2 were compared by stage by means of the Wilcoxon Signed Ranks Test. These results are summarized in Table 4-3.

Table 4-3. Mean $\dot{V}O_2$ by stage with test-retest repeatability for K4 1 PST trials.

	K4 1 (California)			
PST Stage	*N*	Mean $\dot{V}O_2$ (Trial 1)	Mean $\dot{V}O_2$ (Trial 2)	Sig. (2-tailed)
1	10	1434	1405	0.575
2	10	1649	1608	0.241
3	10	1924	1910	0.333
4	10	2275	2285	0.646
5	9	2614	2777	0.953
6	1	2235	3213	[a]

***N* = number of repeated trials; [a]Insufficient valid cases to perform test**

The K4 1 unit was shown to be statistically reliable in repeated tests on the same subjects during the Progressive Skating Test protocol for stages 1 – 5. Stages beyond 5 contained insufficient repeated trials in the California subject group to evaluate statistically.

Comparison of On-Ice and Off-Ice $\dot{V}O_2$ max (PST vs. Cycle Ergometer)

Results of $\dot{V}O_2$ max and HR max were compared via paired t-tests between the PST and cycle ergometer protocols (Table 4-4). There were no significant differences between either $\dot{V}O_2$ max or HR max as elicited by the PST and cycle ergometer tests.

Table 4-4. Evaluation of difference in means for $\dot{V}O_2$ max and HR max for the California subjects as assessed with the PST and the maximal cycle ergometer protocols.

	N	**PST**	**Cycle**	***P***
Mean $\dot{V}O_2$ max (absolute $ml \cdot min^{-1}$)	18	2626 ± 745	2635 ± 735	0.929
Mean HR max (beats $\cdot$ min^{-1})	18	203 ± 5.0	203 ± 4.7	0.772

Sensor Drift and Post-Calibration

Post-calibration readings are summarized in Tables 4-5, 4-6. Individual post-calibration readings were used to correct $\dot{V}O_2$ if less than 15.95 or greater than 16.05, and VCO_2 if not 3.95 - 4.05. Tests were rejected if post CO_2 was out of the range 3.85 - 4.15 or O_2 not 15.50 - 16.50. Rejected tests were dropped from the study.

Table 4-5. Summary of O_2 sensor drift for the K4 1 collection instrument.

	N	**Mean**	**Mean Std. Error**
Cycle	18	15.96	1.57 E-02
Ice Trial 1	20	16.12	2.43 E-02
Ice Trial 2	10	16.08	3.14 E-02

Table 4-6. Summary of CO_2 sensor drift for the K4 1 collection instrument.

	N	**Mean**	**Mean Std. Error**
Cycle	18	4.00	1.03 E-02
Ice Trial 1	20	3.99	2.00 E-02
Ice Trial 2	10	3.99	1.18 E-02

Calgary Subjects

A second series of testing was conducted in Calgary using a different Cosmed K4 instrument than what was used in California. Again the subjects performed two on-ice tests and one maximal cycle ergometer test. These subjects (n = 7) were all females. The subjects were of a similar age and weight to the female subjects in the California group, as well as being of similar proficiency level (Table 3-1).

The Calgary subjects also showed a universal linear response in $\dot{V}O_2$ with time during the PST. The average $\dot{V}O_2$ versus PST stage is presented in Table 4-7.

Table 4-7. Mean ± SD $\dot{V}O_2$ by PST stage for K4 3.

	K4 1 (Calgary)	
PST Stage	*N*	Mean $\dot{V}O_2$ (ml)
1	7	950 ± 137
2	7	1166 ± 155
3	7	1377 ± 173
4	7	1598 ± 201
5	7	1799 ± 263
6	3	1951 ± 309

N = number of subjects completing stage.

A summary of subject stage completion is presented in Table 4-8 for each PST trial. The time range represented by the PST stage completion was 390 s (stage 5.1) to 540 s (stage 7.1). The mean time at exhaustion was 450 s ± 40 s (stage 5.3).

Table 4-8. PST stage completion by subject for trials 1 and 2, respectively, for Calgary subjects.

Subject	Trial 1	Trial 2	Difference
1	6.2	6.3	+ .1
2	5.3	5.3	0
3	5.2	5.3	+ .1
4	5.3	/	n/a
5	5.2	5.2	0
6	5.1	5.2	+ .1
7	6.1	6.2	+ .1

The mean $\dot{V}O_2$ for the end of each stage was regressed against the skating speed by stage. This is shown in Figure 4-3, along with the 95% confidence interval.

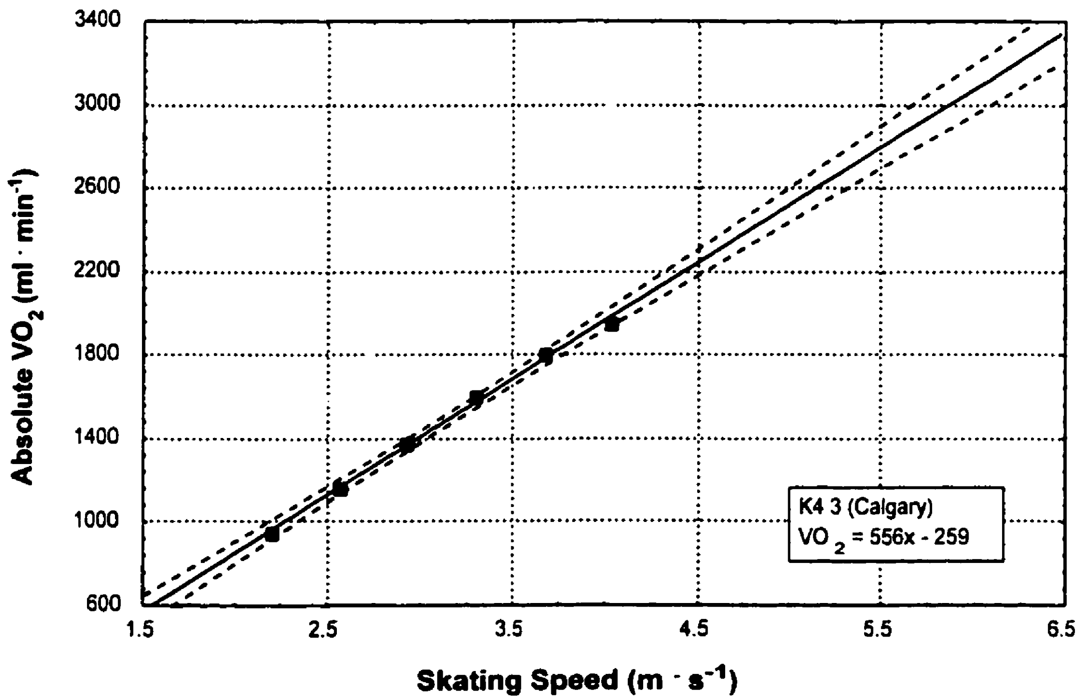

Figure 4-3. Mean absolute $\dot{V}O_2$ vs. skating speed (Calgary subjects).

The test-retest reliability of the K4 3 instrument was evaluated using the Wilcoxon Paired Means test (Table 4-9). There was a significant difference in mean $\dot{V}O_2$ detected at the $P \leq 0.05$ level by the Wilcoxon test between Trials 1 and 2 at all PST stages evaluated.

Table 4-9. Mean $\dot{V}O_2$ by stage with test-retest repeatability for K4 3 PST trials.

	K4 3 (Calgary)			
PST Stage	*N*	Mean $\dot{V}O_2$ (Trial 1)	Mean $\dot{V}O_2$ (Trial 2)	Sig. (2-tailed)
1	6	995	908	0.046*
2	6	1219	1093	0.028*
3	6	1424	1301	0.028*
4	6	1645	1529	0.028*
5	6	1859	1729	0.028*
6	1	2142	1996	a

Comparison of On-Ice and Off-Ice $\dot{V}O_2$ max (PST vs. Cycle Ergometer)

Results of the $\dot{V}O_2$ max and HR max were compared between the PST and cycle ergometer tests for the Calgary subjects (Table 4-10). There was a significant increase in $\dot{V}O_2$ max during the cycle ergometer test compared to the mean PST $\dot{V}O_2$ max. However when a comparison between trials was made there was no significant difference between $\dot{V}O_2$ max achieved by the subjects on the first PST trial vs. the $\dot{V}O_2$ max for the cycle ergometer protocol (Table 4-11).

Table 4-10. Evaluation of difference in means for $\dot{V}O_2$ max and HR max for the Calgary subjects as assessed with the PST and the maximal cycle ergometer protocols.

	N	**PST (mean)**	**Cycle**	***P***
Mean VO_2 max (absolute ml · min^{-1})	7	1847 ± 173	2147 ± 289	0.018*
Mean HR max (beats · min^{-1})	7	203 ± 5.6	203 ± 5.6	1.000

*Significant at P = 0.05 level

Table 4-11. Evaluation of difference in mean $\dot{V}O_2$ max and HR max for PST Trial 1 vs. the cycle ergometer for Calgary subjects.

	N	PST (Trial 1)	Cycle	*P*
Mean VO_2 max (absolute ml · min^{-1})	7	2142 ± 286	2147 ± 289	0.780
Mean HR max (beats · min^{-1})	7	203 ± 5.6	203 ± 5.6	1.000

Summary of the PST Results

$\dot{V}O_2$ vs. Stage

The mean $\dot{V}O_2$ for the last 30 seconds of each stage were regressed against skating speed by stage and is presented in Figure 4-4.

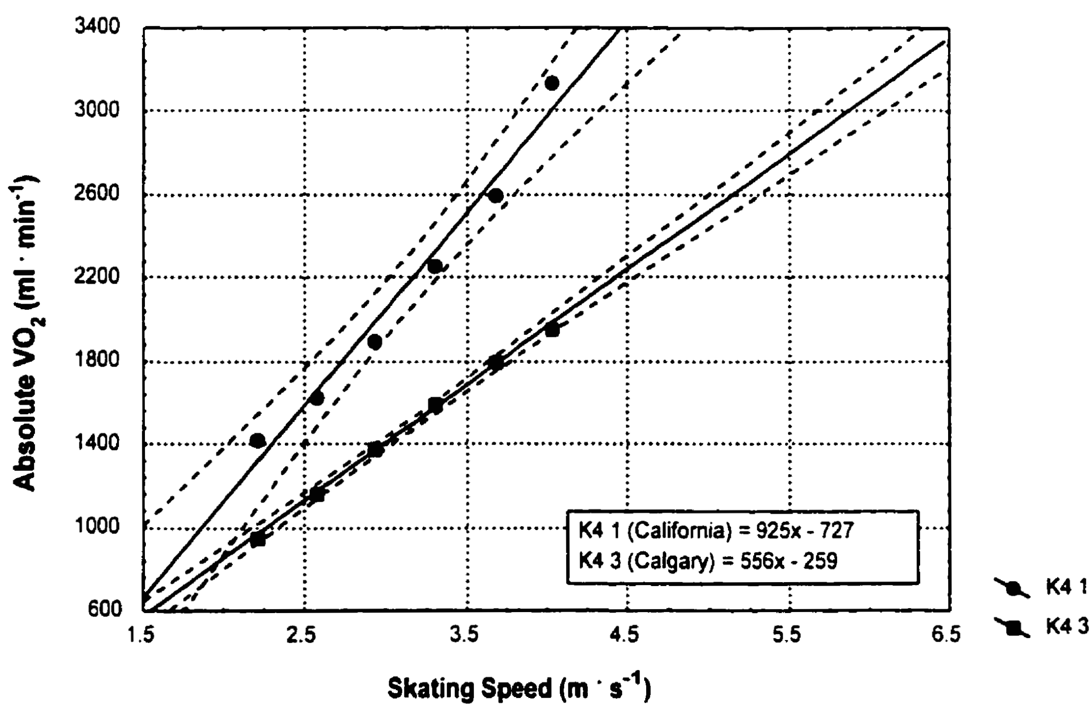

Figure 4-4. Regressed mean $\dot{V}O_2$ vs. Skating Speed for K4 1 (California) vs. K4 3 (Calgary) subject groups.

The 95% confidence interval for each test group/K4 instrument is also shown. For the time ranges where the confidence intervals do not overlap, there is a significant difference between the mean $\dot{V}O_2$. The K4 3 group scored significantly lower in terms of mean $\dot{V}O_2$ ($P \leq 0.05$) for all of the PST stages evaluated.

Stage Completion

The mean completion from the California and Calgary groups were both stage 5.3; there was no significant difference between the subject groups in the stage length completed. The pooled distribution (California and Calgary subjects) of subjects' best attempt in terms of stage completion is shown in Figure 4-5.

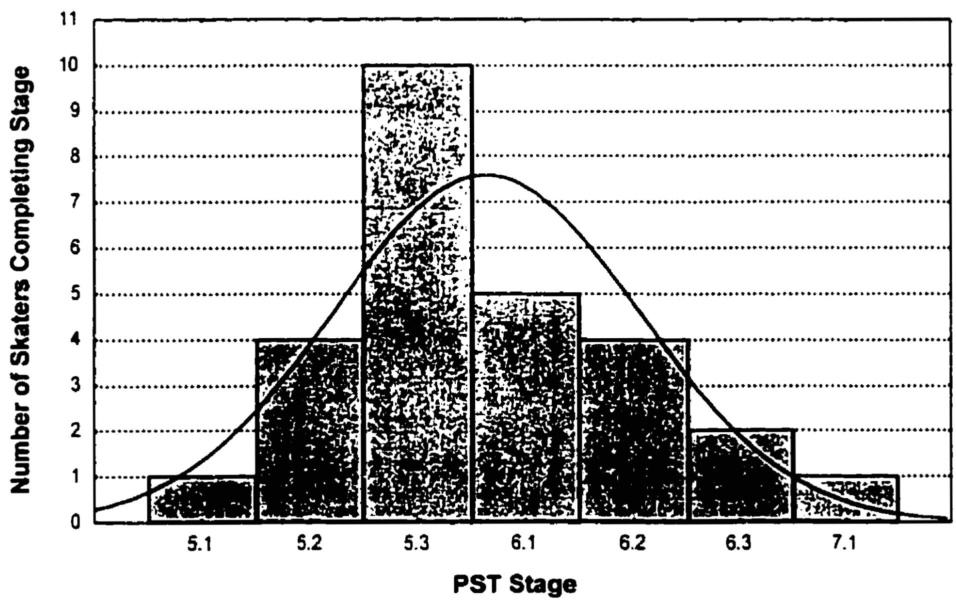

Figure 4-5.Frequency distribution for PST stage completed (pooled subjects).

On-Ice and Off-Ice $\dot{V}O_2$ max Results

The mean $\dot{V}O_2$ max and HR max for the California and Calgary groups, as well as the pooled data is presented in Table 4-12.

Table 4-12. Evaluation of difference in means for $\dot{V}O_2$ max as assessed with the PST and the maximal cycle ergometer protocols.

	N	PST	Cycle	*P*
K4 1 (California)				
Mean $\dot{V}O_2$ max (absolute ml · min^{-1})	18	2626 ± 745	2635 ± 735	0.929
Mean HR max (beats · min^{-1})	18	203 ± 5.0	203 ± 4.7	0.772
K4 3 (Calgary)				
Mean $\dot{V}O_2$ max (absolute ml · min^{-1})	7	2142 ± 286	2147 ± 289	0.780
Mean HR max (beats · min^{-1})	7	203 ± 5.6	203 ± 5.6	1.000
Pooled				
Mean $\dot{V}O_2$ max (absolute ml · min^{-1})	25	2408 ± 725	2498 ± 674	0.247
Mean HR max (beats · min^{-1})	25	203 ± 5.0	203 ± 4.8	0.770

As previously reported there was a significant difference between the Calgary PST and the Calgary cycle $\dot{V}O_2$ max scores for the averaged Calgary PST test but not for the Trial 1 PST test. However, the pooled data reveals no significant difference between the mean $\dot{V}O_2$ max or HR max between the PST and cycle ergometer test.

Validation of the K4 Oxygen Uptake Instrument

Two validation studies were conducted on the Cosmed K4. In the first study, the K4 2 instrument was examined for $\dot{V}O_2$ values at specified power outputs using a Sensormedics cycle ergometer only. In the second study, instrument K4 3 was examined for $\dot{V}O_2$ values at the same specified power outputs and the subjects in this study were also tested using a Horizon MMC metabolic cart. Subjects in each study completed two trials on each apparatus (K4 and MMC, where applicable), and the results were averaged by specified power outputs.

Test-Retest Repeatability (Cycle Ergometer)

K4 units 2 and 3 were examined at specific power outputs for test-retest repeatability. The difference between the means calculated for Studies 1 and 2, respectively, were compared by power output by means of the Wilcoxon Signed Ranks Test (Table 4-13).

Table 4-13. Mean $\dot{V}O_2$ by workload and test-retest repeatability for K4 2, K4 3 Trials 1 and 2, respectively.

	K4 2 (Study 1)				K4 3 (Study 2)			
Workload	*N*	Mean $\dot{V}O_2$ (Trial 1)	Mean $\dot{V}O_2$ (Trial 2)	Sig. (2-tailed)	*N*	Mean $\dot{V}O_2$ (Trial 1)	Mean $\dot{V}O_2$ (Trial 2)	Sig. (2-tailed)
100	7	1484	1492	0.612	0			[a]
135	7	1786	1853	0.237	1	1799	1671	[a]
170	7	2092	2107	0.866	4	2078	2136	0.715
205	7	2378	2459	0.398	6	2331	2377	0.917
240	6	2770	2749	0.753	6	2603	2663	0.917
275	5	2951	3007	0.893	6	2889	2864	0.917
310	4	3452	3535	0.109	4	3137	3110	0.465
345	2	3795	3837	0.655	3	3445	3483	1.000
380	1	3801		[a]	3	3720	3706	0.285
415	0			[a]	1	3913		[a]

[a]Insufficient valid cases to perform test

There was no significant difference between the two trials for each instrument. These findings suggest that the instrument is reliable for the range of power outputs tested.

Comparison of the K4 3 and Horizon MMC $\dot{V}O_2$ Values

The mean $\dot{V}O_2$ values at specified power outputs for the K4 3 instrument were compared to the corresponding mean $\dot{V}O_2$ values obtained from the Horizon MMC. These results are presented in Table 4-14.

Table 4-14. Evaluation of $\dot{V}O_2$ validity: K4 3 vs. MMC (comparison of means by Wilcoxon Signed Ranked Test).

	K4 3		MMC		
Workload	*N*	Mean $\dot{V}O_2$	*N*	Mean $\dot{V}O_2$	Sig. (2-tailed)
100	0		0		[a]
135	4	1769	3	1756	0.180
170	7	2065	5	2154	0.068
205	9	2332	9	2375	0.441
240	9	2605	9	2643	0.594
275	9	2884	9	2948	0.767
310	9	3098	8	3316	0.093
345	8	3457	7	3701	0.091
380	5	3711	5	4006	0.068
415	2	3974	2	4304	[a]

[a]Insufficient valid cases to perform test

There was no significant difference in $\dot{V}O_2$ at any evaluated power output. Therefore, the K4 3 instrument calculates $\dot{V}O_2$ values that may be considered valid when compared to a Horizon MMC using a Sensormedics cycle ergometer to generate the power output.

Comparison of the K4 3 and K4 2 $\dot{V}O_2$ Values

The mean $\dot{V}O_2$ values at specified power outputs for the K4 3 instrument were compared to the corresponding mean $\dot{V}O_2$ values obtained from the K4 2. These results are presented in Table 4-15.

Table 4-15. Evaluation of $\dot{V}O_2$ validity: K4 3 vs. K4 3 (comparison of means by Wilcoxon Signed Ranked Test).

	K4 2		K4 3		
Workload	*N*	Mean $\dot{V}O_2$	*N*	Mean $\dot{V}O_2$	Sig. (2-tailed)
100	10	1480	0		[a]
135	10	1804	4	1769	0.635
170	10	2096	7	2065	0.740
205	10	2410	9	2332	0.549
240	9	2762	9	2605	0.297
275	7	2939	9	2884	0.681
310	4	3471	9	3098	0.050*
345	3	3801	8	3457	0.048*
380	1	3801	5	3711	1.000
415	0		2	3974	[a]

[a]Insufficient valid cases to perform test; *Significant at $P \leq 0.05$

The K4 2 produced highly similar mean $\dot{V}O_2$ values for workloads 135-275 W, and at 380 W. Significant differences were observed at power outputs of 310-345, but the *N* at these wattages was less that what was evaluated at lower workloads (Table 4-14).

Post-Calibration and Sensor Drift

Post-calibration readings for the K4 units' O_2 and CO_2 sensors are summarized in Tables 4-16, 4-17, respectively. Individual post-calibration readings were used to correct $\dot{V}O_2$ if less than 15.95 or greater than 16.05, and VCO_2 if not 3.95-4.05. Tests were rejected if post CO_2 was out of the range 3.85-4.15 or O_2 not 15.50-16.50. Rejected tests were subsequently excluded from the validation study.

Table 4-16. Summary of O_2 sensor drift by K4 collection instrument (validation study subjects).

Instrument		*N*	Mean	Mean Std. Error
K4 2	Trial 1	10	15.86	5.89 E-02
	Trial 2	7	15.93	2.35 E-02
K4 3	Trial 1	9	15.78	4.15 E-02
	Trial 2	6	15.83	4.20 E-02

Table 4-17. Summary of CO_2 sensor drift by K4 collection instrument (validation study subjects).

Instrument		*N*	Mean	Mean Std. Error
K4 2	Trial 1	10	4.00	2.58 E-02
	Trial 2	7	3.99	1.13 E-02
K4 3	Trial 1	9	3.93	2.70 E-02
	Trial 2	6	4.00	1.41 E-02

Comparison of Cosmed K4 1-, K4 2-, K4 3- and Horizon MMC-Derived $\dot{V}O_2$ Scores

A comparison of $\dot{V}O_2$ scores at specified power outputs using a Sensormedics cycle ergometer is presented in Figure 4-6. The 95% confidence intervals are given for each regression, by group, plotted about each regression line. Where the 95% confidence intervals overlap there is no significant difference in the regressions for the instruments. A significant difference is found above approximately 150 W of power output for the K4 1, vs. the $\dot{V}O_2$ as reported by K4 2, 3, and the MMC, respectively. Above 150 W the K4 1 reported $\dot{V}O_2$ systematically greater than the other three devices.

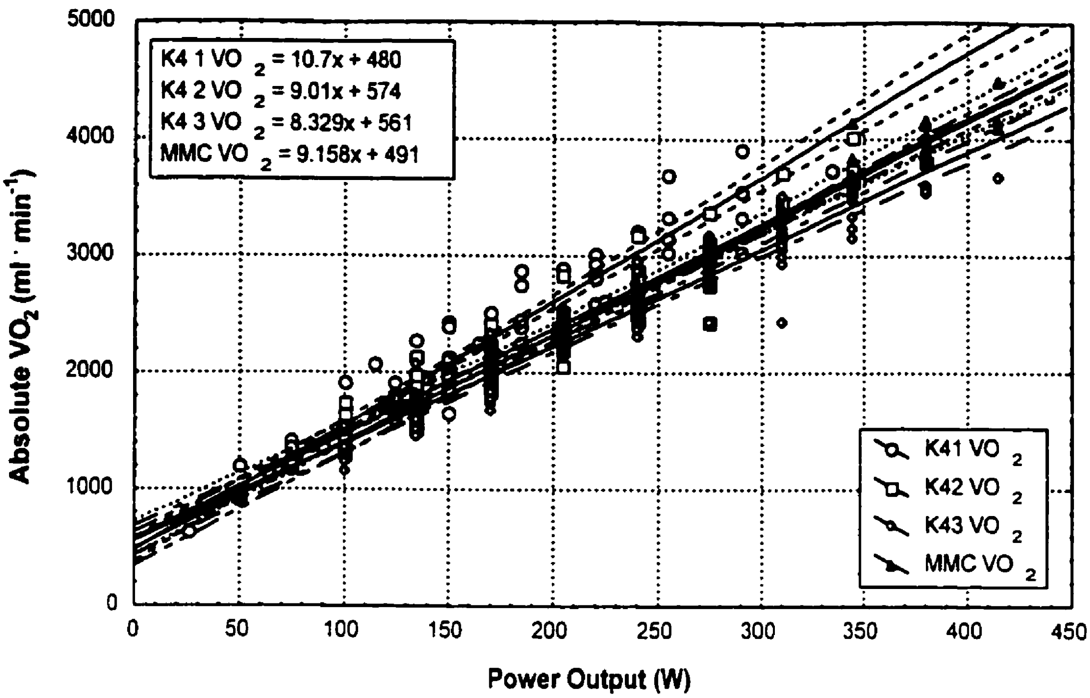

Figure 4-6. Overall summary of $\dot{V}O_2$ vs. power output for ice subjects (K4 1), and bike validation study subjects (K4 2, K4 3, MMC). Note: K4 3 and MMC plots represent paired data (dependent population).

Summary of the Results

Progressive Skating Test

The pooled subject group completed the PST ranging from Stage 5.1 – Stage 7.1. This distribution (Figure 4-6) is normal about Stage 5.3; most subjects terminated the test in the first seconds of Stage 6.1 when the skating speed increased and they were unable to keep up with the audio cues. The mean PST time represented by Stage 5.3 is 450 s. A summary of mean $\dot{V}O_2$ by stage is given in Table 4-1 (California subjects) and Table 4-7 (Calgary subjects) and graphically in Figure 4-4. The Calgary subjects, using the K4 3, scored significantly lower mean $\dot{V}O_2$ at all of the PST stages evaluated compared to the California group using the K4 1 instrument.

As previously described, the mean absolute $\dot{V}O_2$ max on-ice during the PST was 2626 ± 745 ml · min^{-1} for the California group vs. 2142 ± 286 ml · min^{-1} for the Calgary group, respectively. This was compared to the mean cycle ergometer $\dot{V}O_2$ max values: 2635 ± 735 ml · min^{-1} for the California subjects and 2147 ± 286 ml · min^{-1} for the Calgary subjects. The pooled mean $\dot{V}O_2$ max values for all subjects were 2408 ± 725 ml · min^{-1} and 2498 ± 674 ml · min^{-1} for the PST and cycle ergometer, respectively. There were no significant differences found between the pooled groups for either $\dot{V}O_2$ max or HR max as elicited by the PST vs. the cycle ergometer protocols.

Validation and Repeatability of the Cosmed K4 Oxygen Uptake Instrument

The K4 2 and K4 3 demonstrated repeatable results for power outputs between 135 W and 380 W. Furthermore, the K4 2 and K4 3 showed no difference in mean $\dot{V}O_2$ values between 135 – 275 W and at 380 W. There was a significant difference between these instruments found at 310 – 345 W workloads.

Comparison of the K4 3 and Horizon MMC $\dot{V}O_2$ scores revealed no significant differences at power outputs between 135 – 380 W.

Comparing the K4 1, K4 2, K4 3, and the Horizon MMC $\dot{V}O_2$ scores revealed significantly higher $\dot{V}O_2$ values for the K4 1 instrument above 150 W workloads.

CHAPTER 5: DISCUSSION

Design and Validation of the Progressive Skating Test

This study was undertaken to provide a method of evaluating aerobic power in the competitive figure skating population in a sport-specific manner. Although there are several studies discussing the physiological characteristics of competitive skaters (Mannix et al., 1996, Zapalo and Smith, pilot work, 1997) all have taken measurements in non-specific settings. Relating these findings, obtained in the laboratory, to on-ice performance is inferential at best. Skating coaches and professionals would comprehend skating-specific test results more readily; consequently they would be more effective in managing their athletes' fitness specific to competitive performance. Particularly because there are figure skating coaches at all levels who, traditionally, have a limited exposure to physiological testing and its interpretation, an intuitive test would be widely useful in the sport.

For both subject groups (California and Calgary) a linear increase in mean absolute $\dot{V}O_2$ was positively associated with increased skating speed, by stage, during the Progressive Skating Test. This positive relationship was true in each last 30 second interval of each 90 second stage in the PST. However, the relationship between skating speed and absolute $\dot{V}O_2$ ($ml \cdot min^{-1}$), by group, was characteristically different by slope and intercept for nearly the entire range of skating speeds evaluated. These regressions are similar only for the initial stage of the test. The K4 1 is positively dissimilar from the K4 3 as shown by the regression plots of the mean $\dot{V}O_2$ by stage (skating speed) for the

California subjects, the two separate trials for the K4 3, and of the 95% confidence intervals of these three plots. Where the confidence intervals do not overlap there is a significant difference at the 0.05 level.

Because the means were significantly different for the majority of the stage skating speeds tested, it is arguable whether a pooled group statistic is warranted in analyzing the relationship between speed and $\dot{V}O_2$. Whether the Calgary group is different based on the smaller sample size alone rather than another variable is unclear. However, examining the relative $\dot{V}O_2$ (ml · kg^{-1} · min^{-1}) regressed against skating speed (m · s^{-1}) the slopes of the respective regressions are similar for the K4 1 and the two K4 3

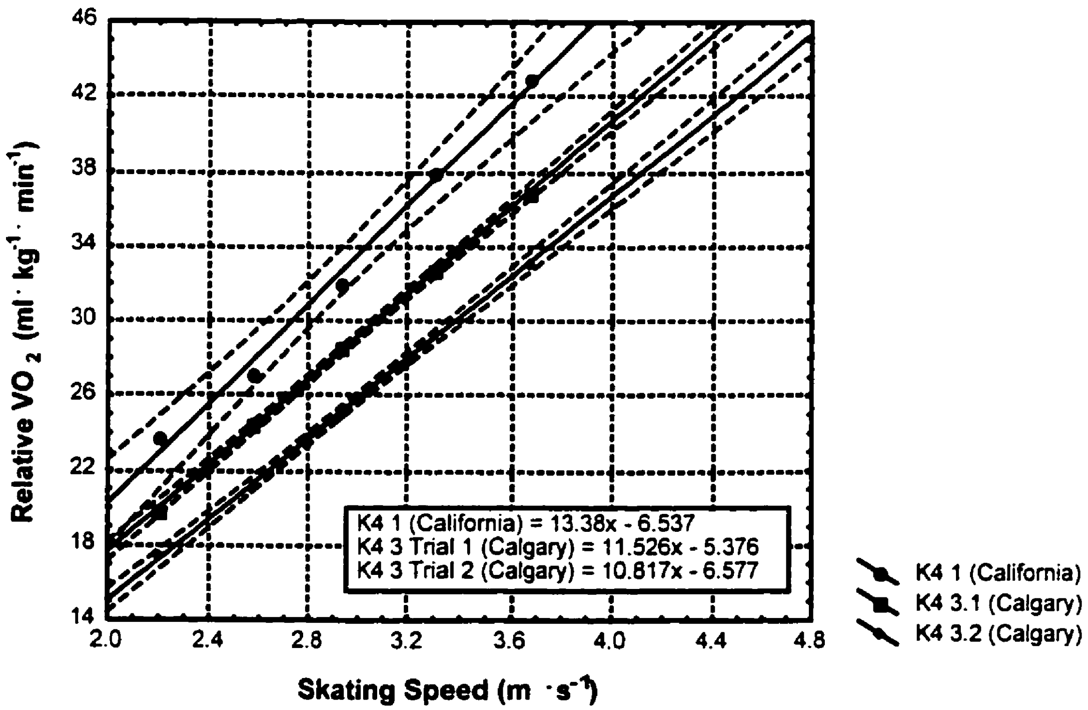

Figure 5-1. Summary plot of regressed $\dot{V}O_2$ means, by stage, for K4 1, and K4 3 on-ice subject groups. The relationship between skating speed greater than 4.0 m · s^{-1}) and $\dot{V}O_2$ is a projection based on observations within the first five stages of the PST.

trials (Figure 5-1). The 95% confidence intervals do not overlap due to a constant shift in terms of ml · min^{-1}.

Factors causing the difference between Calgary and California may be related to the Cosmed K4 instruments being different and giving incorrect $\dot{V}O_2$ values, the quality of the ice surfaces in the arenas, as well as differences in equipment (skates), and by skating efficiency of the subject groups.

Through personal communications with us, Cosmed acknowledged that the CO_2 analyzers installed in earlier hardware versions of the K4 (including the K4 1 unit used in California) were prone to sensor drift, as measured in the post-calibration, particularly at analyzer temperatures above 30° C. Cosmed conducted a unit-by-unit recall of first-generation K4 units specifically to replace these CO_2 analyzers. The K4 2 and K4 3 units used in this investigation had upgraded analyzers and the K4 1 was a first-generation unit. Although the first-generation analyzers were most prone to errors above (analyzer temperature of) 30° C, and the analyzer temperature of the K4 1 unit remained cooler than this throughout the on-ice testing, it is possible that the CO_2 analyzer in the K4 1 contributed to a systematic error in the $\dot{V}O_2$ data. Errors in $\dot{V}O_2$ measurement by Cosmed instruments have been documented in previous studies. Lucia et al. (1993), showed that the Cosmed K2 was unreliable measuring $\dot{V}O_2$ at rest and at half of the submaximal workload intensities the subjects in their study completed.

Even though three separate ice surfaces in California were used at two different arenas, the respective *n* for each of these surfaces was small and the resulting effect may have been diluted in the overall group. The Calgary group with an *n* of 7 all shared the same ice surface. It is hypothesized that variations in ice performance, which are a composite effect of air and ice temperature, ice density, surface depth, chemical factors (ice composition) and maintenance practices (frequency and temperature of resurfaces), may have contributed to the difference between the California and Calgary groups. However there are no published studies relating ice quality to skating performance. A survey of equipment (boots and blades) used by the subjects was not conducted. Thus, the results may reflect economy of movement on ice due to either better skating technique or an improved ice surface. However, subjects were instructed to have a comfortable and recent sharpening on their blades. Figure skating blade performance quality is affected by the technique used to sharpen the blade, and is often highly customized to the comfort and preference of the individual skater. All of the blades used by the subjects were steel. The Calgary subjects were excusively Canadian and had their blades sharpened locally by various professionals. The California subjects were less homogenous in equipment and sharpeners vs. the Calgary group. The precise impact of these variations is unknown but it is possible that blade quality had an effect on the outcome.

When examined exclusively to other variables, the fact that the Calgary group consumed less O_2 by stage may suggest that the Calgary skaters had a greater skating efficiency. However, this finding is not supported by an overall difference between groups in competition or proficiency level, since the California group was more advanced by both proficiency and competitive level. Skating skill/efficiency is not a major determinant of competition outcome; rather it is the ability to consistently complete advanced jumps. Whereas the proficiency tests are not appreciably different in the CFSA (Canadian) vs. USFSA (United States) systems, it is possible that the Calgary subjects were more skilled in basic stroking than the subjects in the California group. Were this true, the Calgary subjects would, theoretically, consume less O_2 for a given skating speed.

Following this argument, if the Calgary subjects had equivalent aerobic ability to the California subjects but were more efficient skaters, they would be able to progress further on the PST. However, since the Calgary subjects had a significantly lower $\dot{V}O_2$ max (as assessed both on-ice and on the cycle ergometer: Table 4-12) in terms of PST stage completion they scored comparatively with the California group.

As stated above, the Calgary subjects scored significantly higher on the cycle ergometer than the on-ice testing in terms of $\dot{V}O_2$ max. If there were no air temperature effects on the Calgary subjects then the PST did not elicit a maximal aerobic response from these subjects. However, the value of the PST protocol as a maximal test of aerobic ability is validated by the K4 1 in terms of a comparison of the mean $\dot{V}O_2$ max values between the PST and the cycle ergometer protocols. This group was shown to have similar mean maximal values for the PST and the cycle ergometer maximal test, which were 2626 and 2635 $ml \cdot min^{-1}$, respectively. Similarly there was no difference in the mean maximal heart rates for the PST vs. the cycle tests in the California subjects. Therefore it may reasonably be concluded that the Progressive Skating Test elicits a maximal response in the overall target population.

The PST test-retest repeatability was investigated by looking at the difference in the means of repeated PST trials by the same subjects for both the California and Calgary groups. Although it was evident from the video records of both groups that the subjects met or beat their initial scores in the second PST trial, no significant difference was found for the K4 1 group between trials 1-2 and were in fact highly repeatable. In the K4 3 group the $\dot{V}O_2$ values, by stage, were significantly *less* over all PST stages compared. This may have been caused by a learning effect whereby the subjects adjusted to complete the PST stages more efficiently on subsequent trials.

The prediction of the $\dot{V}O_2$ max for subsequent skaters using the PST test is based on the $\dot{V}O_2$ (and subsequently) energy cost at each skating speed during the test. The validity and accuracy of the PST will be limited by the individual variation of the athlete's oxygen cost for a given skating speed. The variability in terms of test-retest reliability of the PST was larger for the California group than for the Calgary group; however the California group was also larger and less homogenous in terms of age, size, and skating proficiency levels.

The PST was structured into 90 second stages; this stage length was chosen to allow the skater sufficient time to aerobically respond to each skating speed, and because the 90 second format made it easier to increase the distance skated per stage, and thus skating speed, by adding distance lobe by lobe (half-course). This was important to keep the proportion of the test skating forwards and backwards equal in each stage. However, this stage length may have contributed to local fatigue effects whereby the skaters' legs tired before they reached their aerobic limits of performance. A similar effect was noted by Leger et al. (1989), where he validated his 20-m shuttle run test (Leger et al., 1982) with 1 min stages. He identified lack of motivation, particularly in pediatric populations, as a reason that subjects may terminate the shuttle test before they reached their physiological limit. By shortening the stage length to one minute, the regression of running speed against $\dot{V}O_2$ shifted to the right; however, subjects did not achieve an overall higher $\dot{V}O_2$ max in the 1-min vs. 2-min stage test. Shortening the stages to 1 min actually improved the correlation of the predictive shuttle test to direct measure $\dot{V}O_2$ max (from 0.84 to 0.93).

Shortening the PST stages may have lessened the effects of local fatigue of the skaters' thigh muscles, and therefore reduced an impaired performance because of local fatigue in later stages of the test. However, given the need to gradually increase the skating speed for each stage would have necessitated shortening the stages to 45 seconds each (to keep the speed increases in the same proportion), which may have given the subjects insufficient time to approach steady state before the application of the subsequent speed increment. Therefore, the 90 second stages used were the smallest applicable steps in terms of making the stage transition as manageable as possible for the subjects.

The possibility of local muscle fatigue is comparable to the argument of using treadmill vs. cycle ergometer methods to measure $\dot{V}O_2$ max. The treadmill typically gives $\dot{V}O_2$ max values 5 – 15% greater than when assessed on the cycle ergometer (Hermansen and Saltin, 1969). This finding is probably related to the use of a larger muscle mass while running vs. cycling, as well as the development of local fatigue in the thigh muscles while cycling. Because the exact muscle activation used for forwards and backwards stroking in figure skating is not known it is difficult to definitively identify the degree of local fatigue that could be expected or how fatigue could cause differences in $\dot{V}O_2$ max between skating and the cycle ergometer protocols.

Additionally, Leger et al. (1988), observed a higher energy cost of running for children which changed the relationship between running speed and $\dot{V}O_2$ with age and therefore necessitated separate regressions for each age group below 18. However, for subjects older than 18 there was no significant age effect and the data was therefore collapsed for ages above 18.

Prediction of $\dot{V}O_2$ max With PST Stage Completion

A summary of PST stage completed and mean on-ice $\dot{V}O_2$ for the subjects terminating at each stage is given in Table 5-1. There was, overall, a positive relationship between $\dot{V}O_2$ max and stage completed on the PST. The large scatter seen when comparing stage completion to $\dot{V}O_2$ (both absolute and relative, Figures 5-2, and 5-3, respectively) reflects previous studies showing large variations in oxygen cost by running speed (Sjodin et al., 1985). The variation observed was related to the differences in the subject's individual economies of running. In this study the differences in the equipment, ice, and individual skating skills of the subjects, as well as anatomical and physiological variations were likely contributors to a high variation in the efficiency, and therefore, oxygen cost of skating.

Table 5-1. Summary of PST stage completion vs. relative on-ice $\dot{V}O_2$ max.

PST Stage Completed	N	Relative $\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$) ± SD	Mean Standard Error
5.1	1	39.9	[a]
5.2	4	42.1 ± 3.7	0.92
5.3	10	43.0 ± 3.6	0.54
6.1	4	44.2 ± 1.7	0.43
6.2	5	44.7 ± 9.7	1.95
6.3	2	47.2 ± 9.9	4.97
7.1	1	48.6	[a]

[a]Insufficient cases to generate SD, MSE

Nonlinear variations in the mean $\dot{V}O_2$ are most likely attributable to differences in skating efficiency. Additionally, these findings show that the error in relating $\dot{V}O_2$ max to performance on the PST increases linearly with the relative $\dot{V}O_2$ max. However this effect is likely to be largely related to the small number of subjects with high aerobic fitness; if more subjects were able to complete higher PST stages standard errors more similar to what was observed for stages 5.2 – 6.1 would be expected.

Examining the relationship between $\dot{V}O_2$ max obtained on the cycle ergometer vs. the PST, these findings suggest for the non-specific cycle protocol, the absolute $\dot{V}O_2$ max is the better predictor of PST stage completion vs. the relative $\dot{V}O_2$ max.

The development and validation of the Progressive Skating Test was limited by the availability of more high-caliber subjects and by the variations of the collection instruments used. Therefore, more study is needed to further validate this regression model, particularly at higher ranges of $\dot{V}O_2$ and skating speed.

There was a consensus among the subjects and their coaches that skating skill was a large factor in PST performance not only in terms of ability to execute the test at higher stages and speeds, but also in how confident the subjects were to attempt these stages. This may have also related to the fact that the K4 unit partially obstructed the subjects' peripheral vision, particularly while skating backwards. The ice surface was free of other skaters and debris but at high speeds the skaters' spatial awareness was essential to their ability to follow the PST course pattern.

Although no skaters fell at any point while wearing the K4 the subjects experienced a degree of anxiety related to 1) potential injury due to a fall at high speed; 2) fear of damaging the K4 equipment.

Despite the differences in the test groups, there was a linear relationship between $\dot{V}O_2$ and skating speed for each stage of the PST. Additionally the protocol was reliable in test-retest situations, in terms of stage completion. The variations in $\dot{V}O_2$ observed between the California and Calgary subject groups may have been due to a combination of differences in Cosmed K4 instruments, altitude, arena air and ice, and the skating skills of the subjects.

Validation of the K4 Collection Instruments

The Cosmed K4 oxygen uptake instrument is unique in allowing the researcher to take real-time measurements of oxygen uptake in the field. The characteristics of the K4's portability greatly facilitate the application of specific testing to the activity in question, while avoiding the limitations of previously contrived field-collection systems. Comparing the K4's relatively small size and weight to previously used techniques, such as the cross-country skier towing a bulky Douglas bag apparatus, it is evident why the K4 is a desirable alternative. Furthermore, the ability for the researcher to observe real-time results gives a much greater degree of immediate control over the testing protocol.

A study of the K4 units' validity and reliability in terms of measuring $\dot{V}O_2$ in similar applications as to the Progressive Skating Test was necessitated by the instrument's nascent presence in telemetric data collection instruments. There is the "gold-standard" method of assessing oxygen consumption in the physiology laboratory by the metabolic cart. Therefore, by directly comparing the K4 instrument to the metabolic cart a practical index of the K4's accuracy was evaluated.

The mean $\dot{V}O_2$ values for the K4 3 and MMC were not different for all workloads evaluated. They were in fact highly similar in the central range of power outputs where more subjects completed the same workloads (205 – 275 W) compared to the low and high ends ($\leq$135 W, $\geq$310 W) of the power outputs completed by the subjects. The power and overall correlation of these devices at the extremes could likely be improved by increasing the *n* in this aspect of the study. This would necessitate the recruitment of more aerobically fit subjects than were used in this study (for further investigation at higher levels of O_2 consumption).

Because these collection instruments were applied in an equivalent testing environment, at equivalent workloads and test protocols, on identical cycle ergometers, and the tests were completed by the subjects within a relatively short time frame and in a randomized order, the outcome is what would be expected if the K4 3 is a valid and reliable collection instrument. Furthermore, although it is unfair to do a direct comparison with previous K4 studies because of the difference in the exercise protocols, these findings reflect what was reported by Bigard et al., 1995 and Hausswirth et al., 1997: that the K4 is a valid tool for measuring oxygen uptake during exercise. Both of these studies, like this one, investigated the validity and reliability of the K4 instrument at submaximal and maximal workloads, and both concluded that the K4 measured $\dot{V}O_2$ accurately and reliably.

Likewise, the K4 2 unit was shown to be similar to the K4 3 for the central workload ranges 135 W – 275 W. No comparison was available at 100 W because only the K4 2 group completed this power output. The units were significantly different at the $P \leq 0.05$ level at $\geq$310 W. Based on the small comparison *n* at this power output, and the trends observed in the K4 3 comparison of these extremes, this result is not infeasible. With a greater *n* it is possible that no significant difference would be found, and that therefore the observed difference is attributable to the physiological variation in the K4 2 and K4 3 subject groups alone. This variation due to a small number of cases is further evident in the 380 W comparisons: although the Mann-Whitney test shows no difference at 380 W the *n* for the K4 2 group is only 1, which suggests that there is not enough evidence to concretely suggest a conclusion.

An overall comparison of the three K4 instruments and the MMC (refer to Figure 4-4) shows a systematic difference, particularly observed at higher workloads, between the K4 1 and the other test units. There are several factors that may have contributed to this difference.

Firstly, the K4 may have given systematically higher values, by workload/PST stage. Secondly, there was a difference in the elevations of the testing venues. This is discussed at length above. Additionally attributable to the testing environment, the K4 1 cycle tests took place in the ice arena, albeit away from the ice surface itself, but still within the limitations potentially attributable to a lower average air temperature and to unknown air quality.

A third source of variation may be differences in the individual cycle ergometers used in the data collection. Although similar ergometers (same manufacturer and model) were used and the ergometers were precisely calibrated in each testing session, variation may have been introduced through differences in ergometer performance. This may have included software performance (based on ROM version of the bikes' respective firmware) in braking the cycle, condition of brakes, and internal lubrication.

Because the K4 1 unit used to collect the majority of the on-ice subjects' data is positively skewed, particularly at higher ventilatory and O_2 consumption ranges, a systematic correction might be useful to align this data set with the K4 3 used in the Calgary on-ice subjects and the gold-standard MMC.

Test-Retest Repeatability

Test-retest repeatability was high for nearly all workloads assessed in multiple trials by both K4 2 and K4 3, respectively, for the cycle ergometer tests (refer to Table 4-8). Data correction for the raw $\dot{V}O_2$ values given by the K4 units was warranted where sensor drift occurred over the course of an exercise test. Drift within the ± 0.05 constraint commonly used in the laboratory was considered a pass, whereas drift outside this range was corrected by manually recalculating the $\dot{V}O_2$ data based on the algorithm in the Cosmed b^2 software plus a time weight factor which assumed linear drift. Although assuming equally distributed linear drift over the course of each experiment limits the overall certainty of the experimental data, the following was likely:

1) The end-stage $\dot{V}O_2$ values were likely to be as far off the "true" value as the post-calibration gas readings demonstrated;
2) There was no contrary evidence to pinpoint the degree of sensor drift at any given point of the experiment.

Therefore, correcting assuming linear drift was rationalized to be the fairest method of minimally aligning the data with the initial sensor calibrations at the start of each test.

For the O_2 sensor, the mean standard errors for the Cosmed instruments (K4 2 and 3) were small (ranging from approximately ± 0.023 - ± 0.059) relative to what is given by the metabolic cart (MMC). However, the mean post calibration values ranged from, at best, 15.93 to at worst 15.78. It would be typical to reject and retest subjects obtaining similar values on the MMC. The data obtained from the K4 was kept and corrected because in extensive retest situations of all three units it became evident that the Cosmed sensors constantly exhibited this degree of drift. To discard "failed" tests by our original standard would be to discard the majority of all tests completed by the subjects. This must be considered a limitation of the Cosmed K4 and weighed against the benefits of being able to collect real-time data in the field.

Similarly, the CO_2 sensor post-calibrations averaged from 3.93, which is barely beyond the MMC ± 0.05 tolerance, to a normal 4.00. This average was systematically biased by the investigator because for tests outside of a pre-selected post-calibration tolerance of ± 0.1, individual exercise tests were rejected from the study. This was necessary for the CO_2 sensor vs. the O_2 sensor primarily because, whereas ± 0.05 is a relatively low percentage of 16.00 (O_2 %), it is fourfold increased as a percentage of 4.00 (CO_2 %).

The mean standard errors for the CO_2 sensor were also relatively small, ranging from ±0.011 – ±0.027. These results placed the post calibration errors of the K4 CO_2 analyzers within the same range as those of the MMC in most cases.

It has been documented by Cosmed that in some of their earlier K4 production units (including the K4 1 used in this study), overheating of the CO_2 sensor consistently caused large sensor drifts. At sensor temperatures $\geq$ 30° C the K4 units failed to post-calibrate within the tolerance outlined above. This phenomenon was avoided entirely in the use of the K4 1 because the test environment was so cold it kept the CO_2 sensor below this critical temperature threshold at all times.

The validation test design allowed 1:1 comparison of the subjects' data, by power output, between the paired samples on the K4 3 and the MMC. The greatest limitation of this data was the relatively small *n* used in this study, but given the overall number of repeated tests performed by each subject and the strength of the Wilcoxon Signed Rank Test (non-parametric method) there is a higher degree of reliability in the test outcomes.

The relationship between the K4 1 with the other two Cosmed units and the MMC was limited by several factors:

1) Testing venue (elevation, air quality, and temperature);
2) Difference in cycle ergometers used;
3) Variations in subjects used and, as a result, power outputs completed.

The Cosmed K4 is a reliable and valid instrument for measuring oxygen consumption. They are useful particularly for data collection in the field where portability is precedent over accuracy. However, these units are limited by troublesome performance, particularly in relation to temperature and air quality. Therefore, great pains must be taken to assure accuracy of the data collected when using the K4, particularly in terms of taking meticulous post-calibration readings of reference gasses and subsequently correcting data.

Summary of Conclusions

Progressive Skating Test

The original purpose of this study was to derive a regression model relating aerobic power to skating speed in order to provide coaches with a practical, sport specific test that would be used to predict $\dot{V}O_2$ max. There was a linear increase in $\dot{V}O_2$ with skating speed using the last 30 s of each 90 s stage. There was no difference in the stage completion in repeated on-ice trials. A composite regression model could not be determined because there was a significant difference between relative $\dot{V}O_2$ values (ml · kg^{-1} · min^{-1}) for the two groups of subjects tested. Based on the cycle ergometer $\dot{V}O_2$ values, it is suggested that the K4 1 instrument gave significantly higher values than the K4 3 which was found to give similar $\dot{V}O_2$ values to those measured on a metabolic cart at specified power outputs. Furthermore, the test-retest PST $\dot{V}O_2$ scores for the Calgary group were significantly different, a difference that could have been due to learning or to incorrect $\dot{V}O_2$ -derived scores.

Despite these problems, the $\dot{V}O_2$ max scores for the PST and cycle ergometer tests using the same instrument were not significantly different. This suggests that the PST is a reliable sport-specific test and further research should be conducted with a validated K4 instrument in order to develop the regression equation between aerobic power and skating speed.

Validation of the K4 Instruments

Based on this study and those reported in the literature, the Cosmed K4 instrument is both valid and reliable. In this study the $\dot{V}O_2$ values obtained from the K4 1 unit may not be valid, specifically, higher absolute $\dot{V}O_2$ values observed above 150 W. This cannot be confirmed because the specific bicycle ergometer used and the test environment may have also contributed to the observed difference. However, there were no significant differences between the $\dot{V}O_2$ values for the K4 2 and 3 units compared to those obtained from the Horizon metabolic cart. These findings confirm that the K4 is a valid and reliable instrument for the measurement of oxygen uptake.

Recommendations for Further Research

The following recommendations are warranted in continuing the development of the PST: The largest immediate factor that could strengthen the existing findings would simply be increasing the number of subjects tested with a valid K4 instrument. Additionally, obtaining subjects at a more advanced level (in terms of skating skills and/or aerobic ability) would allow an extension of the regression model into higher stages of the PST protocol. A comparison of subjects' previous competition outcomes to their performance on the PST may reveal a relationship between competitive success and aerobic ability. It would also be interesting to investigate the usefulness of the PST as a diagnostic tool to track a skater's aerobic conditioning throughout the competitive season.

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APPENDIX A: Correction Protocol for Raw K4 Data

As outlined in Chapter 4, the raw K4 data was corrected through a series of calculations based on the readings taken from known reference gasses.

For a given data point generated by the K4 unit:

$$\text{Time weight factor} = \frac{\text{current time (s)}}{\text{total test time (s)}}$$

$$O_2 \text{ Correction Factor} = 1 + (1 - \frac{\text{post - calibration } O_2 \text{ reading}}{16.00}) \cdot (\frac{\text{current time (s)}}{\text{total test time (s)}})$$

$$\text{Corrected } \dot{V}O_2 = O_2 \text{ expired} \cdot O_2 \text{ Correction Factor}$$

$$\text{Corrected mixed expired } O_2 = FeO_2 \cdot O_2 \text{ Correction Factor}$$

$$CO_2 \text{ Correction Factor} = 1 + (1 - \frac{\text{post - calibration } CO_2 \text{ reading}}{4.00}) \cdot (\frac{\text{current time (s)}}{\text{total test time (s)}})$$

$$\text{Corrected } \dot{V}CO_2 = CO_2 \text{ expired} \cdot CO_2 \text{ Correction Factor}$$

$$\text{Corrected mixed expired } CO_2 = FeCO_2 \cdot CO_2 \text{ Correction Factor}$$

$$\text{Haldane Correction} = Ki = \frac{100 - \text{corrected } FeO_2 - \text{corrected } FeCO_2}{100 - FiO_2 - FiCO_2}$$

$$\text{Corrected } \dot{V}O_2 = ((\text{Dead space (L)} \cdot 1000) \cdot Ki \cdot (FiO_2/100) - (\text{Corrected } FeO_2) - (70 \cdot ((FiO_2/100) - (FetO_2/100)))) \cdot (\text{current time/total test time}) \cdot \text{STPD}$$

APPENDIX B: Consent Form

Validation of an on-ice predictive test of O_2 consumption for figure skaters

Investigators: P. Zapalo and D. J. Smith

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research project is about and what your participation will involve. If you would like more detail about something mentioned here or information not included here, you should feel free to ask. Please take the time to read this carefully, with a parent or coach if necessary, and to understand any accompanying information.

The purpose of this testing is to develop and validate a field test for aerobic power for competitive figure skaters. The experimental procedures for this project are as follows:

You will be asked to perform a maximal cycle ergometer test and two on-ice maximal tests within the time frame of one week.

Cycling $\dot{V}O_2$ max

After a light warm up on the cycle, you will perform an incremental maximal cycle ergometer test on an electronically braked cycle to determine your $\dot{V}O_2$ max. The starting resistance is 80 – 100 W (based on your body weight) and will increase by 35 W every 2 minutes. You will be connected via a face mask to the Cosmed K4 pulmonary gas exchange analyzer to measure your ventilatory gasses and your heart rate. The workload at which you reach $\dot{V}O_2$ max will be recorded.

Progressive Skating Test

You will have the opportunity to warm up with light stroking and stretching. The test will follow a predefined course covering the entire ice surface. You will be oriented to the test protocol and layout previously to your actual test session. The test course will be indicated by pylons and markers drawn on the ice. Along the course will be three markers equally spaced: one at the center ice and one centered at each end. Starting at the center marker, you will stroke along the course, reaching the timing markers at precise intervals as dictated by tones emitted from a recording. The starting speed will be $2.37\ m \cdot sec^{-1}$ (relatively slow) and will increase by $0.37\ m \cdot sec^{-1}$ per stage. Each stage lasts 90 sec and the test will terminate when you fail to be within 2 m of an interval marker on time as determined by the test administrators. Your $\dot{V}O_2$, heart rate, and minute ventilation will be measured throughout the test with the K4 telemetric system that you will wear.

The results of this study will be confidential. Only the researchers and technicians who analyze the data will have access to the information. Your identity will remain confidential by using code numbers to identify your specific data. The benefits of participating in this study are that you will receive information regarding your fitness level and will gain instruction about a possible training aid.

You will likely be uncomfortably winded following the aerobic tests. Additionally, figure skating is an inherently risky sport and you should be aware of the injury risks associated with falling on the ice and colliding with the boards while skating at high speeds. If at any time during the testing you feel discomfort, you are obligated to alert the technicians or investigators. The testing protocols will be intense but should not be far outside what you have already experienced as a competitive figure skater. You will likely be physically tired following each testing session and may withdraw completely from this study at any time.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in this research project and agree to participate as a subject. In no way does this waive your legal or professional responsibilities. If you have further questions concerning matters related to this research, please contact either Peter Zapalo at (403) 220-8549 or Dr. David Smith at (403) 220-3440.

If you have any question concerning your rights as a possible participant in this research, please contact the Office of the Vice-President (Research) and ask for Karen McDermid, (403) 220-3381 at the University of Calgary, Calgary, Alberta, Canada.

____________________	____________________
Name of subject	Signature of Subject
____________________	____________________
Name of parent	Signature of parent (subjects under 18)
____________________	____________________
Name of witness	Signature of witness
____________________	
Date	
____________________	____________________
Name of investigator	Signature of investigator

A copy of this consent form will be given to you. Please keep it for your records and future reference.

APPENDIX C: Consent Form

Validity and reliability of the K4 telemetric gas exchange system

Investigators: P. Zapalo and D. J. Smith

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research project is about and what your participation will involve. If you would like more detail about something mentioned here or information not included here, you should feel free to ask. Please take the time to read this carefully, with a parent or coach if necessary, and to understand any accompanying information.

The purpose of this testing is to establish the reliability of the K4 telemetric gas exchange device. The experimental procedures for this project are as follows:

You will be asked to perform four maximal cycle ergometer tests within the time frame of about one week.

Cycling $\dot{V}O_2$ max

After a light warm up on the cycle, you will perform an incremental maximal cycle ergometer test on an electronically braked cycle to determine your $\dot{V}O_2$ max. The starting resistance is 80 – 100 W (based on your body weight) and will increase by 35 W every 2 minutes. You will be connected via a face mask to either the Cosmed K4 pulmonary gas exchange analyzer or the Horizon MMC metabolic cart to measure your ventilatory gasses and your heart rate. The workload at which you reach $\dot{V}O_2$ max will be recorded.

The results of this study will be confidential. Only the researchers and technicians who analyze the data will have access to the information. Your identity will remain confidential by using code numbers to identify your specific data. The benefits of participating in this study are that you will receive information regarding your fitness level.

You will likely be uncomfortably winded following the aerobic tests. If at any time during the testing you feel discomfort, you are obligated to alert the technicians or investigators. The testing protocols will be intense but should not be far outside what you have already experienced if you are currently training aerobically. You will likely be physically tired following each testing session and may withdraw completely from this study at any time.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in this research project and agree to participate as a subject. In no way does this waive your legal or professional responsibilities. If you have further questions concerning matters related to this research, please contact either Peter Zapalo at (403) 220-8549 or Dr. David Smith at (403) 220-3440.

If you have any question concerning your rights as a possible participant in this research, please contact the Office of the Vice-President (Research) and ask for Karen McDermid, (403) 220-3381 at the University of Calgary, Calgary, Alberta, Canada.

Name of subject	Signature of Subject
Name of parent	Signature of parent (subjects under 18)
Name of witness	Signature of witness
Date	
Name of investigator	Signature of investigator

A copy of this consent form will be given to you. Please keep it for your records and future reference.