A Comparison of Young Female Rope Skippers with Untrained Matched Controls

by

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B.S., University of New Hampshire, 1993

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTERS OF SCIENCE

in the School of Physical Education

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Abstract

The purpose of this study was to compare measures of fitness in 11 experienced female competitive rope skippers, aged 8 - 15 years, with 11 untrained control participants matched by age and maturation. A secondary purpose was to evaluate the exercise intensity of a typical rope skipping training session. The experienced rope skippers trained 3 times a week, for 60 - 90 minutes. Self-assessed maturity status was used to separate subjects into prepubescent (6 experienced, 6 control) and pubescent (5 experienced, 5 control) groups. Stature and weight were recorded and the following measures of physical fitness were assessed: maximal oxygen uptake ($\dot{V}O_2max$) predicted by a 20-meter shuttle run test, peak power in 1s and 5s and total work over 30s estimated from a Wingate Anaerobic Cycle test, muscular power predicted from vertical jump, muscular endurance measured by partial curl ups and straight-legged push ups, dynamic balance assessed by the Modified Bass Test of Dynamic Balance, and flexibility measured by the Leighton flexometer for shoulder flexion/extension and the sit & reach test for general body flexibility.

A two-way ANOVA revealed no significant rope skipping experience (trained vs. untrained) main effect or an experience by maturity status interaction for any dependent measure. A significant maturity effect ($p < 0.05$) was found for height, weight, $\dot{V}O_2max$, peak power in 1s & 5s, total work over 30s, muscular power, balance, and left shoulder extension. High reliability ($r = 0.89$) was reported for the straight-legged push ups performed by the females in this study, indicating its appropriate use among similar populations. Both rope skippers and control subjects

exhibited normal to higher fitness levels when compared to normative and criterion standards. Heart rates monitored in 2 subjects during a typical rope skipping training session demonstrated great variability, with brief periods of high intensity work combined with extended periods of low intensity activity, reflecting a less than optimal work:rest ratio and intensity level for effective aerobic training. The lack of any rope skipping training effects may be attributed to a combination of low training intensity (< 60% max HR) and duration (< 30 min). It is also possible that the control participants had higher physical fitness levels than that expected of a normal, untrained population of females.

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Acknowledgments

I would like to express many thanks to my supervisor, Kathy, for her patience and flexibility in working around the frequently unpredictable schedule of my life. Her long hours spent both at work and at home enabled me to complete this thesis within my projected timeline. I would also like to thank the other members of my committee, Dr. Docherty and Dr. Muir, for their continual encouragement and availability whenever I hit a bump in the road. Special thanks to Gladys for lending her time, effort and friendly ear during these past two years.

I would like to acknowledge the Island Hoppers Rope Skipping Team and their parents who volunteered much time and energy during the testing sessions. I am grateful to all of my fellow grad students for their friendship, support and endless celebrations; and to Shana and Peter for their limitless encouragement and hospitality during my short stays. Finally, I thank my parents for their love and support in all of my life ventures; and Ted for his confidence in me and for showing me the world.

Introduction

With the growing popularity and success of younger athletes participating in organized sport and exercise programs, many questions have been raised by scientists, coaches, teachers, and parents regarding the effects of regular exercise in children. Numerous studies have investigated the aerobic metabolism of children and its response to physical training programs, while more recent interest has focused on the characteristics of the anaerobic and muscular systems in trained young athletes. However, our understanding of the physiological demands and effects of physical activity and exercise training in children is limited and somewhat controversial.

Most studies have shown that peak aerobic power ($\dot{V}O_2max$) values for trained children of all ages are higher than for untrained children (Krahenbuhl, Skinner, & Kohrt, 1985; McManus, Armstrong, & Williams, 1997; Rowland, 1985; Rowland & Boyajian, 1995), with greater differences in values occurring in adolescence as compared to the younger age group (Krahenbuhl et al. 1985; Rowland, 1992). However, some studies suggest that the trainability of the prepubescent child is limited compared to adult trainability (Krahenbuhl et al., 1985; Rowland, 1992). Numerous cross-sectional studies have examined $\dot{V}O_2max$ in trained pediatric male populations (Cunningham, Telford, & Swart, 1976; Daniels & Oldridge, 1971; Eriksson, Gollnick, & Saltin, 1973; Falgairette, Duche, Bedu, Fellmann, & Coudert, 1993; Mayers & Gutin, 1979; Mero, Kauhanen, Peltola, Vuorimaa, & Komi,1990). Mero et al. (1990) found $\dot{V}O_2max$ values obtained from a treadmill test in twelve 10 to 13 year old male prepubescent weight lifters, endurance runners, and sprint runners to be significantly higher than an untrained control group. Opportunities for young girls to participate in sport have increased in recent decades, however, fewer studies have evaluated $\dot{V}O_2max$ in young female athletes (Baxter-Jones, Goldstein, &

Helms, 1993; Brown, Harrower, & Deeter, 1972; Cunningham, 1989; Drinkwater & Horvath, 1971). Drinkwater & Horvath (1971) concluded that a group of 12 - 18 year old female track athletes had higher maximum oxygen uptake values than those already obtained from a general, nonselected population of American children. Although some investigations have evaluated the aerobic performance of female figure skaters (Delistraty, Reisman, & Snipes, 1992) and gymnasts (Obert et al., 1997), more research is needed pertaining to activities that most young females commonly perform.

The literature is inconsistent in revealing appropriate exercise training stimuli for use with children. It has been proposed by some that the use of adult training criteria for exercise intensity, duration and frequency (20 - 60 minutes, most days of the week at an exercise intensity of 60 - 90% maximum heart rate) should successfully increase $\dot{V}O_2max$ in children (Rowland, 1985; Vaccaro & Mahon, 1987). Others have reported increases in $\dot{V}O_2max$ when children were training at an exercise intensity of 75 - 85% maximum heart rate (Gaul, 1990; Mahon & Vaccaro, 1989; Massicotte & MacNab, 1974; McManus et al., 1997). The majority of these training studies consisted of distance running (Rowland, 1985), continuous cycling (Gaul, 1990), sprint training (McManus et al., 1997) and a combination of continuous and interval training (Mahon & Vaccaro, 1989).

In addition to influencing aerobic performance, it is generally accepted that regular physical activity also improves the other components of fitness including anaerobic performance, muscular strength, power and endurance, flexibility, agility and balance. The development and maintenance of these components are essential for the proper health, wellness and athletic performance of children and adults. Research has shown that anaerobic performance and muscular strength, power and endurance are trainable in both the prepubescent and pubescent child (Grodjinovsky et al., 1980; McManus et al., 1997; Sale, 1989). Little research is available pertaining to the trainability of flexibility, agility and balance in children.

Pediatric research of trained subjects often includes those involved in male oriented activities and sports, such as ice hockey and soccer (Cunningham et al., 1976; Docherty, Wenger, & Collis, 1987). Research investigating the demands and effects of physical activities in which young females commonly participate could do much to enhance the understanding of physiological adaptations in this population. Rope skipping, as an exercise, has been used in training programs for school children, sedentary adults, and athletes for a variety of reasons (Baker, 1969; Benedict, Vaccaro, & Hatfield, 1985; Kasch, 1976). Due to the combination of short bursts of jumping and continuous jumping, rope skipping could enhance the overall health and fitness of children by developing aerobic, anaerobic and muscular fitness, and balance. As a competitive sport, rope skipping is a full body activity that can be performed alone or in a group, indoor or outdoor, with inexpensive equipment, and minimal space. The majority of competitive skippers are young females, but this activity has gained the interest of young males with the implementation of recreational and competitive rope skipping clubs in schools. In fact, North America has seen an increase in the number of children involved with precision rope skipping in national and international competitions in the past decade (Adams, Parham, & Taylor, 1990; Lavay & Horvat, 1991). However, few published studies have evaluated the physiological characteristics of rope skipping in children.

In one of the first published studies to investigate the effects of rope skipping in adults, Jones, Squires and Rodahl (1962) found that rope skipping for five minutes daily over a period of four weeks significantly improved cardiovascular function. Later studies focused on the energy expenditure of rope skipping in adults (Jette, Mongeon, & Routhier, 1979; Quirk & Sinning, 1982; Town, Sol & Sinning, 1980), demonstrating the high anaerobic aspect of this activity. Quirk & Sinning (1982) found significant differences in oxygen uptake at different rope skipping rates, and concluded that rope skipping stresses both the aerobic and anaerobic systems of a normal adult. It is quite common to observe heart rate responses of 160 to 180 $b \cdot min^{-1}$ during rope skipping in adults and oxygen uptake values of 60% to 80% of $\dot{V}O_2max$ or higher (Stamford, 1986). Rope skipping training programs of four weeks or longer have resulted in improvements in VO_2max in sedentary women and men (Buyze et al., 1986; Jones et al., 1962). Research evaluating the muscular fitness, coordination and balance demands of rope skipping has not been conducted in adults.

The physiological effects of a rope skipping program have not been as well documented in children as in adults. In the only available skip-training study on children, Benedict et al. (1985) investigated the effects of an eight week precision jump rope program on percent body fat and maximal oxygen uptake in a small group of 9 - 11 year old males and females (n = 11). Significant increases in both height and weight were observed. Neither maximal oxygen consumption nor percent body fat values changed significantly as a result of the training program. The limited design of this study, with its short duration and lack of control to distinguish training-induced changes from those due to normal growth, is a possible reason for the non-significant changes observed in the eight week training period.

There are no available studies that have specifically examined the bioenergetic demands involved in performing rope skipping activities, or the possible effects of competitive rope skipping training on the fitness of participating children. This information would be beneficial for athletes, coaches, teachers and parents as they promote the proper health and fitness development of children involved in either recreational activity or elite sport. By investigating rope skipping exercises used in training and competition, valuable information could be obtained concerning the intensity of the exercises and the fitness of young competitive skippers. This knowledge would aid in developing optimum training programs for both competitive and recreational rope skippers. As well, rope skipping could be incorporated into training programs for young athletes involved in sports sharing similar metabolic demands. Rope skipping also requires timing, coordination, rhythm and perceptual-motor skills, all common elements of activities that are popular among young females of all fitness levels (Greendorfer, 1977). A study designed to determine if rope skipping elicits any physical fitness improvements could be used to learn more about the responsiveness of females to exercise, and increase the information available on fitness and the young female. Therefore, investigating this activity provides the opportunity to gain further insight into the physiological responses of a full body exercise in which both prepubescent and pubescent females are commonly involved.

Purpose

The purpose of this study was to compare measures of physical fitness in experienced, young female rope skippers with untrained controls matched by age and maturation. A secondary purpose was to compare measures of physical fitness in prepubescent and pubescent maturity groups. The final purpose was to evaluate the exercise intensity of a typical rope skipping training session.

Research Questions

1. Does regular participation in rope skipping training enhance the physical fitness of young females? Specifically,
   (a) Is there a difference in adiposity, expressed as the sum of five skinfolds, between the rope skippers and controls?
   (b) Is there a difference in predicted $\dot{V}O_2max$, obtained from the 20-meter shuttle run test, between the rope skippers and the controls?
   (c) Is there a difference in anaerobic capacity and power, measured with the Wingate Anaerobic Cycle Test (WAnT), between the rope skippers and the controls?
   (d) Is there a difference in muscular power of the muscles of the thigh, leg, and foot, as measured by vertical jump, between the rope skippers and the controls?
   (e) Is there a difference in muscular endurance, as measured by both a push up and curl up test, between the rope skippers and the controls?
   (f) Is there a difference in dynamic balance between the rope skippers and the controls?
   (g) Is there a difference in flexibility between the rope skippers and the controls?

2. Do maturity-related differences exist among the measured variables of anthropometry and fitness performance within the entire sample of girls?

3. At what intensity levels do rope skippers work during a typical rope skipping training session?

Delimitations

1. A relatively small number of subjects with a broad range of ages was used for this study.
2. Only female skippers participated so the results of this study cannot be generalized to males.
3. This study used an indirect field test method, the 20-meter shuttle run, to predict maximal aerobic power. This method is a reliable and valid measure of $\dot{V}O_2$max, and is more time-efficient and easier to administer than direct techniques.

Limitations

1. Subjects were not randomly selected. All were recruited from, and by, a local competitive skipping team.
2. The risk of accumulating Type I (α) error with the use of a two-way ANOVA was relatively high due to the several comparisons made among the several variables and the small number of subjects.

Assumptions

1. The maturity status forms were answered accurately and honestly.
2. Maximal effort was exerted by all subjects during all tests.
3. Untrained controls were not involved in any other type of fitness training. Trained skippers were not involved in fitness training other than rope skipping.

Operational definitions

Maximal aerobic power ($\dot{V}O_2max$): the highest or peak rate of oxygen uptake, distribution, and utilization by the body predicted from the last stage completed in the performance of a maximal 20-meter shuttle run; expressed in absolute terms ($L \cdot min^{-1}$) and relative to body weight ($mL \cdot kg^{-1} \cdot min^{-1}$)

Trained rope skippers: those who performed organized skipping training exercises and routines at least one hour, three days a week, for a minimum of nine months

Untrained controls: those who were inexperienced in rope skipping exercises, and not involved in any other type of organized fitness training

Methods

Subjects

Eleven apparently healthy, female trained rope skippers, aged 8 - 15 years, volunteered for this study. Eleven females, ages 8 - 15 years, were recruited as the age and maturation matched control group. Mean ages were 9.2 years (SD = 1.2) and 13.9 years (SD = 1.2) for the prepubescent (prepub; n = 12) and pubescent (pub; n = 10) groups, respectively. The control group subjects were untrained in rope skipping exercises. Seven of the control subjects reported participating only in various recreational sports throughout the year that did not involve organized fitness training, while the remaining 4 subjects were not involved in any physical activities. The subjects and their parents were informed of the purpose and procedures of this study (Appendix B), after which written consent was obtained from both the participants and parents (Appendix C). The group samples are shown in Table 1.

Research design

Using a cross-sectional research design, participants were tested during two visits, separated by 48 hours, to the UVic Sport and Fitness Center. At the start of each session, the participants were introduced to the research team and familiarized with the testing schedule, the testing equipment and procedures. On Day 1 of testing, anthropometric measurements and maturational status procedures were performed, followed by the balance test, push ups, curl ups, and the WAnT. Day 2 of testing consisted of the 20-meter shuttle run, flexibility tests, a second push ups test, vertical jump test, and, for a randomly selected few, a second balance test. The same order of tests was used for all of the participants. In addition, training heart rates of two rope skipping

Table 1

Participants separated by maturity and rope skipping training status

Training status	Maturity group		N
	Prepubescent	Pubescent	
Rope skipping	6	5	11
Control	6	5	11
Total	12	10	22

participants were monitored throughout a rope skipping training session at a local gymnasium within one week of Days 1 and 2 of testing.

Intraclass correlation coefficients were used to assess the reliability of the push up and balance tests. To determine inter-day reliability for the push up test among the young girls in this study, the push up performances of all 22 participants on Day 1 were correlated with their performances on Day 2. As well, the results of both balance test scores reported from all 22 subjects on Day 1 of testing were correlated to demonstrate an intra-day balance test-retest reliability coefficient among young females. To determine inter-day balance test reliability, the mean score of 8 subjects who were randomly chosen to perform the balance test again on Day 2 of testing was correlated with their best score from Day 1 of testing.

Measurement procedures

Maturity status. Maturity status was self-assessed by the subjects using drawings and written descriptions illustrating the five stages of development suggested by Tanner for female breasts and female pubic hair (Morris & Udry, 1980). Each participant was given private, individual verbal instruction on how to complete the two forms of illustrations (Appendix D) by a female member of the testing team. To ensure confidentiality, forms were labeled by subject number only. The girls privately marked the drawing on each form that corresponded to their stage of development, and the scores from both were totaled. Prepubescence was indicated by a combined score of four or less. A score of five or greater was considered pubescent. Correlation coefficients between self- assessment techniques by adolescents and physician observations have been reported at $r = 0.63$ and 0.81 for female breast and pubic hair distribution, respectively (Morris & Udry, 1980).

Anthropometry. Weight was measured in kilograms using a balanced scale, with subjects wearing light clothing and no shoes. Height was recorded in centimeters during maximal inspiration, with subjects wearing no shoes. Five skinfold sites (biceps, triceps, subscapular, iliac crest, and calf) were measured using Harpenden calipers (British Indicator Ltd.) according to the methods of the Canadian Physical Activity, Fitness, and Lifestyle Appraisal (Canadian Society for Exercise Physiology, 1996). The sum of five skinfolds was calculated for each subject to reflect adiposity.

Maximal aerobic power. $\dot{V}O_2max$ was predicted from maximal running speed in the 20-meter shuttle run test (Léger & Lambert, 1982). Subjects ran continuously back and forth between two lines spaced 20 meters apart on the gymnasium floor at a pace set by an audio signal from a prerecorded tape in a calibrated cassette player. The test consisted of 20 one minute stages, with speed increasing every stage as the test progressed. The goal of the test was to complete as many stages as possible without stopping. The test was terminated when the child could not continue, or was not within two stride lengths of the line, twice in a row, when the signal was heard. Relative $\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$; Rel$\dot{V}O_2max$) was predicted based on the maximal aerobic speed determined from the last stage completed, according to age and gender. A predicted absolute $\dot{V}O_2max$ ($L \cdot min^{-1}$, Ab$\dot{V}O_2max$) was determined for each participant by multiplying individual predicted Rel$\dot{V}O_2max$ by body weight and dividing by 1000. Heart rate was recorded for each participant every minute during the test using Polar heart rate monitors. The 20-meter shuttle run has been shown to be a valid predictor of maximal aerobic power in both adult and pediatric populations. A validity correlation of 0.76 has been reported between $\dot{V}O_2max$ values from a maximal treadmill test and the 20-meter shuttle run performed by boys and girls aged 12 - 14 years (van Mechelen, Hlobel, & Kemper, 1986). The test-retest reliability has been shown to be as high as 0.89 for boys and girls aged 6 - 16 years (Léger, Mercier, Gadoury, & Lambert, 1988).

Anaerobic power and capacity. Anaerobic capacity and power were measured using a modified 30-second WAnT on a Monark cycle ergometer (Bar-Or, 1996). The seat height and handlebars were adjusted appropriately for each participant. A warm-up of light cycling for 3 - 5 minutes was administered prior to the exercise test, interspersed with one 2- to 3-second all-out practice sprint with resistance. The test began from a rolling start, and after a countdown of "3-2-1" a flywheel resistance adjusted to 90 $g \cdot kg^{-1}$ body weight for each subject was applied and an electronic revolution counter was activated. The subjects were instructed to remain seated and pedal as fast as possible throughout the test. Verbal encouragement to sustain maximal pedal speed throughout the 30-sec exercise bout was offered. Using an electronic revolution counter, flywheel revolutions were calculated for each 1-sec segment of the 30-sec test. Anaerobic power was determined in absolute terms as the peak power output, expressed in Watts, during any one of the 1-sec intervals (Abs peak1sec) and also as the peak 5 second power output in any 5 second interval of the test (Abs peak5sec). Peak power output was also expressed relative to body weight (Watts $\cdot$ kg^{-1}) for both the 1 second interval (Rel peak1sec) and the 5 second interval (Rel peak5sec). Anaerobic capacity was defined in absolute terms (Abs total30) as the total work, expressed in joules, of the entire 30-sec exercise test and was also expressed relative to body weight (joules $\cdot$ kg^{-1}; Rel total30). Previous studies conducting the WAnT in pediatric populations have indicated that it is a reliable (test-retest correlations of 0.92 to 0.97) and valid (r = 0.75 with various anaerobic tasks) predictor of anaerobic capacity and power (Bar-Or, 1987; Grodjinovsky, Inbar, Dotan, & Bar-Or, 1980; Tharp, Johnson, & Thorland, 1984).

<u>Muscular power</u>. Explosive strength of the thigh, leg, and foot muscles was assessed through a static vertical jump test (Sargent, 1921). The subjects stood with their dominant side to a measuring tape affixed to the wall. The subjects stood with feet flat and together, and reached as

high as possible to record the initial reach. The subjects then dusted their fingers with chalk and stood about 15 cm from the wall. To perform the static vertical jump, the subjects started in a squat position with the knees bent at 90° and accelerated in the upward direction as high as possible with a two foot take-off. Only arm and leg movements were permitted during the upward acceleration to ensure the subjects did not swing the arms or step into the jump. The subjects touched the wall tape at the highest point of their jump with the dusted fingers. Subjects were allowed three practice trials prior to the recorded two testing trials. The difference between the highest and the initial mark was measured to the closest 0.5 cm. The highest jump of each subject (VJcm) was used for statistical analysis. To calculate power output from the vertical jump (VJpower), the following formula (Canadian Society for Exercise Physiology, 1996) was used:

$$\text{Power } (\text{kg} \cdot \text{m} \cdot \text{s}^{-1}) = 2.21 \text{ x body weight (kg) x } \sqrt{\text{distance jumped (m)}}.$$

$$\text{Power (Watts)} = \text{power } (\text{kg} \cdot \text{m} \cdot \text{s}^{-1}) \text{ x } 9.804$$

The vertical jump test-retest reliability after three to four practice attempts has been reported to be 0.92 among adults (Glencross, 1966). Validity of the test among 48 adolescent boys has been found to be 0.77 when compared with peak power scores from the WAnT (Bar-Or, 1996).

Muscular endurance. Partial-curl ups were performed to access muscular endurance according to the Prudential FITNESSGRAM protocol (Hastad & Lacy, 1998, pp.128 - 129). Each subject lay in a supine position with knees bent to approximately 140° and arms at full extension on the mat. The appropriate measuring strip was placed on the mat under each subject's knees so the tips of the fingers were touching the edge of the strip. The measuring strip was 30 in. x 4 ½ in. for 10 - 15 year olds, and 30 in. x 3 in. for 8 - 9 year olds (Safrit, 1995, pp. 50 -51). A metronome was set allowing each subject to complete 20 curl-ups per minute in a controlled, paced manner. The exercise involved starting in a posterior pelvic tilt, curling the torso upwards and sliding the fingers across the measuring strip until they touched the other side of the strip, and returning down until the head contacted the floor in a controlled manner. Each subject was encouraged to exhale as they curled up, and performed as many curl-ups as possible. The total number of correctly completed curl-ups was recorded as the score. Partial curl-ups have been found to be a valid measure of abdominal muscular endurance in pediatric populations through EMG data, and also a reliable measure ($r = 0.88$) in 43 school children (Dickinson, Bannister, Allen, & Chapman, 1984).

Untimed push-ups were also performed to assess upper body muscular endurance. The upper body was kept in a straight line without the abdomen or thighs contacting the mat. The subject was encouraged to exhale on the effort. The total number of complete push-ups performed rhythmically and continuously was recorded as the score. Reliability of this test among females is not present in the literature. Day 1 to Day 2 test-retest reliability in this study was found to be $r = 0.89$ ($p < 0.01$), suggesting this test to be reliable among the young girls in this study.

Balance. Dynamic balance is the ability to maintain total body equilibrium while moving from one point to another (Baumgartner & Jackson, 1991, p. 250). The Modified Bass Test of Dynamic Balance was used to assess the ability of each subject to accurately jump and maintain balance while moving (Bass, 1939; Johnson & Nelson, 1986, pp. 242 - 243). A pattern marked with tape in 10 places on a gymnasium floor was used for the test (Appendix E), with the subject starting with the right foot on the start mark. The subject jumped to the first tape mark landing on the left foot and attempted to balance on the ball of the foot for a maximum of 5 seconds. The subject then leapt to the second mark with the right foot and maintained balance for as many seconds as possible up to 5 seconds. This continued for the length of the floor pattern, alternating feet from mark to mark. The landing foot had to completely cover the marking tape. Each successful landing was awarded 5 points, and one point was given for each second the balance was held up to 5 seconds per mark, so a total of 10 points could be earned per mark. Several practice trials were allowed prior to the two recorded tests. When subjects were tested on separate days, this test was reported to be a reliable ($r = 0.75$) and somewhat valid ($r = 0.46$ when correlated with the Bass test of dynamic balance) measure of dynamic balance (Johnson & Nelson, 1986, pp. 242 - 243) among college-aged adults. An intraday test-retest reliability coefficient of 0.96 ($p < 0.01$), and an interday test-retest reliability of 0.86 ($p < 0.01$), were found for this balance test among the young females in this study.

Flexibility. Flexibility is the range of motion available within a joint or a number of joints. Unassisted active range of motion of the shoulder joint was measured using the modified Leighton flexometer technique (Hubley-Kozey, 1991; Leighton, 1942). The Leighton flexometer has a 360-degree dial with a weighted pointer. This is a direct method of measuring flexibility by obtaining measurements of separate motions instead of total ranges of motion. The flexometer was positioned over the proper standardized landmark for the specific site to be measured. To allow for measurement of separate motions, such as flexion and extension, the flexometer was positioned in a zero reference position between these opposing movements. At this reference position, the instrument was zeroed and the dial was locked in place. The subjects moved through the full range of motion in one direction, and when steady, the pointer was locked and the reading taken and recorded. The pointer was unlocked, and the subjects moved the joint through the full range of motion in the opposing direction. The pointer was then locked and the reading of the flexometer recorded. Total range of motion for the joint was calculated by totaling the two ranges in one plane. Reliability of the Leighton flexometer technique was found to be quite high (r = 0.901 - 0.996) for 10 - 18 year old males (Leighton, 1956).

Flexibility measures were taken immediately following the completion of the 20-meter shuttle run test, which was assumed to provide an adequate warm up. Shoulder flexion (flex) and extension (ext) were measured with the subject standing at a projected corner of a wall. With the arms at the side, the flexometer was strapped to the lateral side of the upper arm. The center of the instrument was on a line joining the lateral epicondyle of the humerus and the center of the glenohumeral joint. For shoulder flexion, the arm was moved forward and upward in an arc as far as possible, with the palm sliding along the wall. Shoulder extension was measured by moving the arm downward and backward in an arc. Extraneous body movement was prohibited during both measurements.

In addition, a sit-and-reach box test (Wells & Dillon, 1952) was administered to measure general body flexibility. The sit-and-reach box had a measuring scale in centimeters on top of the box. To perform the test, each participant sat on a mat with legs straight out in front and feet placed flat against the sit-and-reach box. With one hand on top of the other hand and palms down, the participants reached forward along the top of the box as far as possible and held for at least one second. The legs remained straight during the reach. Three trials were performed, with the best score used for statistical analysis. The validity of this test has been shown to be 0.60 to

0.73 when compared with hamstring flexor strength in girls (Jackson & Baker, 1986). The reliability of the test has been reported to be high, with coefficients of r = 0.80 - 0.96 for 11 - 14 year old girls, and r = 0.94 - 0.97 for 11 - 14 year old boys (Safrit & Wood, 1987).

Heart rate response. The intensity of rope skipping training was evaluated by monitoring the heart rate of two subjects throughout a typical rope skipping training session within one week of Days 1 and 2 of testing. Heart rates were measured and stored in a Polar heart rate monitor during an entire training session, and manually retrieved after the training session. These heart rate values were compared to the maximum heart rate obtained during the 20-meter shuttle run test in order to describe the training intensity of the rope skipping training session.

Statistical analysis

Statistical analysis was performed using SPSS version 9.0 statistical package (SPSS Inc., 1999). Descriptive statistics for all fitness component measures were used for all subject groupings. A two-way analysis of variance (ANOVA) was used to determine the significance of differences between rope skipping experience (trained, untrained) and maturity status (prepub, pub), and the interaction of these two independent variables on each of the dependent variables. In addition, test-retest reliability coefficients for the push ups test and balance test were obtained through the application of an intraclass correlation procedure. Statistical significance was set at $p < 0.05$.

Results

The results of a 2 x 2 ANOVA model for the variables examined in this study are presented in this section. No significant rope skipping experience by maturity status interaction was found for any measure of physical fitness. The groups encompassing the 22 participants within Tables 2 - 6 in this section are not mutually exclusive, but are arranged according to rope skipping training status and maturity status.

Anthropometric measurements

Table 2 presents the main effects based on the anthropometric measurements of the participants. Rope skippers and controls did not significantly differ in height, weight, or sum of five skinfolds. Pubescent girls were significantly taller ($F = 59.73$, $p < 0.01$, $\eta^2 = 0.77$) and heavier ($F = 39.79$, $p < 0.01$, $\eta^2 = 0.69$) than their prepubescent counterparts. No significant maturity main effect was found for sum of five skinfolds.

Maximal aerobic power

Aerobic performance values are presented in Table 3. No significant rope skipping training effect was found for either absolute or relative $\dot{V}O_2max$. A significant main effect between maturity levels was found for $\dot{V}O_2max$. $\dot{V}O_2max$ was greater for the pubescent girls ($F = 59.27$, $p < 0.01$, $\eta^2 = 0.54$) than the prepubescent girls when described as an absolute value ($L \cdot min^{-1}$). When these values were expressed relative to body weight ($mL \cdot kg^{-1} \cdot min^{-1}$), prepubescent girls had higher $\dot{V}O_2max$ values than pubescent girls ($F = 20.81$, $p < 0.01$, $\eta^2 = 0.70$).

Table 2

Mean (SD) anthropometric measures of the 22 subjects according to maturity and rope skipping training status

	According to maturity status		According to training status	
Measure	Prepubescent (n = 12)	Pubescent (n = 10)	Skippers (n = 11)	Control (n = 11)
Height (cm)	135.03 (7.08)	158.93 (6.62)**	146.18 (13.64)	145.61 (14.83)
Weight (kg)	34.6 (4.5)	52.5 (8.3)**	41.7 (10.1)	43.7 (12.5)
Sum of 5 skinfolds (mm)	63.5 (20.6)	62.9 (21.3)	59.4 (22.7)	67.1 (18.0)

** Significant difference between prepubescent and pubescent girls, $p < 0.01$.

Table 3

Mean (SD) maximal aerobic power measures of the 22 subjects according to maturity and rope skipping training status

Measure	According to maturity status		According to training status	
	Prepubescent (n = 12)	Pubescent (n = 10)	Skippers (n = 11)	Control (n = 11)
Ab$\dot{V}O_2$max ($L \cdot min^{-1}$)	1.67 (0.24)	2.27 (0.38) **	1.89 (0.34)	1.99 (0.52)
Rel$\dot{V}O_2$max ($mL \cdot kg^{-1} \cdot min^{-1}$)	48.21 (3.01)	43.52 (4.94) *	46.14 (5.39)	46.01 (3.85)

* Significant difference between prepubescent and pubescent girls, $p < 0.05$;
** Significant difference between prepubescent and pubescent girls, $p < 0.01$.

<u>Anaerobic performance measures and muscular power</u>

No significant main effects were found for rope skipping training for any peak power or total anaerobic work score (Table 4). A significant maturity difference was found for absolute values of peak power for 1 second ($F = 59.27$, $p < 0.01$, $\eta^2 = 0.77$) and peak power in 5 seconds ($F = 63.85$, $p < 0.01$, $\eta^2 = 0.78$), with the more mature girls having higher scores (Table 4). Even when these scores were corrected for body weight differences and expressed as relative values, these significant maturity-related differences existed for peak power for 1 second ($F = 14.57$, $p < 0.01$, $\eta^2 = 0.45$) and peak power in 5 seconds ($F = 8.24$, $p < 0.05$, $\eta^2 = 0.31$). Both absolute total anaerobic work values over the 30 second test ($F = 88.40$, $p < 0.01$, $\eta^2 = 0.83$) and total anaerobic work adjusted for body weight ($F = 5.78$, $p < 0.05$, $\eta^2 = 0.24$) were also significantly different between the prepubescent and pubescent groups, with the pubescent girls having the higher values (Table 4).

There was no significant difference in vertical jump performance between the rope skippers and control subjects (Table 4). There was a significant difference between the prepubescent and pubescent groups in vertical jump performance. For both the total jump height (cm) recorded ($F = 6.12$, $p < 0.05$, $\eta^2 = 0.25$) and power output ($F = 38.18$, $p < 0.01$, $\eta^2 = 0.68$) on the vertical jump, pubescent girls jumped higher and recorded greater power output values than prepubescent girls (Table 4).

Table 4

Mean (SD) anaerobic performance and muscular power measures of the 22 subjects according to maturity and rope skipping training status

Measure	According to maturity status		According to training status	
	Prepubescent (n = 12)	Pubescent (n = 10)	Skippers (n = 11)	Control (n = 11)
Abs peak1sec (Watts)	311.43 (57.02)	560.75 (87.52) **	422.22 (152.43)	427.29 (145.34)
Abs peak5sec (Watts)	267.73 (56.48)	472.47 (59.93) **	359.29 (131.60)	362.30 (110.83)
Abs total30 (Joules)	5932.50 (1267.80)	10244.27 (815.16) **	7750.01 (2834.99)	8034.77 (2103.58)
Rel peak1sec (Watts · kg^{-1})	8.97 (0.92)	10.74 (1.35) **	9.88 (1.87)	9.66 (0.88)
Rel peak5sec (Watts · kg^{-1})	7.70 (1.01)	9.12 (1.38) *	8.42 (1.68)	8.27 (1.05)
Rel total30 (Joules · kg^{-1})	171.79 (27.42)	198.44 (27.25) *	182.46 (38.34)	185.35 (20.21)
VJ (cm)	22.8 (5.1)	29.0 (6.6) *	26.7 (7.4)	24.5 (5.6)
VJ power (Watts)	356.13 (69.20)	580.30 (97.40) **	472.20 (162.62)	443.85 (119.71)

* Significant difference between prepubescent and pubescent girls, $p < 0.05$;
** Significant difference between prepubescent and pubescent girls, $p < 0.01$.

Balance and muscular endurance

Table 5 presents the performance measures of balance, push ups and curl ups. There was no significant rope skipping training main effect for balance. Balance test scores were significantly different between maturity groups ($F = 4.74$, $p < 0.05$, $\eta^2 = 0.21$), with pubescent girls scoring higher than prepubescent girls. No significant maturity or rope skipping training main effects were found for either the number of push ups performed or the number of curl ups performed.

Flexibility

Flexibility results are presented in Table 6. Only left shoulder extension values were found to be significantly different between maturity groups ($F = 8.55$, $p < 0.01$, $\eta^2 = 0.32$), with the pubescent girls recording a greater amount of flexibility than the prepubescent girls. There were no significant maturity or rope skipping training main effects found for all other measures of flexibility.

Table 5

Mean (SD) balance and muscular endurance measures of the 22 subjects according to maturity and rope skipping training status

	According to maturity status		According to training status	
Measure	Prepubescent (n = 12)	Pubescent (n = 10)	Skippers (n = 11)	Control (n = 11)
Balance (total marks)	79 (17)	92 (7) *	88 (14)	81 (15)
Push ups (total #)	5 (3)	6 (3)	6 (3)	5 (3)
Curl ups (total #)	25 (14)	36 (11)	31 (15)	28 (12)

* Significant difference between prepubescent and pubescent girls, $p < 0.05$.

Table 6

Mean (SD) flexibility of the 22 subjects according to maturity and rope skipping training status

	According to maturity status		According to training status	
Measure	Prepubescent (n = 12)	Pubescent (n = 10)	Skippers (n = 11)	Control (n = 11)
Left shoulder ext (°)	34 (5)	42 (7) **	37 (10)	37 (4)
Left shoulder flex (°)	139 (12)	141 (8)	141 (12)	138 (7)
Right shoulder ext (°)	32 (9)	38 (9)	33 (11)	35 (7)
Right shoulder flex (°)	151 (12)	154 (14)	150 (12)	153 (13)
Sit and reach (cm)	34.9 (5.8)	35.6 (8.6)	35.5 (6.7)	34.9 (7.7)

** Significant difference between prepubescent and pubescent girls, $p < 0.01$.

Heart rate response data

Figures 1 and 2 present the exercising heart rate responses of two trained rope skippers, Subject 1 (age 8 years, prepub) and Subject 2 (age 15 years, pub), which were recorded and stored every minute throughout a typical rope skipping training session. The raw data are provided in Appendix F.

Subject 1. While running the 20-meter shuttle run, subject 1 achieved a recorded maximum heart rate (MHR) of 215 b · min^{-1} and a predicted $\dot{V}O_2max$ of 47.48 ml · kg^{-1} · min^{-1}. Her mean heart rate during a 52 minute training session was 126 beats · min^{-1} (59% of MHR), with a range of 92 - 180 beats · min^{-1} (43% - 84% of MHR). The heart rate mode during the training session was 112 b · min^{-1} (52% of MHR).

Subject 2. Subject 2 obtained a $\dot{V}O2max$ of 40.50 ml · kg^{-1} · min^{-1} during the 20-meter shuttle run test and recorded a MHR of 192 b · min^{-1}. During a 68 minute training session, this rope skipper achieved a mean training heart rate of 144 b · min^{-1} (75% MHR), ranging from 93 to 238 b · min^{-1} (48% - 124% MHR). A heart rate of 148 beats · min^{-1} (77% MHR) was recorded as the mode during the session.

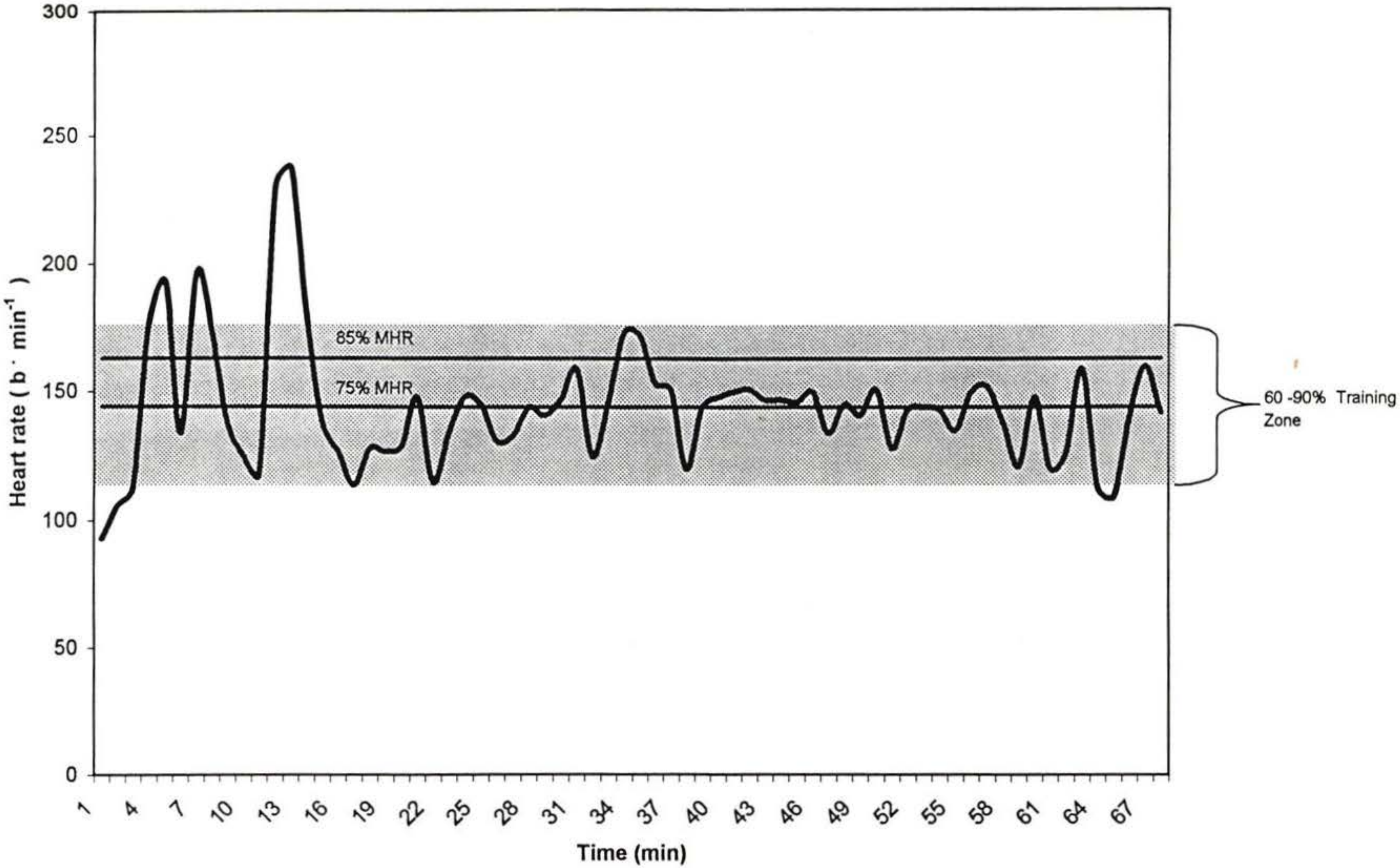

Figure 1. Heart rate response recorded throughout a 52 minute rope skipping training session for Subject 1 (Prepub; age 8 years) with corresponding heart rate training zones of 60% - 90% and 75 - 85% of maximum heart rate (215 b · min^{-1}).

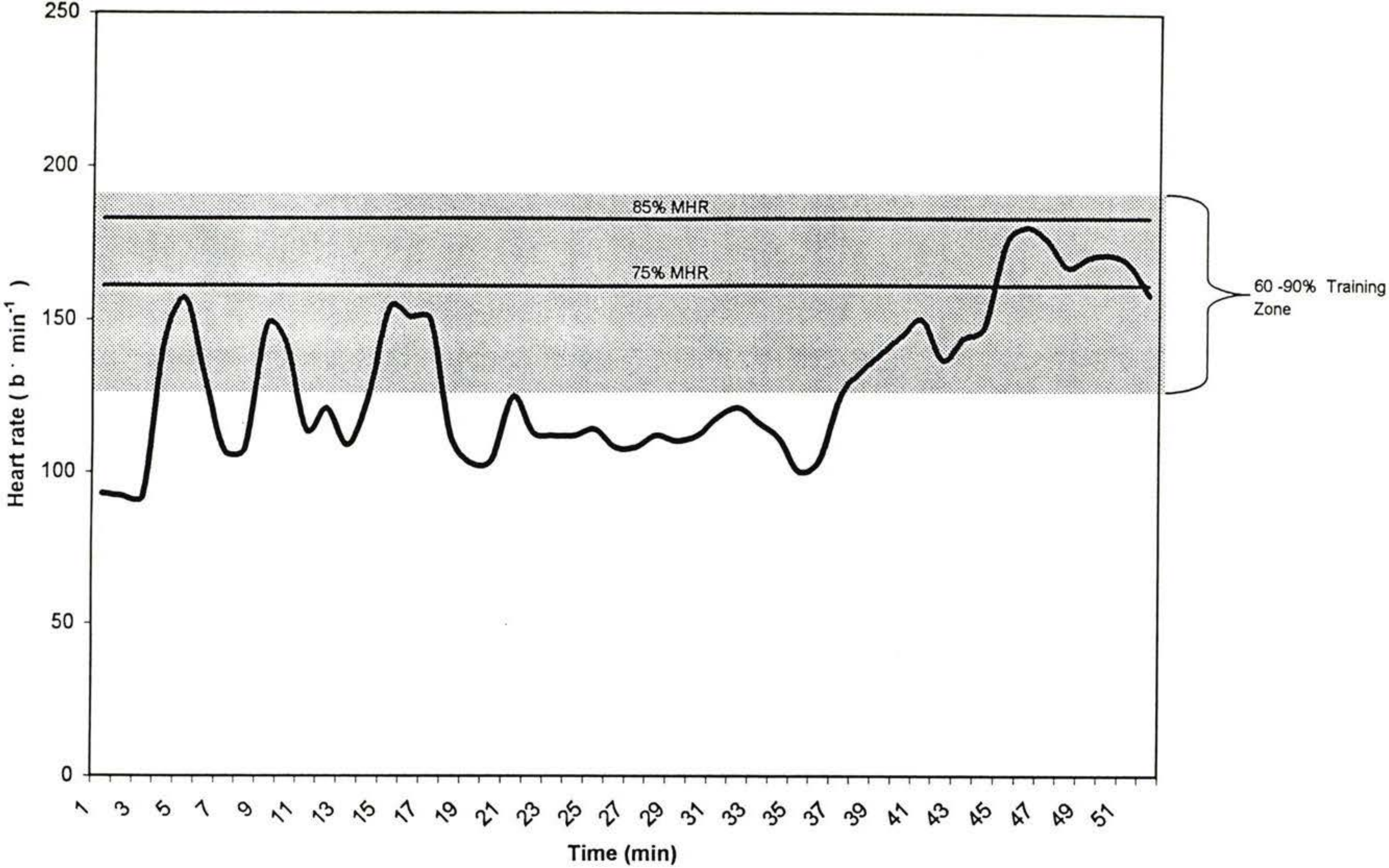

Figure 2. Heart rate response recorded throughout a 68 minute rope skipping training session for Subject 2 (Pub; age 15 years) with corresponding heart rate training zones of 60% - 90% and 75 - 85% of maximum heart rate (192 b · min^{-1}).

Discussion

The major objective of this study was to determine if involvement in regular rope skipping physical activity and training enhances the physical fitness of prepubescent and pubescent females. The range of biological ages and maturity levels of the participants in the present study justified separately examining the girls' fitness performance by maturity status and rope skipping experience using ANOVA. The major finding of this study was that no significant differences were found in any measures of physical fitness between the experienced rope skippers and the control group. It is possible that the low rope skipping training intensity, displayed in Figures 1 and 2, was not sufficient to elicit a physical fitness response, primarily an aerobic fitness response. It is also possible that the control participants were not sedentary.

It is a general assumption that children today are not involved in sufficient activity to sustain adequate levels of physical fitness as a result of sedentary lifestyles. However, Corbin and Pangrazi (1992) reported that children and youth actually do participate in adequate activity for healthful living. Although none of the control participants in this study reported a regular schedule of physical training, most enjoyed and were involved in various recreational sports and activities year round. It is difficult to find children who are not interested in physical activity to volunteer for physical fitness testing. Vaccaro and Mahon (1987) and others (Blair, Clark, Cureton, & Powell, 1989) suggested that research may often show a lack of significant differences between active prepubescent subjects and controls due to the high "innate" level of physical activity in the presumed inactive control subjects. This is a limitation in most cross-sectional fitness-related studies of children that include the performance of inexperienced subjects to control for the effects of growth.

The subjects in this study were not randomly selected. The rope skipping team based in Victoria consisted of only 11 team members who met the training criteria of this study (involvement in rope skipping training for at least 9 months). As well, each rope skipper was asked to bring a friend of the same age that was not actively training for a sport or activity to serve as a control subject. Most likely, the friends who were recruited shared a similar interest in physical activity and fitness, although they did not report being "very active."

Anthropometry

Rope skipping training and anthropometry. The entire group of rope skippers were of similar stature and weight as other Canadian girls of a similar age and maturity level (Crawford, 1996). Using the same established Canadian age group norms, the control subjects also fell within the median percentile in stature and weight as other girls of the same age and maturity level, and were of similar size as the rope skipping group (Table 2). A number of previous studies have reported a lack of difference between sport competitors and non-competitors in these two anthropometric variables (Andrew, Becklake, Guleria & Bates, 1972; Cunningham & Enyon, 1973; Magel & Anderson, 1969).

The mean sum of five skinfolds for both the prepubescent rope skippers and the prepubescent controls (ages 8 - 11 years) was greater than the established median normative rating for Canadian girls of the same ages (Martin & Ward, 1996). Pubescent rope skippers (ages 12 - 15 years) had a mean sum of five skinfolds that was similar to the median normative rating of Canadian girls of the same ages, while pubescent controls had higher values than the median Canadian norms (Martin & Ward, 1996). However, no difference was found in adiposity, reflected by the sum of five skinfolds, between the rope skippers and control group (Table 2). This finding was similar to the results of Benedict et al. (1985) who found no reduction in percent body fat, estimated with the underwater weighing technique, after eight weeks of rope skipping training in 9 - 11 year old boys and girls. Bloomsfield, Blanksby, Ackland, & Elliot (1985) reported similar measures of body fat, determined by the sum of three skinfold measures, among 7 - 12 year old prepubescent boy and girl swimmers, tennis players and non-competitors. As well, Clarke and Vaccaro (1979) reported no significant change in percent body fat after seven months of intense swimming training in a group of 9 - 11 year old children.

Although little research is available on training and lipid metabolism in children, it is possible that children and adults have similar metabolic responses of adipose tissue to training. In adults, Pollock (1973) stated that submaximal aerobic endurance training programs lasting for more than one hour were most favorable in decreasing body fat. Consequently, the physiological demands of the rope skipping training sessions in which the skippers in this study participated (Figures 1 and 2) may not have been of the appropriate duration or intensity to elicit a decrease in adiposity. Reductions in body fat are a result of caloric deficits wherein energy expenditure exceeds energy consumption. Therefore, the energy expenditure involved in rope skipping may not have been sufficient to elicit a difference in adiposity between the rope skippers and controls.

Maturational differences in anthropometry. Stature and weight were significantly different between the prepubescent and pubescent girls, with recorded values being similar to those reported for Canadian girls of the same age and maturational level (Crawford, 1996). The prepubescent mean sum of five skinfolds was higher than the median norm for Canadian girls of similar ages, while pubescent values fell closer to their corresponding median norm (Martin & Ward, 1996). The lack of a maturity level main effect for sum of skinfolds was most likely due to the large range of scores reported for both prepubescent and pubescent girls. This finding is supported by Gaul (1990) who reported a similar variability between girls of comparable maturity status.

Maximal aerobic power

Rope skipping training and $\dot{V}O_2$max. It is important to recognize that the present study was not a training study, but rather a cross-sectional descriptive study with the objective of comparing the physical fitness of "trained" rope skippers and "untrained" controls.

Rel$\dot{V}O_2$max for both the rope skippers and controls (Table 3) were comparable to the mean normative value of 45.91 mL · kg^{-1} · min^{-1} obtained from the 20-meter shuttle run results of Québec children of the same age (Léger, Lambert, Goulet, Rowan, & Dinelle, 1984; Léger, Mercier, Gadoury, & Lambert, 1988). Both prepubescent and pubescent rope skippers had lower Ab$\dot{V}O_2$max and Rel$\dot{V}O_2$max than trained female track athletes of similar age (Brown et al., 1972; Drinkwater & Horvath, 1971).

In the present study, there were no differences between rope skippers and control subjects in either Rel$\dot{V}O_2$max or Ab$\dot{V}O_2$max. This result is supported by the work of Benedict et al. (1985), who found no increase in Rel$\dot{V}O_2$max in 9 - 11 year old boys and girls after 8 weeks of rope skipping training (2 minute routines for a total of 15 minutes during two formal 1 hour sessions a week at 80% of maximum heart rate). Others also support little or no change in $\dot{V}O_2$max in prepubertal boys and girls following aerobic training (Table 7). Bar-Or and Zwiren (1973) and

Stewart and Gutin (1976) administered strenuous interval runs, 4 times a week over 9 and 8 weeks, respectively, with no significant increase in $\dot{V}O_2max$, while Schmücker and Hollman (1974) found no difference after 4 weeks of endurance training. The lack of aerobic improvement reported in these studies is probably due to inadequate levels of exercise intensity and the short duration of the training programs.

It has been proposed by some that the use of adult training criteria for exercise intensity, duration and frequency should successfully increase maximal aerobic power in children (Rowland, 1985; Vaccaro & Mahon, 1987). According to commonly cited adult training criteria used to elicit improvement in aerobic fitness, an exercise intensity of 60 - 90 % of maximum heart rate (MHR) should be maintained for 20 - 60 minutes for most days of the week (American College of Sports Medicine, 1995). When examining exercise training studies in prepubertal children that conformed to these adult standards, most have reported an increase in Rel$\dot{V}O_2max$ ranging from 7 - 26% as a result of training (Rowland, 1985). These studies consisted of endurance training programs of distance running (Krahenbuhl, Skinner, & Korht, 1985; Rowland,1985), continuous cycling for 30 minutes or more (Gaul, 1990; Massicotte & MacNab, 1974; McManus, Armstrong, & Williams, 1997), interval training with a work:rest ratio of 1:1 (Docherty, Wenger, & Collis, 1987), sprint training programs (McManus et al., 1997) and a combination of continuous and interval training (Ekblom, 1969; Mahon & Vaccaro, 1989). Although intensity was not reported in every study, it appears that subjects worked at 75 - 85% of MHR in most successful training programs. These results suggest that ACSM guidelines for adults may not be fully applicable to pediatric groups, and that training intensities need to be above 75% MHR in order to elicit improvements in $\dot{V}O_2max$ in children.

Heart rate response data for two rope skippers in the present study are shown in Figures 1 and 2. According to adult ACSM guidelines for exercise intensity (60 - 90% HRM), Subject 1 has a training heart rate range of 129 - 194 b · min^{-1} to improve her aerobic fitness. Figure 1 shows that this prepubertal subject was within the low end of this target heart rate zone, as indicated by the shaded area, but non-continuously for 22 minutes. She therefore appears to have not met the adult ACSM criteria for exercise intensity (60 - 90% MHR) or duration (at least 20 continuous minutes).

Adopting the exercise intensity range used in training studies of prepubescent children (75 - 85% MHR), the optimum exercise training intensity for Subject 1 would be 161 - 183 b · min^{-1}, as shown in the shaded area between the horizontal lines in Figure 1. Subject 1 would therefore need to be exercising in these ranges for at least 20 continuous minutes of aerobic work in order to elicit any increases in $\dot{V}O_2max$. Figure 1 shows that this criteria was not met, with Subject 1 attaining this heart rate range for 7 non-continuous minutes throughout the training session. Although this subject did not meet the adult ACSM fitness training criteria, she did meet the ACSM health promotion recommendations for children and adults by obtaining 20 - 30 minutes of daily exercise at least 3 days out of the week (ASCM, 1988).

Subject 2, at age 15 years, had a recorded MHR of 192 b · min^{-1}. The adult ACSM intensity criteria of 60 - 90% MHR yields an exercise heart rate range of 115 - 173 b · min^{-1}, as shown in the shaded area in Figure 2. This pubertal subject spent a total of 55 minutes at this intensity, recording 46 minutes of continuous exercise within this training zone. A training intensity of 75 - 85% MHR, as demonstrated in Figure 2 by the horizontal lines, would correspond to an exercise heart rate range of 144 - 163 b · min^{-1}. Subject 2 attained heart rates in this range for a total of 25 non-continuous minutes during the training session. Subject 2 did, therefore, meet the adult ACSM criteria for both intensity (60 - 90% heart rate maximum) and duration (at least 20 continuous minutes) required for increasing aerobic power. However, she did not meet the criteria of at least 20 minutes of continuous exercise at the 75 - 85% MHR intensity typical of pediatric studies. Although Subject 2 did not meet the pediatric fitness-related guidelines for an exercise intensity of 75 - 85% MHR, she did meet the child and adult ACSM health promotion recommendation of 30 minutes of moderate physical activity at least on 3 days of the week to maintain a healthy lifestyle.

Energy expended by physical activity during daily duties, leisure-time activities, and sleep is vital to maintain general health. Exercise is a component of physical activity, and is planned and organized with the goal of improving physical fitness. Physical fitness is a set of personal attributes related to the ability to perform physical activity (Nieman, 1995, pp. 29 - 31). ACSM health promotion guidelines suggest that general health in children and adults can be maintained through moderate physical activity without an emphasis on fitness training. For the development of optimal levels of overall physical, mental and social health and well-being in children and adults, ACSM recommends regular physical fitness training. Since the $\dot{V}O_2max$ values in this study were obtained by the use of a cross-sectional research design rather than a longitudinal study, it is not known whether rope skipping training did significantly improve aerobic fitness in these two subjects. As well, the heart rate responses and corresponding intensity levels of Subjects 1 and 2 may not represent the exercise responses and intensity of other team members. Caution is therefore also suggested in generalizing these results to other populations of young females involved in rope skipping.

Maturational differences in $\dot{V}O_2max$. A significant maturity-related effect was found for both Ab$\dot{V}O_2max$ and Rel$\dot{V}O_2max$ (Table 3) in this study. The higher mean Ab$\dot{V}O_2max$ found in pubescent girls as compared to prepubescent girls is supported by the majority of studies that have shown absolute peak oxygen uptake to increase with an increase in chronological age and growth in size in both girls and boys (Bailey & Mirwald, 1988; Bar-Or, 1983; Krahenbuhl et al., 1985; Rowland, 1990). The higher Ab$\dot{V}O_2max$ values seen in older children can be partially explained by the effect of growth on the oxygen transporting and utilizing organs (Krahenbuhl et al., 1985; Sunnegårdh & Bratteby, 1987).

The finding of a higher mean Rel$\dot{V}O_2max$ in prepubescent girls as compared to the pubescent girls is also consistent with the results of others who have shown the decline of Rel$\dot{V}O_2max$ in young girls after approximately 13 years of age (Armstrong & Welsman, 1994; Krahenbuhl et al., 1985). One suggested reason for this reported decline in $\dot{V}O_2max$ is the accumulation of metabolically inactive body fat tissue that occurs during puberty (Rowland, 1990; Sunnegårdh & Bratteby, 1987). An increase in total body mass occurs as a result of this accumulation, with a limited increase in metabolic activity. However, the pubescent females in the present study did not have greater adiposity, as measured by the sum of 5 skinfolds, than the prepubescent females. It is possible that the pubescent females were less active than the prepubescent girls, which may have resulted in a decline of Rel$\dot{V}O_2max$ (Sallis, 1995).

Anaerobic power and capacity

Rope skipping training and anaerobic performance. The 30-second WAnT is designed to measure the power produced during phosphagen breakdown and anaerobic glycolysis before the aerobic system becomes a significant factor in energy production (Tharp, Johnson, & Thorland, 1984). Much controversy exists in determining the optimal braking force for peak power, mean power and total work on a cycle ergometer in children. Previous studies report a range of loads adjusted from 45 to 90 $g \cdot kg^{-1}$ body weight (Gaul & Docherty, 1998; Grodjinovsky, Inbar, Dotan, & Bar-Or, 1980; Falgairette, Duche, Bedu, Fellmann, & Coudert, 1993; McManus et al., 1997; Tharp et al., 1984), with higher resistance settings producing higher peak and mean power performances (Carlson & Naughton, 1994). In this study, a braking force adjusted to 90 $g \cdot kg^{-1}$ body weight was chosen to elicit the highest peak power performance for each subject.

In comparing the performance of the prepubescent and pubescent rope skippers with that of prepubescent and pubescent female athletes (Gaul & Docherty, 1998), rope skippers had similar absolute and relative peak anaerobic power and 30 second total work values. The control prepubescent and pubescent subjects also reported power and total work outputs that were comparable to female athletes on all WAnT measures.

Table 4 shows that no significant differences were found in anaerobic performance between rope skippers and control subjects. A similar result was found between trained prepubertal male swimmers and non-active controls, with no differences in maximal anaerobic power (force-velocity test) or mean power (30-second WAnT) between the two groups (Falgairette et al., 1993). However, other studies have shown improvements in anaerobic power and capacity in both boys and girls following training (Grodjinovsky et al., 1980; McManus et al., 1997), and cross-sectional studies have shown greater anaerobic capacity in boys and girls involved in sport than nonathletes (Grodjinovsky & Bar-Or, 1984; Mayers & Gutin, 1979). It is probable that the specificity of training determines to a large degree the amount of improvement in anaerobic fitness and the manner in which it is assessed. In both the Grodjinovsky et al. (1980) and the McManus et al. (1997) training studies that showed improvement in anaerobic fitness following training, the mode of training was either high-intensity cycling or sprint training. It is possible that the WAnT was not specific enough to accurately measure anaerobic power and capacity in the athletic females assessed by Gaul and Docherty (1998). Furthermore, rope skipping training may have elicited improvements in the anaerobic fitness of participants, but the high anaerobic fitness levels of the control group may have reduced any possible differences between them.

Maturational differences in anaerobic performance. Both the mean absolute and relative anaerobic peak power and total work outputs were significantly lower in the prepubescent girls when compared to the pubescent girls (Table 4). These results are supported by both cross-sectional data (Bar-Or, 1983, pp.311-314) and longitudinal data (Falk & Bar-Or, 1993) that demonstrate increases in absolute and relative anaerobic power and capacity, measured by the WAnT, from prepubescence to pubescence in girls and boys. It is speculated by several that muscle glycogen concentration, muscle phosphofructokinase and the rate of glycogen utilization increases with maturation (Berg, Kim, & Keul, 1986; Eriksson, Gollnick, & Saltin, 1973; Inbar & Bar-Or, 1986). This may explain the lower anaerobic fitness performance of children when compared to more mature subjects. It has also been hypothesized that muscle strength may be involved in the maturity-related improvement in anaerobic power and capacity, as anaerobic power measured by the WAnT may be related to increases in leg strength and muscle strength with maturation (Sale, 1989). More mature subjects also have more efficient neuromuscular control than children (Sale, 1989), which would give adults an advantage over less mature subjects for better performance on the WAnT. Further research into this area must be developed in order to enhance our understanding of anaerobic metabolism in both prepubescent and pubescent males and females.

Muscular power

Rope skipping training and muscular power. Muscular power of the rope skippers, as measured by the vertical jump, was less than previously reported for female gymnasts and swimmers (Haywood, Clark, & Mayhew, 1986) and figure skaters (Delistraty, Reisman, & Snipes, 1992) of similar ages. The lack of significant muscular power differences between rope skippers and control subjects in both height jumped and predicted power relative to body mass (Table 4) is in contrast to studies which have demonstrated differences in vertical jump power between child athletes and non-competitors (Bloomfield et al., 1984; Haywood et al., 1986). Strength and muscular explosiveness have been shown to reflect neuromuscular characteristics in children (Suei, McGillis, Calvert, & Bar-Or, 1998). Perhaps the use of a depth jump test using counter- movements, rather than the vertical jump test, would have elicited a plyometric stimulus and a significant difference in power between groups, as a plyometric-type jump may have more thoroughly evaluated the stretch-shortening cycle that occurs in an activity such as jumping (Komi, 1984). Conversely, it is possible that the force production involved with rope skipping was not of sufficient intensity to increase the strength of the leg extensor muscles, as strength training and sprint running have shown to do in prepubescent boys (Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990). Again, it is also possible that control subject scores were not reflective of a sedentary or untrained population.

Maturational differences in muscular power. As reported with anaerobic power and capacity measured by the WAnT, a significant difference was seen between maturity groups in performance on the vertical jump. Both the height jumped and the predicted muscular power output were higher in the pubescent girls as compared to the prepubescent girls. Similar to that suggested for the maturational difference in WAnT performance, these results may be related to increases in leg strength and muscle strength observed with maturation (Sale, 1989). It could also be that the vertical jump requires a degree of coordination and neuromuscular control not yet achieved by many of the prepubescent girls.

Muscular endurance

Rope skipping training and muscular endurance. Endurance of the abdominal and upper body muscles, as measured by partial curl ups and full push ups, was not significantly different between the rope skippers and control subjects (Table 5). Mean scores for partial curl ups for both rope skipping and control prepubescent groups were within the health-related criterion-referenced standards developed by the Prudential FITNESSGRAM fitness test protocol (Institute for Aerobics Research, 1992). Pubescent rope skippers and control group results were above the criterion-referenced standards for their age group, indicating superior abdominal muscular endurance in comparison to their peers. These results again give evidence to support the possibility that control subject scores do not represent a general, sedentary population.

Physical fitness test batteries that include a push up test to evaluate upper body muscle endurance in children do not offer an unmodified push up test for females. This is most likely based on an assumption that females are unable to complete one push up with extended legs.

Procedures and normative, or criterion, standards are only available for the modified push up test wherein the knees are placed on the floor, resulting in less resistance when pushing the body upwards. Consequently, no direct comparisons can be made with other studies in push up performance. An important finding of this section of the present study was that all of the girls were able to complete at least one push up. The high test-retest reliability (r = 0.89) for push up performance found among the young girls in this study was not inflated due to several "zero" scores, as has been reported in previous research with the pull up test among females (Safrit, 1990). This finding indicates that a full-body push up procedure is appropriate for similar, young female populations.

Maturational differences in muscular endurance. There were no maturity-related differences in measures of local muscular endurance, as measured by push ups and curl ups. In comparing the mean number of curl ups completed in this study, the prepubescent and pubescent girls were at the high end of the criterion-referenced standards and above the standards, respectively. This is an important finding as it suggests that all of the girls had sufficient abdominal muscular endurance for health-related implications, such as preventing future low-back pain.

Balance

Rope skipping training and balance performance. Dynamic balance is an important aspect of gymnastics and dance (Bass, 1939), and is assumed to be a fundamental component of fitness and competitive rope skipping. Female rhythmic gymnasts aged 9 to 15 years performed better than nonathletes in age-matched control groups on dynamic balance (Kioumourtzoglou, Derri, Mertzanidou, & Tzetzis, 1997), while improvements in static balance were attributed to karate training in 8 to 13 year old boys (Violan, Small, Zetaruk, & Micheli, 1997). However, in the present study no difference was observed in dynamic balance between the rope skipping trained and control groups (Table 5). There are no available norms for girls aged 8 - 15 years for the Modified Bass test of Dynamic Balance used in this study, restricting a comparison with the general population. The test-retest reliability was found to be quite high for this test among the young girls in this study (r = 0.86 - 0.96). However, it is possible that differences in body size may have influenced performance on this test. The balance test floor pattern was not changed for each subject to account for differences in height. Shorter girls may have had to compensate for a smaller stride length by first jumping to a floor mark and then maintaining balance, while taller girls might only have had to step to each mark in the pattern. This would give taller subjects an advantage over short-limbed peers.

Maturational differences in balance performance. The significant difference reported between prepubescent and pubescent groups in dynamic balance is supported by Assaiante and Amblard (1992) who found peripheral visual influence on locomotor equilibrium control increased from age 8 years into adulthood. Due to this increase, Assaiante and Amblard (1992) concluded that dynamic balance control improved with age during childhood. Again, it is also possible that differences in leg length between the younger and older girls could have influenced performance on the Modified Bass Test of Dynamic Balance, resulting in lower performance scores in the less mature, shorter girls.

Flexibility

Rope skipping training and flexibility. Both the rope skippers and controls in this study had lower shoulder flexion and extension values than those reported for Canadian boys and girls (Docherty & Bell, 1985) and swimmers, tennis players and non-competitors (Bloomfield et al., 1985) of similar ages. Sit and reach scores for both the rope skippers and control groups were comparable to scores for Canadian girls of the same ages (Stephens, 1983). No differences were found between the rope skippers and controls in any measure of flexibility (Table 6). These findings were similar to other studies that compared control group boys and girls up to 13 years of age with those involved in swimming and tennis (Bloomfield et al., 1985) and karate training (Violan et al., 1997).

For adults, the American College of Sports Medicine (1995) recommends a flexibility program, involving 3 - 5 repetitions of several static stretches that are held 10 - 30 seconds, be followed at least 3 days a week. The rope skipping training that the study participants performed included approximately 10 minutes of static stretching exercises before and frequently after each session. It is possible that the flexibility training was not of sufficient length or intensity to elicit a training response. As well, flexibility measured by the Leighton flexometer in this study was joint specific and cannot be regarded as reflecting the participants' general flexibility (Hupperich & Sigerseth, 1950). Therefore, it is also possible that the two tests chosen for this study did not accurately measure the joints that might respond to rope skipping training. Lastly, the lack of difference in flexibility supports the earlier contention that the control subjects may have been physically active, and should not be considered sedentary.

Maturational differences in flexibility. Previous research has shown that shoulder flexibility measured by the Leighton flexometer remains relatively constant throughout Grades 7, 8 and 9 in girls (Burley, Dobell, & Farrell, 1961). Conversely, other research has demonstrated a significant decline in shoulder flexibility measured by the Leighton flexometer from age 6 to 18 years in females (Docherty & Bell, 1985; Hupperich & Sigerseth, 1950). In the present study, prepubescent and pubescent groups differed significantly only on left shoulder extension (Table 6), with pubescent girls being the more flexible. No explanation can be offered to clarify the lack of bilateral symmetry in both left and right shoulder extension other than the possibility that the high range of scores reported for right shoulder extension led to the non-significant maturity-related effect on this measure.

Docherty and Bell (1985) demonstrated that sit and reach test scores significantly increased from age 6 to 15 years in females. This is in contrast to the lack of difference seen in sit and reach test scores between maturity groups in the present study. It is important to note that the populations of females in the present study and Docherty and Bell (1985) may have been different, as Docherty and Bell (1985) did not compare a specifically active, or trained group, with sedentary control subjects. Again, this non-significant finding may be attributed to the large range and variation of scores within prepubescent and pubescent groups.

Implications and future considerations

Although no differences were reported between rope skippers and control subjects in fitness performance on a number of tests, there are a few important implications that can be taken from the results of this study and should be addressed. From a health standpoint, it is encouraging that both groups exhibited normal to higher fitness levels when compared to normative and criterion standards. Although involvement in competitive rope skipping may not elicit superior physical fitness levels, young competitive rope skippers may receive other benefits of participation such as team membership, competition, travel, health benefits from physical activity and general enjoyment of the sport. It is also important to reflect upon the rationale for participation in rope skipping in adults and children. Unlike adults who most likely use rope skipping as a mode of exercise training to improve and maintain cardiovascular health, children probably rope skip because it is a fun and social activity that they enjoy. To promote the development of an active lifestyle, an enjoyable physical activity such as rope skipping should therefore be encouraged among children.

The results of this study suggest the following future considerations for pediatric research:

1. The young female population has been largely ignored in pediatric exercise physiology literature. Therefore, more research needs to be conducted which utilizes trained, active and sedentary prepubescent and pubescent females.

2. The demands and possible effects of competitive rope skipping should be evaluated further by the incorporation of a longitudinal training study. In this way, greater control of the training sessions, in terms of intensity, duration and frequency, could be achieved to properly assess any improvements in the various components of physical fitness.

3. A limitation of this study was the small sample size of the rope skippers and control participants. This, in addition to the numerous health- and fitness-related variables measured in this study, led to an increased risk of accumulating α error. Future research on the demands and possible effects of rope skipping in children should employ a large number of both rope skipping participants and control subjects.

4. More longitudinal research implementing training programs to monitor the physiological responses of children to exercise training would help to evaluate the concurrent effects of maturation.

5. Finally, future research needs to be conducted using different exercise and sport training programs which adhere to defined and quantified training stimuli. This may aid in the development of prepubescent and pubescent exercise training criteria that will elicit improvements in the various components of physical fitness. Only adequately designed research with appropriate methodology will further our knowledge of the trainability of all fitness components in the realm of children's sport and overall wellness.

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Appendix A

Review of the Literature

Physical activity, fitness training and rope skipping in children

Introduction

The increasing number of children participating in recreational and organized sport, as well as other physical activities, has encouraged the growth of research in pediatric exercise physiology. Still, details pertaining to the physiological demands and effects of exercise during the pediatric years remain relatively inconsistent among different ages, maturity groups and genders. Most studies that have examined the effects of exercise and physical activity during childhood have involved male subjects, with fewer investigations focused on exercise responses in young females. Although opportunities for girls to participate in sport and exercise have increased in recent decades, fitness levels and physical activity participation are reported to be declining in adolescent females (Sallis, 1995; Sunnegårdh & Bratteby, 1987). Childhood physical activity and exercise behaviors may influence exercise habits in adulthood, as recently shown by Trudeau, Laurencelle, Tremblay, Rajic, and Shepard (1999) in women. Risk factors involved in the development of coronary heart disease in adulthood, such as inadequate physical activity, obesity, high blood pressure and elevated blood lipids, have been shown to originate during childhood (Vaccaro & Mahon, 1989). Decreased physical activity in females during adolescence could therefore have a serious impact on adult health. Research has shown that a properly prescribed exercise program may decrease the risk of coronary heart disease in adults (Blair, 1994). It is unclear whether exercise has the same possible effects in children (Vaccaro & Mahon, 1989), yet physical activity and exercise habits should be developed during childhood to encourage healthful lifestyle behaviors in adulthood. Therefore, more research is needed to understand the physiological responses to physical activity and exercise, and its future implications in children.

The effects of physical activity on the health and physical fitness of children

Do the daily physical activity (PA) levels of children significantly influence their health and physical fitness? One problem associated with investigating this issue is the difficulty in measuring PA. Diaries and questionnaires about daily PA may not be recorded with great accuracy among children, especially below the age of 10 - 12 years (Rowlands, Eston, & Ingledew, 1997). Sallo and Viru (1996) demonstrated that parental PA reports of children aged 4 - 10 years may also not be reliable, but a teacher's rating seems to be sufficient in determining PA patterns of prepubescent children. Heart rate has been used as a good indicator of metabolic expenditure and activity levels in children (Armstrong, Williams, Balding, Gentle, & Kirby, 1991; Gilliam, Freedson, Geenan, & Shahraray, 1981;). However, heart rate also reflects stress levels, temperature, training level, and type of activity (Rowlands et al., 1997), which could lead to difficulty in measuring how much activity was actually involved. Gilliam et al. (1981) reported that 6 - 7 year old boys and girls in the United States had heart rates above 160 $b \cdot min^{-1}$ for 21 minutes a day and 9 minutes a day, respectively, over intermittent time periods. These results suggest that children tend to perform several short burst activities throughout the day, rather than sustained exercise activity. The use of an accelerometer is a more recent measuring technique, but also suffers from limitations. Acceleration of the limbs and body during PA, which increases energy expenditure, is measured by the accelerometer. However, activities such as walking, climbing stairs, cycling and rowing require energy expenditures that are not fully reflected in the acceleration or deceleration of the mass of the body (Ainsworth, Montoye, & Leon, 1994; Rowlands et al., 1997), so activity energy expenditure may be incorrectly estimated.

Some studies have reported that physical fitness in the prepubertal years is mainly affected by maturation and growth in body size, with the effect of PA being negligible (Ekblom, 1969; Weber, Kartodihardjo, & Klissouras, 1976). No significant relationship was found between PA ratings determined by both a questionnaire (Sallo & Viru, 1996) and heart rate monitoring (Armstrong et al., 1991) and cardiovascular fitness, reflected by peak oxygen uptake, in some studies of prepubescent and pubescent girls and boys. Sallo and Viru (1996) found that prepubescent children participating in training groups of various sports or in dancing classes for 20 minutes, 2 - 3 times a week did not have higher peak oxygen uptake values than children with less PA. In contrast, others have found that habitual physical activity, determined by a questionnaire, in prepubescent and pubescent boys and girls is related to peak oxygen uptake (Mirwald, Bailey, Cameron & Rasmussen, 1981; Sunnegårdh & Bratteby, 1987).

PA in the general adolescent population can lead to a small reduction in body fat and a small increase in fat free mass (Sallis, 1995). The minimum amount of physical activity necessary for both non-obese and obese adolescents was not determined, but a combination of caloric restrictions and almost daily PA, similar to guidelines for decreasing body fat in adults (Pollock, 1973), are most likely needed for significant reductions in adiposity in adolescents (Sallis, 1995). Gutin, Cucuzzo, Islam, Smith, and Stachura (1996) have shown body fat reductions in obese prepubertal girls after aerobic training 5 days a week, for 30 minutes at 70% maximum heart rate. Studies have shown a negative relationship between body fatness and peak $\dot{V}O_2$ (Armstrong et al., 1991; Raudsepp & Jürimäe, 1996). Raudsepp & Jürimäe (1996) also found that the sum of five skinfolds (SS) and body mass (BM) of prepubertal females significantly correlated negatively ($r = -0.40$ to -0.78) with the fitness indices of endurance shuttle run, bent arm hang and balance, as well as a moderate-to-vigorous PA score from a parental questionnaire. PA, BM and fatness are, therefore, significantly and negatively correlated with some physical fitness measures. This suggests that prepubertal females who participate in moderate-to-vigorous PA have an apparently higher level of fitness and a reduced body fatness as compared with less active children. Further investigations need to be performed to determine the exact relationship between PA and health and fitness in children.

Rope skipping research

Research investigating the demands and effects of activities in which young females commonly participate could do much to enhance the understanding of physiological adaptations in this population. Rope skipping is an activity with high female participation, and as an exercise it has been used in training programs for school children, sedentary adults, and athletes for a variety of reasons (Baker, 1969; Benedict, Vaccaro, & Hatfield, 1985; Kasch, 1976). As a competitive sport, rope skipping is a full body activity that can be performed alone or in a group, indoor or outdoor, with inexpensive equipment, and minimal space. The majority of competitive skippers are young females, but this activity has gained the interest of young males with the implementation of recreational and competitive rope skipping clubs in schools. In fact, North America has seen an increase in the number of children involved with precision rope skipping in national and international competitions in the past decade (Adams, Parham, & Taylor, 1990; Lavay & Horvat, 1991). However, few published studies have evaluated the physiological characteristics of rope skipping in children.

Competitive rope skipping appears to be physiologically demanding. Competitive events would seem to require high levels of speed, explosive power, and muscular strength and endurance to complete a routine. At a competition, it is not unusual for an athlete to perform up to 14 events in one day. This requires the ability to recover fully within and between events for optimal performance, and demonstrates the importance of highly developed aerobic and anaerobic fitness. In addition, the levels of coordination, balance, agility and flexibility required to perform the actions of turning a rope, jumping simultaneously and executing several gymnastic moves suggests a need for optimal fitness and skill levels if athletes wish to contend in this sport. It appears that rope skipping performance relies on a number of fitness components: aerobic and anaerobic fitness, explosive power, muscular strength and endurance, balance and coordination and flexibility. The following review of the literature will explore the expected physiological demands and effects of rope skipping in children.

Adult studies

In one of the first published studies to investigate the effects of rope skipping in adults, Jones, Squires, and Rodahl (1962) found that rope skipping for five minutes daily over a period of four weeks significantly improved predicted maximal aerobic power in women. Later studies focused on the energy expenditure of rope skipping in adults (Jette, Mongeon, & Routhier, 1979; Quirk & Sinning, 1982; Town, Sol, & Sinning, 1980), demonstrating the high anaerobic aspect of this activity. Quirk & Sinning (1982) found significant differences in peak oxygen uptake at different rope skipping rates, and concluded that rope skipping stresses both the aerobic and anaerobic systems of a normal adult. It is quite common to observe heart rate responses of 160 to 180 b · min^{-1} during rope skipping in adults and oxygen uptake values of 60% to 80% of maximal aerobic power or higher (Stamford, 1986). It is therefore not surprising that rope skipping training programs of four weeks or longer have resulted in improvements in maximal aerobic power in sedentary women and men (Buyze et al., 1986; Jones et al., 1962).

Pediatric studies

The physiological effects of a rope skipping program have not been as well documented in children as in adults. In the only available skip-training study on children, Benedict et al. (1985) investigated the effects of an eight week precision jump rope program on percent body fat and maximal oxygen uptake in a small group (n = 11) of 9 - 11 year old males and females. Over the eight week period, all subjects trained by completing a variety of precise two-minute jumping routines for one hour, two days a week. During the one hour session the cumulative skipping time of the subjects was 15 minutes, with no consistent work:rest ratio, at a mean heart rate of 80% maximum heart rate. The subjects also practiced the jumps informally at home three other days per week, for five to twelve minutes each session. Body composition and maximal aerobic power were measured before and after training. After the eight week period, significant increases in both height and weight occurred. These increases were expected and attributed to normal growth typical of this age group. Neither maximal oxygen consumption nor percent body fat values changed significantly as a result of the training program. The limited design of this study, with its short duration and lack of control to distinguish training-induced changes from those due to normal growth, makes the results observed in the eight week period difficult to interpret. There are no available studies that have specifically examined the bioenergetic demands involved in performing rope skipping activities, or the effects of competitive rope skipping training, on the fitness of participating children. A complete review of the available literature on the physiological responses of children to exercise is necessary to understand what physiological demands and effects might occur during rope skipping in children.

Aerobic fitness

Rope skipping has been found to require adequate aerobic fitness in adults (Quirk & Sinning, 1982). A strong aerobic system permits low intensity work to be performed for longer durations (Fox, Bowers, & Foss, 1993, p. 36). In adults, aerobic training may decrease the amount of lactic acid produced during exercise which lessens fatigue and may increase the capacity of the ATP-CP system (Fox, Bowers, & Foss, 1993, p. 350). If aerobic training has similar effects in children, a well-developed aerobic system would enhance the performance of competitive rope skipping routines by decreasing lactic acid accumulation and therefore delaying the onset of fatigue.

Maximal aerobic power ($\dot{V}O_2max$) is generally accepted as the best available measure of the performance of the aerobic system in children and adults. It represents the maximal rate of oxygen that can be consumed by the body per time unit (Bar-Or, 1983, p. 3). In adults, a valid VO_2max is considered attained once objective and subjective criteria are achieved during maximal exercise testing. Objective indices include a respiratory exchange ratio above 1.15 (Issekutz, Birdlhead, & Rodahl, 1962), blood lactate levels higher than 8 $mmol \cdot L^{-1}$ (Astrand & Rodahl, 1986, p. 301), a leveling of heart rate and attaining a plateau in $\dot{V}O_2$ with increasing workloads during exhaustive exercise.

Problems exist when utilizing these criteria for determining $\dot{V}O_2max$ during maximal exercise testing in children. Children are reported to achieve lower blood lactate levels than adults during maximal exercise (Astrand, 1952, Pfitzinger & Freedson, 1997), which would limit their ability to achieve a blood lactate level of 8 mmol · L^{-1}. Furthermore, the determination of blood lactate levels requires the use of invasive techniques, so ethical considerations limit its use in children. Some children do not attain a plateau in VO_2 during exercise to true exhaustion (Armstrong, Welsman, & Kirby, 1998; Astrand, 1952) which may reflect a lack of effort, inappropriate definitions for what constitutes a plateau (Krahenbuhl, Skinner, & Korht, 1985) or an inability to generate sufficient energy anaerobically to enable them to continue exercising beyond the limits of aerobic metabolism (Welsman & Armstrong, 1996). Therefore, in children, "maximal" oxygen uptake is often reported as "peak" oxygen uptake (peak $\dot{V}O_2$), defined as the highest VO_2 achieved during an exercise test to exhaustion instead of maximal $\dot{V}O_2$ representative of a plateau. A leveling off of heart rate prior to the final exercise intensity at a value at least 95% of the age-predicted heart rate maximum, an increase in $\dot{V}O_2$ of no more than 2.0 mL · kg^{-1} · min^{-1} for a 5 - 10% increase in exercise intensity, a respiratory exchange ratio of at least 1.0, post-exercise blood lactate levels of 6 - 7 mmol · L^{-1} and the subjective criteria of visual signs of exhaustion have all been reported to be useful criteria to indicate that a child has demonstrated maximal effort (Armstrong, Kirby, McManus, & Welsman, 1995; Krahenbuhl et al., 1985; Welsman & Armstrong, 1996).

Effects of growth on aerobic power in children

The majority of studies examining oxygen uptake in children suggest that absolute peak oxygen consumption increases with an increase in chronological age and growth in both boys and girls (Bailey & Mirwald, 1988; Bar-Or, 1983, p. 3; Krahenbuhl et al., 1985; Rowland, 1990). In a review of 66 cross-sectional and longitudinal studies, Krahenbuhl et al. (1985) demonstrated an increase in mean values for $\dot{V}O_2max$ from approximately 1.0 L · min^{-1} at age six to 2.0 and 2.8 L · min^{-1} by age 15 in girls and boys, respectively. This review also reported that untrained male and female children have similar absolute $\dot{V}O_2max$ values until approximately age 12 years, with a rate of rise of about 200 mL · min^{-1} per year. By age 14 years, the difference in absolute $\dot{V}O_2max$ between untrained males and females is 25%, increasing to greater than 50% by 16 years of age. From these findings, it has been concluded that mean absolute values for $\dot{V}O_2max$ plateau in adolescent girls, but continue to rise in boys during adolescence. The higher absolute $\dot{V}O_2max$ values seen in older children can be partially explained by the effect of growth on the organs related to oxygen transport and utilization (Krahenbuhl et al., 1985; Sunnegårdh & Bratteby, 1987).

When expressed per kilogram body mass, $\dot{V}O_2max$ has been shown to remain unchanged in untrained boys 6 - 16 years of age, with mean values of 50 - 53 mL · kg^{-1} · min^{-1} (Bar-Or, 1983; Krahenbuhl et al., 1985). In contrast, a progressive decrease with age in relative $\dot{V}O_2max$ has been reported in untrained girls, with a mean value of 52 mL · kg^{-1} · min^{-1} at age 6 declining to 40.5 mL · kg^{-1} · min^{-1} at age 16 (Krahenbuhl et al., 1985). It is important to note that caution is necessary in interpretation of these results, as this information was cross-sectional. This decline in $\dot{V}O_2max$ has been attributed by some to the accumulation of metabolically inactive body fat tissue that occurs during puberty in females (Sunnegårdh & Bratteby, 1987; Rowland, 1990). Conversely, males have increases in metabolically active muscle tissue during puberty. It is also possible that adolescent females are less physically active than prepubescent girls, which would lead to an increase in adiposity and a subsequent decrease in Rel$\dot{V}O_2max$ (Armstrong et al., 1991; Rowland, 1990).

Aerobic training response

To assess the ability of children to respond physiologically to aerobic training, most studies measure $\dot{V}O_2max$ before and after a period of regular sport or exercise training (Bar-Or & Zwiren, 1973; Brown, Harrower, & Deeter, 1972; Docherty, Wenger, & Collis, 1987; Drinkwater & Horvath, 1971; Gaul, 1990; McManus, Armstrong, & Williams, 1997). Training studies have used a variety of designs and exercise programs, including interval and continuous running and cycling programs, to improve aerobic power. It is difficult to make inter-study comparisons due to the variability among the types of training programs, differences in mode, intensity, frequency and duration of the exercise, and the variability among the modes of measuring aerobic power. Many studies have been limited by small sample sizes, lack of untrained controls subjects and poor documentation of exercise intensity (Bar-Or, 1989; Krahenbuhl et al., 1985; Rowland, 1985; Vaccaro & Mahon, 1987). Furthermore, the concurrent effects of growth and maturation may conceal training effects or be larger than the effects elicited by training, so it is important to have an understanding of the influences of growth on the aerobic fitness of children before interpreting changes due to physical training.

Training response during prepubescence. The trainability of the prepubescent child has met much controversy in the literature. Some cross-sectional studies that compare prepubertal children participating in sport to an untrained control group have demonstrated a lack of difference in aerobic fitness between groups (Hamilton & Andrew, 1976), while others have shown higher $\dot{V}O_2max$ values in those involved in sport training (Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990; Obert et al., 1997). Table 7 displays the results of some pediatric studies in which there

Table 7

<u>Studies demonstrating slight or no increase in maximal aerobic power following training</u>

Reference	N	Age	Sex	Training or activity status	Duration	Program	Frequency (#/week) & Intensity	$\dot{V}O_2max$ Δ $mL \cdot kg^{-1} \cdot min^{-1}$
Daniels & Oldridge (1971)	14	10 - 15	M	active	22 mon	Long distance runs	not reported	None
Bar-Or & Zwiren (1973)	22 24	9 - 10 9 - 10	M F	untrained untrained	9 wks	Interval runs 145m	2 - 4 x 40min; 145m with 1-1.5 min walks	None in M; Slight ↑ in F
Stewart & Gutin (1976)	13	10 - 12	M	untrained	8 wks	Interval runs	4 x 22min @ 90% MHR	None *
Schmücker & Hollmann (1974)	13	6 - 7	M & F	untrained	4 wks	Cycle training	not reported	None *
Benedict et al. (1985)	11	9 - 11	M & F	untrained	8 wks	Rope skipping; not continuous	2 x 60min @ 80% MHR	None

* Comparison with a control group

was little or no significant improvement following a regular program of aerobic training. Bar-Or (1989) suggests two possible reasons for this apparent low responsiveness to training: (1) children have high habitual daily activity levels when not taking part in a training program that may optimize their pretraining $\dot{V}O_2max$, so a training program adds little to their fitness, and (2) $\dot{V}O_2max$ may not be a valid or sensitive indicator of aerobic fitness in children. The notion that prepubescent children will have little change in $\dot{V}O_2max$ due to their inherently high levels of physical activity has been supported by others (Krahenbuhl et al., 1985; Vaccaro & Mahon, 1987). It is also possible that changes in aerobic fitness may be a result of modulating effects of pubertal hormones such as the androgens, aldosterone, growth hormone and insulin, and this relationship has been described by the "trigger hypothesis" (Katch, 1983; Rowland, 1997). Prepubescent children lacking the influence of such hormones will therefore have limited VO_2max changes as a result of training, as the trigger, being puberty, has yet to release. However, this possible inability to increase $\dot{V}O_2max$ during prepubescence does not mean that physical performance cannot improve. Some studies reported a significant improvement in running performance without a significant increase in $\dot{V}O_2max$ (Daniels & Oldridge, 1971; Bar-Or & Zwiren, 1973). This could be due to an improvement in motor coordination and running technique (Daniels & Oldridge, 1971). Lastly, it is possible that "untrained" controls used in these studies had high levels of habitual activity that led to improved $\dot{V}O_2max$ performance values above those expected in truly sedentary individuals. Therefore, even though they may not have followed the same aerobic training program, the differences between $\dot{V}O_2max$ values of the trained subjects and untrained controls were minimal.

It has been proposed by some that the use of adult training program criteria for exercise intensity, duration and frequency should successfully increase maximal aerobic power in children (Rowland, 1985; Vaccaro & Mahon, 1987). According to the American College of Sports Medicine (1995), in order to elicit improvement in the aerobic fitness of adults, exercise intensity should be set at 60 - 90 % of maximal heart rate and be maintained for 20 - 60 minutes for most days of the week. When examining exercise training studies in prepubertal children that have conformed to the accepted adult training program standards for improving $\dot{V}O_2max$, most have reported an increase in Rel$\dot{V}O_2max$ ranging from 7 - 26% as a result of aerobic training (Rowland, 1985). Table 8 presents a sample of studies which reported an increase in $\dot{V}O_2max$ following aerobic training in prepubescent children. These studies consisted of endurance training programs of distance running (Rowland, 1985; Krahenbuhl et al., 1985), continuous cycling for 30 minutes or more (Massicotte & MacNab, 1974; Gaul, 1990; McManus et al., 1997), interval training with a work:rest ratio of 1:1 (Docherty, Wenger & Collis, 1987), sprint training programs (McManus et al., 1997) and a combination of continuous and interval training (Ekblom, 1969; Mahon & Vaccaro, 1989) Although intensity was not reported in every study, it appears subjects were working at 75 - 85% of maximal heart rate in most training programs.

Training response during pubescence. Increases in $\dot{V}O_2max$ have also been reported in pubescent females (Gaul, 1990) and pubescent and post-pubescent males following training (Eriksson & Koch, 1973; Kobayashi et al., 1978; Mahon & Vaccaro, 1989). As mentioned previously, the pubertal trigger hypothesis may explain the apparent trainability of pubescent males and females (Katch, 1983). Some studies have suggested that the pubescent child may be

Table 8

Some studies demonstrating significant increases in maximal aerobic power following adult criteria for training

Reference	N	Age or Maturity Status	Sex	Training or activity involvement	Duration	Program	Frequency (#/week) & Intensity	$\dot{V}O_2max$ Δ $mL \cdot kg^{-1} \cdot min^{-1}$
Brown et al. (1972)	12	8 - 13	F	track athletes	6 wks 12 wks	Running	4-5 x 60-120min, varied intensities > 60% VO_2max	18% ↑ 26% ↑
Eriksson & Koch (1973)	9	11 - 13	M	untrained	16 wks	Running, x-country ski, gymnastics	3 x 60min often @ > 85 - 90% VO_2max	16 ↑
Massicotte & MacNab (1974)	9	11 -13	M	untrained	6 wks	Continuous cycling	3 x 12min @ 170 - 180 bpm	11 % ↑
Mahon & Vaccaro (1989)	8	10 - 14	M	untrained	8 wks	Continuous & Interval runs	2 x 10-30min @ 70-80% VO_2max 2 x 100-800m @ 90-100% VO_2max	7.5% ↑
Gaul (1990)	12 21	prepub pub	F F	untrained untrained	12 wks	Continuous cycling	3 x 30min @ 65-70% VO_2max	8.6% ↑ * 7.9% ↑ *
McManus et al. (1997)	30	prepub	F	untrained	8 wks	Cycle training or Sprint training	3 x 20min @ 80-85% MHR 3 x (1:3)	10% ↑ 8.4% ↑

* Corrected for growth-related changes

especially susceptible to training effects during and after the peak height velocity (PHV) age in boys (Kobayashi et al., 1978; Mirwald et al., 1981). However, others state that the notion of gaining greater training effects by exercise training during PHV-age or some other critical age is still speculative (Vaccaro & Mahon, 1987; Weber, Kartodihardjo, & Klissouras, 1976). More longitudinal research is necessary to distinguish between training induced and growth and maturation-related changes in aerobic power in children.

Intensity of exercise

The use of the target heart rate zone of 60 - 90% maximum heart rate (MHR) as an indication of training intensity has been recommended in both adults (American College of Sports Medicine, 1995) and children to increase VO_2max (Rowland, 1985). Rowland (1996, p. 35) suggests that maximal exercising heart rate is unchanged with age at least until the late teen years, with MHR ranging from 185 - 238 $b \cdot min^{-1}$ in healthy children (Cumming, 1993). If childhood MHR is age-independent, the adult age-predicted MHR formula, MHR = 220 - age, may be inappropriate for use with children (Rowland, 1996, p. 127; Wilmore & Sigerseth, 1967). It may therefore be necessary to use measured MHR, or peak heart rate, attained during maximal exercise testing when prescribing an optimum training target heart rate zone for exercising in children.

Rowland (1992) suggested that heart rate at anaerobic threshold may be a more suitable target training intensity to improve aerobic power in children. Anaerobic threshold (AT) is termed as either the $\dot{V}O_2$ value, or % $\dot{V}O_2max$, at which anaerobic metabolism increases as oxygen uptake increases, due to the inability of the aerobic system to meet the demands of the task (Bar-Or, 1983). AT has been reported to occur at a higher relative intensity of exercise in children than in adults, and therefore tends to decrease, as a % of $\dot{V}O_2max$, with increasing age (Mocellin, Heusgen, & Korsten-Reck, 1990; Weymans, Reybrouck, Stijns, & Knops, 1985). To adequately stress and improve oxygen delivery, a training intensity that approaches AT (without exceeding it) may be appropriate. The average heart rate at AT in children has been reported to be 165 - 177 $b \cdot min^{-1}$, which is about 85% MHR (Mahon and Vaccaro, 1991; Rowland, 1992). In light of this evidence, it can be suggested that studies reporting minimal or no improvement in $\dot{V}O_2max$ after aerobic training in children may have used an inappropriate exercise intensity, frequency and/or duration (Rowland, 1992). Furthermore, it is possible that the type of test methodologies used in these studies were not appropriate to detect improvements in $\dot{V}O_2max$. Although adult training intensity recommendations may be applied to children, there are no available guidelines for prescribing exercise training for increasing aerobic power in either prepubescent or pubescent children. Clearly, more research is needed to clarify appropriate exercise training intensity in children.

Testing of aerobic power

Direct measurement. Direct measurement of $\dot{V}O_2max$ requires elaborate laboratory testing which utilizes expensive equipment, expertise, and much time. For these reasons, laboratory methods are generally not feasible for testing large populations of children, particularly in the school setting.

The two most common modes of assessing $\dot{V}O_2max$ in the laboratory are cycle ergometry and treadmill running. Cycling engages a smaller muscle mass than treadmill exercise, which may result in local muscular fatigue and pain terminating the test before true maximal values of

$\dot{V}O_2max$ are attained. Treadmill running utilizes a greater muscle mass than cycling, usually results in higher VO_2max values than cycling and reflects central mechanism limitations (Armstrong & Welsman, 1994; Krahenbuhl et al., 1985). In general, reliability of treadmill test results (r = 0.97) are similar to cycle test reliability (r = 0.95) in both children and adults. Therfore, either mode can be used with reasonable accuracy in children (Boileau, Heyward, & Massey, 1977).

Indirect measurement. Field tests involve indirect methods of predicting $\dot{V}O_2max$. These tests assume a linear relationship between heart rate, workload and $\dot{V}O_2$. Field tests are usually easier than laboratory tests to administer to large populations and the equipment required is minimal and inexpensive.

The multistage 20-meter shuttle run is a commonly used test to estimate $\dot{V}O_2max$ in children (Léger & Lambert, 1982; van Mechelen, Hlobil, & Kemper, 1986). The test involves running a 20-meter course with a progressive increase in speed every minute until maximal exertion. $\dot{V}O_2max$ is predicted based on the maximal aerobic speed determined from the last stage completed (Léger & Lambert, 1982). Unlike other running field tests, such as 12 minute runs and 2000 meter runs, this test is not as dependent on pacing. van Mechelen et al. (1986) reported a validity correlation of 0.76 between the number of shuttle run stages completed and $\dot{V}O_2max$ determined by treadmill running for 82 boys and girls aged 12 - 14 years. Test-retest reliability has been shown to be as high as 0.89 for 139 boys and girls aged 6 - 16 years (Léger et al., 1988). These validity and reliability values suggest a good prediction of $\dot{V}O_2max$ can be made using the multistage 20-meter shuttle run.

Anaerobic fitness

Rope skippers derive energy from all three energy systems: aerobic, anaerobic alactic and anaerobic lactic. These three energy systems contribute to an athlete's performance in different ways. Rope skipping requires a large amount of power. The explosive movement of jumping, repetitive jumping and the various short burst gymnastic movements used throughout routines would most likely rely on anaerobic alactic fuel sources. Speed skipping routines, lasting 1 - 2 minutes, would most likely rely on both anaerobic alactic and lactic fuel sources.

Influence of growth and maturation on anaerobic fitness

The literature suggests that anaerobic power and capacity are lower in children compared to adolescents and adults (Bar-Or, 1983, p. 9; Inbar & Bar-Or, 1986; Mercier, Mercier, Granier, LeGallais, & Préfaut, 1992). Cross-sectional studies using a Wingate Anaerobic Cycle Test (WAnT) have demonstrated progressive increases in both peak anaerobic power and mean anaerobic power, reported in absolute terms and relative to body mass, from 8 - 14 years of age (Bar-Or, 1983, pp. 311 - 314). Similar findings have been reported with increasing maturity status in both males and females (Armstrong, Welsman, & Kirby, 1997). In one of the few longitudinal studies involving circumpubertal boys (Falk and Bar-Or, 1993), peak and mean anaerobic power expressed relative to body mass, measured by WAnT, also increased progressively across the age groups. As the WAnT may be related to leg strength, these age-related differences in anaerobic performance may be attributed to muscle strength increases with maturation (Sale, 1989). Differences in the biochemical characteristics of children's and adult's skeletal muscle may be related to the age- and maturation-dependent differences in anaerobic performance.

Alactic anaerobic system. Energy is supplied by the splitting of ATP and creatine phosphate (CP) stores in skeletal muscle using alactic anaerobic metabolism, also referred to as the phosphagen system. There is a limited amount of research on alactic energy production in children due to the ethical constraints of performing needle muscle biopsy techniques, typically used in adults, on normal, healthy young subjects. Eriksson & Saltin (1974), in one of a series of muscle investigations on young boys, reported quadriceps femoris ATP concentrations at rest to be the same across four groups of males aged 11 - 16 years, and similar to adult values. CP concentrations at rest were also found to be primarily the same, with a slight tendency to increase with increasing age. The resting CP values were also found to be comparable to adult values (Karlsson, 1971). During exercise, ATP concentration remained essentially unchanged, except at maximal exercise where a minor reduction was seen. This finding was supported by Eriksson, Karlsson, & Saltin (1971) in pubertal boys, and is similar to that seen in adults (Eriksson & Saltin, 1974). CP concentration gradually declined with increasing exercise in boys (Eriksson et al., 1971; Eriksson & Saltin, 1974), which is comparable to adult men (Karlsson, 1971). Therefore, it has been suggested that the alactic anaerobic capacity of young males is comparable to that in adults (Eriksson & Saltin, 1974; Inbar & Bar-Or, 1986).

Lactic anaerobic system. Energy can also be produced by glycolysis in the lactic anaerobic system. Glycolysis involves the splitting of glycogen or glucose to pyruvate. In the absence of oxygen, pyruvate is converted to lactic acid in the muscle. This by-product of anaerobic glycolysis, lactic acid, has been shown to be related to muscle fatigue in adults (Lehninger, Nelson, & Cox, 1993, p. 417). Glycogen concentration, measured from a quadriceps femoris muscle biopsy in 11 - 16 year old males, was reported to increase with increasing age (Eriksson & Saltin, 1974). The mean value found in the oldest boys was comparable to adult levels. A gradual decrease in glycogen, indicating the occurrence of glycolysis, was reported with exercise, with the youngest boys using less glycogen than the older boys. Although the authors cautioned against any generalizations of the results due to the small sample sizes and the use of peripubertal boys, this lower glycogen utilization could be attributed to the reduced concentration and activity of the rate limiting enzyme in glycolysis, phosphofructokinase (PFK), noted as "less than 50% of that usually observed in adults," (Eriksson, Gollnick, & Saltin, 1973). Peak muscle and blood lactate concentrations during and post exercise have been found by some to be lower in children than in adults (Eriksson et al., 1971; Eriksson & Saltin, 1974; Pfitzinger & Freedson, 1997; Pianosi, Seargeant, & Hayworth, 1995), which could reflect a reduced glycolytic enzyme activity in children. These findings suggest that the lactic anaerobic system is age- and maturity-dependent. However, Cumming, Hastman, McCort, and McCullough (1980) have reported high post-exercise serum lactates in children, and suggested that studies reporting low serum lactate levels may not have had the children performing anaerobic work close to exhaustion. There are several methodological problems associated with obtaining lactate samples in children that could explain these equivocal results. Lactate levels can be influenced by the site of blood/muscle sampling, the test protocol or lactate cut-off levels, timing of sampling, method of assay and mode of exercise testing (Armstrong & Welsman, 1994).

Several authors have postulated why children may have an apparently lower glycolytic capacity than adults. It is possible that lower blood lactic acid concentrations, assumed to reflect lower lactic acid production at the muscle level, during exercise in children may be due to a deficiency in lactic acid production from a lower glycogen concentration and lower rate of utilization (Inbar & Bar-Or, 1986). However, blood measures are not reflective of lactic acid production, so it is possible that production may be the same in children and adults. Another theory proposes that children have lower sympathetic activity during exercise (Zwiren, 1989), which could increase lactate removal by the liver due to reduced vasoconstriction to the liver. It is also possible that there is a decreased need for lactic acid production because of a faster mobilization of aerobic metabolism at the onset of work in boys (Eriksson et al., 1971). Using the activity of succinate dehydrogenase (SDH) as a marker of aerobic enzyme function and PFK activity as a marker of anaerobic enzyme function, Eriksson (1972) found SDH activity to be higher in 11 - 13 year old boys than untrained men, while PFK activity was substantially lower. Haralambie (1982) reported glycolytic enzyme activity to be similar in 13 - 15 year old males and females and adults. They suggested that adolescents may have a glycolytic capacity comparable to adults, but that they may oxidize pyruvate at a rate higher than adults. Berg, Kim, & Keul (1986) reported increases in anaerobic enzyme activity and concomitant decreases in aerobic enzyme activities with increasing age in a cross-sectional study of males and females. However, Bell, MacDougall, Billeter, & Howald (1980) reported relative volume densities of mitochondria in skeletal muscle of six year old children to be comparable to adults, suggesting no difference in oxidative characteristics of the muscle.

It is possible that maturation plays a key role in the development of glycolytic capacity. A slightly greater capacity for oxidative metabolism was reported in an investigation of prepubertal rat castration (Dux, Dux, & Guba, 1982) wherein the weight of glycolytic fibers decreased and the weight of oxidative fibers increased in the absence of androgens due to castration. If extended to humans, it is possible that oxidative metabolism is more established in the prepubertal years when lower levels of androgens are present. These results support the relationship between maturation and the production of glycolytic enzymes in skeletal muscle of young males (Eriksson et al., 1971) and the relationship between blood lactate production, serum testosterone level and muscle type II fiber area in prepubescent boys (Mero, 1988). More research is needed in the area of anaerobic metabolism in the pediatric years, as the research to date has resulted in equivocal results.

Anaerobic training response during prepubescence and pubescence

Cross-sectional studies have shown that physically active prepubescent males do not have significantly different peak or mean anaerobic power outputs than untrained controls (Falgairette, Duche, Bedu, Fellman, & Coudert, 1993; Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990). Docherty et al. (1987) demonstrated a lack of anaerobic trainability in young boys, with a 4 week interval training program. However, other studies have shown increases in anaerobic performance in prepubescent children following longer duration training programs (Eriksson et al., 1973; Grodjinovsky, Inbar, Dotan, & Bar-Or, 1980; McManus et al., 1997). A six week training program of high-intensity interval cycling or sprint training in prepubescent boys elicited small but significant improvements in mean anaerobic power, relative to an untrained control group, while the cycle trained group also increased peak anaerobic power (Grodjinovsky et al., 1980). These findings could be indicative of specificity of training since anaerobic performance was measured by the WAnT. In one of the few available studies on prepubertal girls, McManus et al. (1997) demonstrated significant increases in peak (5 seconds) anaerobic power after 8 weeks of training (3 times a week of either continuous cycling for 20 minutes at 80 - 85% maximal heart rate or sprint running with a work:rest ratio of 1:3), but no increase in mean power over the 30 second test. No significant changes were seen in the corresponding control group on either measure. Although it appears that prepubertal boys and girls may respond to anaerobic training, it is possible that apparent anaerobic training responses could be related to motor control adaptations to the exercise or testing mode rather than metabolic changes, or to a lack of specific anaerobic training.

Less research has been done involving pubescent subjects and anaerobic trainability. Gaul (1990) found no improvements in anaerobic capacity in pubescent females, measured by the WAnT, after a 12 week aerobic training program of continuous cycling at 75% of heart rate maximum for 3 days a week. More research is necessary to understand the possible changes involved in anaerobic metabolism in both prepubescent and pubescent males and females, particularly following specific anaerobic training programs

The Wingate Anaerobic Cycle test (WAnT)

In children, anaerobic performance is most commonly measured by the 30 second WAnT (Bar-Or, 1983; Grodjinovsky et al., 1980; McManus et al., 1997; Tharp, Johnson, & Thorland, 1984), although other field tests can be utilized (40-50 yard dash, 30 - 40 meter sprint). The WAnT is a direct assessment of anaerobic-dependent exercise performance using a cycle ergometer. Peak anaerobic power is often measured as the highest work output achieved during any time interval in the 30 second test, a value indicative of the explosive characteristics of a muscle contraction. Anaerobic capacity is typically recorded as the mean power, or total work, generated during the entire 30 second test. It is important that the correct modifications are made to the cycle, such as properly adjusted seat and handlebar height and pedal crank length, when this test is used with children. If pedal crank length is not suitable for a child's leg length, changes in muscle tension, torque and muscle energetics could potentially influence power output (Rowland, 1996, p. 40). Previous studies assessing the efficiency of the WAnT in pediatric populations have indicated that it is a reliable (test-retest correlations of 0.92 to 0.97) and valid ($r = 0.75$ with various anaerobic tasks) predictor of anaerobic capacity and power (Bar-Or, 1987; Grodjinovsky et al., 1980; Tharp et al., 1984).

Other fitness components related to rope skipping

Adult research of rope skipping has demonstrated that rope skipping involves high levels of both aerobic and anaerobic fitness. No studies have investigated the influence of various other fitness components in the performance of either recreational or competitive rope skipping in adults or children. Regular rope skipping may enhance all components of fitness beyond aerobic and anaerobic contributions, and these components could play a key role in the success of competitive rope skippers. Therefore, a brief review of the available pediatric literature dealing with relevant measures of physical fitness other than aerobic and anaerobic components is necessary.

Muscular strength, endurance and power

The maintenance or improvement of the components of strength, endurance and power is important for the activities involved in daily living as well as for success in athletics, for both children and adults. Adequate muscular strength and endurance will allow rope skippers to maintain their own body weight efficiently while jumping and performing various gymnastic moves. Strong legs will also give the base necessary to improve leg power and explosiveness. Explosive power is important for the plyometric activity of jumping at different intensities and heights throughout a routine. As explosive power is related to speed, high levels of explosive power will elicit quick reactions during routines requiring smooth and fast movement transitions or speed skipping. The development of muscular strength and endurance will help protect the joints, soft tissue and lower back muscles from injury due to the constant pounding of the body during jumping.

Skeletal muscle response to training

In investigating skeletal muscle in children, Bell et al. (1980) found 59% of the muscle fibers were slow twitch-oxidative (ST), 20% were fast twitch-glycolytic (FT-G) and 21% were fast twitch-oxidative (FT-O). Eriksson (1972) found 12 - 15 year old boys to have 60% ST fibers and 40% FT fibers. These ST fiber percentages are higher than a typical sedentary adult who have about 35 - 45% ST fibers, but are similar to trained adult endurance athletes (Eriksson, 1972).

Numerous studies have shown that both prepubescent and pubescent children can increase strength and power through training (Blimkie, 1993; Blimkie & Bar-Or, 1996; Sale, 1989), although the optimal resistance training intensity for the prepubescent child has yet to be determined. Prepubescent children have been reported to be less trainable than pubescent children and adults when absolute strength gains are considered, but comparable (or even more trainable) when strength is reflected by relative, percentage improvement (Blimkie & Bar-Or, 1996). Muscular hypertrophy does not seem to occur in prepubescent children, possibly due to the lack of circulating androgens (Sale, 1989). Therefore, training-induced gains in muscular strength are largely attributed to intrinsic contractile muscle characteristics and neural changes in prepubescent children (Blimkie & Bar-Or, 1996;Sale, 1989). Neural changes may result in a greater number of motor units activated simultaneously, a higher frequency of firing of motor units, and/or reduced inhibitory signals on motor neurons from the central nervous system. Therefore, both muscular strength and power can be said to reflect neuromuscular characteristics (Suei, McGillis, Calvert, & Bar-Or, 1998). Strength gains during puberty have been attributed to both muscle hypertrophy and neural changes in both males and females, with males achieving greater gains in hypertrophy than females into adulthood (Blimkie, 1993; Blimkie & Bar-Or, 1996).

Less information is available on the trainability of muscular endurance in children. Clarke and Vaccaro (1979) found arm and shoulder girdle muscle endurance, as measured by pull ups and push ups, increased by more than 100% in 9 - 11year old boys and girls after 7 months of intense swimming (4 days/week, 3,000 - 10,000 yard swims). Suei et al. (1998) reported that muscle strength, power and endurance increases in males, and, less consistently, in females with increasing age and maturation. These increases were especially prevalent at the onset and throughout puberty.

Adiposity

Rope skipping is an activity that requires quick accelerations and decelerations of the body. Activities such as this could be hindered with an excess of body fat (Raudsepp & Jürimäe, 1996). Male and female children, adolescents and young adults involved with sport and physical activity (PA) have been found to have lower body fat than those not involved with sport and PA (Boreham, Twisk, Savage, Cran, & Strain, 1997; Raitakari et al., 1997). Gutin et al. (1996) found a significant decrease in body fat in 7 - 11 year old obese black females after 30 minutes of continuous and interval aerobic training at 70% MHR, 5 days a week. The minimum amount of activity necessary to decrease body fat in non-obese prepubescent children has not been determined. A combination of calorie restrictions and almost daily PA are most likely needed for significant reductions in adiposity in both obese and non-obese adolescents (Sallis, 1995). It is important to mention that decreased adiposity may not be possible in all children due to genetic limitations.

The use of skinfolds to estimate a child's body fat and describe adipose deposition pattern is supported by the indication that obesity is related to increased health risk. The risk factors associated with adult cardiovascular disease have been found to be present in children (Vaccaro & Mahon, 1989), so it is important to assess body fatness patterns throughout childhood and adolescence. When the sum of skinfolds is correlated with the criterion measure of body fat determined by hydrostatic weighing, it generally has a moderately high validity. Lohman (1986) reported coefficients of 0.73 to 0.86 for sum of triceps and subscapular skinfolds when compared with body fat determined by hydrostatic weighing. Safrit and Wood (1987) found the sum of triceps and subscapular skinfolds to be reliable ($r = 0.89 - 0.98$). The use of two skinfold sites is adequate for screening puposes, but the four site (biceps, triceps, subscapular and suprailium) or five site (biceps, triceps, subscapular, suprailium and calf) procedure should be used for a more comprehensive assessment (Safrit and Wood, 1987).

Balance

Competitive rope skipping routines involve jumping single and double ropes, one foot landings and gymnastic and dance manuevers such as handstands, cartwheels, flips and splits. These motor performance tasks require adequate static and dynamic balance capabilities, and whole body coordination. From a health perspective, rope skipping as an activity for children may be beneficial, as balance may be improved with regular skipping participation. Kioumourtzoglou, Derri, Mertzanidou, & Tzetzis (1997) found that female elite rhythmic gymnasts, aged 9 - 15 years, performed better than a control group on whole-body coordination, dynamic balance and static balance. Interestingly, there was no difference in performance of dynamic balance across the age groups of the elite gymnasts. Experience in the sport seems to be attributed to better performance on these task-specific ability measures. Prepubertal girls have been found to surpass boys in balance, measured by the Flamingo static balance test, and flexibility, measured by the sit and reach test (Raudsepp & Pääsuke, 1995). Balance was found to be significantly associated with body mass index in the girls, indicating that less body fat enables better static balance. No training studies have been performed that examine the responsiveness of children to balance training.

Flexibility

General, overall body flexibility would appear to be important for competitive rope skippers. Flexibility exercises develop body awareness, an important aspect of rope skipping. The variety of gymnastic movements performed during competition events require high levels of flexibility in the joints. Executing stretching exercises to relax muscles as part of a rope skipping training program is beneficial, as relaxed muscles prepare the body for more strenuous exercise (McArdle, Katch, & Katch, 1991, p. 512). In this way, the muscles may be less resistant to powerful contractions so there may be an increased potential to generate explosive power (Burley, Dobell, & Farrell, 1961).

Low back and hamstring flexibility, more specifically decreased lumbar flexion and hip flexor tightness, is believed to be related to low back pain in children and adults (American Alliance for Health, Physical Education, Recreation and Dance, 1980; Kujala, Taimela, Salminen, & Oksanen, 1994). Therefore, it has important health-related implications for populations of all ages. The sit and reach test is often used as a measure of low back and hamstring flexibility. However, flexibility is joint specific and this test is a measure of muscle flexibility or tightness. When this test was compared with a test of back flexibility and a test of hamstring flexibility (non-joint specific tests) in 14 year old females, a moderate validity was found ($r = 0.60 - 0.73$) for hamstring flexibility while low correlation coefficients ($r = 0.27 - 0.30$) were found for low back flexibility (Jackson & Baker, 1986). These results imply that the sit and reach is not a valid measure of back flexibility and is limited as an assessment of hamstring flexibility. The reliability of the test is actually quite high, with coefficients of $r = 0.80 - 0.96$ for 11 - 14 year old girls, and $r = 0.94 - 0.97$ for 11 - 14 year old boys (Safrit & Wood, 1987). Based on the validity concerns, the sit and reach test should be used as a measure of general whole body flexibility.

Effect of gender, growth and maturation on flexibility. Prepubertal and pubertal girls are generally more flexible than boys (Dochety & Bell, 1985; Raudsepp & Pääsuke, 1995). Previous research has shown that flexibility decreases with age in boys (Docherty & Bell, 1985; Leighton, 1956). In girls, some studies have demonstrated that shoulder and trunk flexibility measured by the Leighton flexometer (Leighton, 1942) remains relatively constant with maturity (Hupperich & Sigerseth, 1950), while other research has demonstrated a significant decline from age 6 to 15 years in females (Burley et al., 1961; Docherty & Bell, 1985). Docherty & Bell (1985) demonstrated that sit and reach test scores significantly increased from age 6 to 15 years in females. More longitudinal research is necessary to clearly understand the effect of growth on flexibility in children.

Effects of training on flexibility. It has been shown that children involved in sport training have better overall body flexibility than non-athletic children (Kujala, Salminen, Taimela, Oksanen, & Jaakkola, 1992; Naughton & Carlson, 1991). Maffulli, King, and Helms (1994) found that boy and girl gymnasts, aged 9 to 18 years, had lower flexibility of the glenohumeral joint than swimmers, tennis players and soccer players. However, the gymnasts had the greatest flexibility of the lumbar spine and hamstrings, hip, adductor muscles and posterior muscles of the thigh. Given the similarity of some of the movements executed in competitive rope skipping routines and gymnastic floor routines, it is possible that the shoulder flexibility and low back/hamstring flexibility of rope skippers would be similar to gymnasts. Other studies that compared control group boys and girls up to 13 years of age with those involved in swimming and tennis (Bloomfield, Blanksby, Ackland, & Elliot, 1985) and karate training (Violan, Small, Zetaruk, & Micheli, 1997) found no differences between the groups on measures of flexibility. More investigations are needed to develop recommendations for training program intensity, frequency and duration to elicit improvements in flexibility in children, as no guidelines are available to date.

Conclusions

It is apparent from this review that the physiology of pediatric exercise is complex, with several investigations yielding equivocal results. More research investigating physical activities that most children enjoy performing, such as rope skipping, would do much to further our understanding of the health and fitness benefits gained from regular participation in physical activity. With the increased popularity of competitive rope skipping as a team sport in many communities, an assessment of the demands and effects of this activity would provide information necessary to develop optimal exercise training programs for participants that include the appropriate fitness components. Furthermore, future research is needed in all of the fitness component areas to understand the mechanisms involved during both growth and exercise training in children. Information pertaining to both general and sport-specific training guidelines for the aerobic, anaerobic, strength and flexibility components of fitness would do much for the child athlete. Lastly, due to a limited amount of information, primary emphasis should be placed on investigating the demands and effects of physical activity and exercise training in the young female.

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Appendix B

Letter of Purpose

TO: Participants in the University of Victoria study of "A comparison of young female rope skippers with untrained matched controls" and parents/guardians

FROM: Kathy Gaul, Ph.D., School of Physical Education, University of Victoria
Jill Peters, graduate student, School of Physical Education, University of Victoria

We are conducting a research project involving the measurement of a number of fitness parameters in children both trained and untrained in competitive rope skipping. The Island Hoppers skipping team offers a unique opportunity to investigate the physiological effects of rope skipping in young females. We would like to invite each member of the Island Hoppers skipping team to participate in some fitness testing at the University of Victoria during two days in October. We would also like each team member to invite one female friend, who is not experienced in rope skipping activities, to join the project. These friends will act as the "control group" for this study. The "control" participants should be similar to you in age, and should not be involved in any sport/fitness training.

The project will be conducted in the Sport and Fitness Center at UVic over two sessions to be held on different days. Prior to the first session there will be an informational discussion to familiarize participants with the project, facilities and research team. Then, two fitness testing sessions will include running a 20-meter shuttle run test to predict maximal aerobic power, cycling on a cycle ergometer as fast as possible for 30 seconds in our laboratory to measure anaerobic fitness, and other related fitness measures (endurance and flexibility).

With the growing popularity and success of children participating in recreational activity and organized sport, many questions have been raised regarding the demands and effects of regular exercise training on children. Therefore, the purpose of this study is to compare the effects of jump rope training on body composition, aerobic and anaerobic metabolism, muscular strength and endurance, balance and flexibility of young female rope skippers to an untrained control group. In addition, the physiological demands of rope skipping during a typical training session will be investigated to improve our understanding of the use and development of metabolic systems in children.

Research investigating the activities in which young females commonly participate could do much to improve our understanding of how this population responds to regular activity. The results of this study will be beneficial for parents, teachers, coaches and athletes interested in promoting the health and fitness of children involved in either recreational rope skipping or elite competition.

This is an opportunity to obtain valuable information about your personal fitness and learn how exercise physiologists measure fitness in children and adults. Many of the tests to be used are exactly the same as those we use when working with National Team and Professional athletes from various sports. There is no cost involved in participating, other than a few hours at the UVic Sport and Fitness Center. We hope you take this opportunity to participate in an exciting scientific research project!

If you are interested in volunteering for the project or would like further information before volunteering to participate, please feel free to contact Jill Peters (**tel**: 477-1953; **email**: jtpeters@uvic.ca) or Dr. Kathy Gaul (**tel**: 721-8380; **email**: kgaul@uvic.ca. ; **fax**: 721-6601). We will be happy to discuss the project further and answer any questions or concerns you may have regarding this study.

Sincerely,

Jill Peters, M. Sc. Exercise Physiology Graduate Student, University of Victoria

Kathy Gaul, Ph. D., School of Physical Education faculty, Grad Supervisor, University of Victoria

Appendix C

Description of Project - Informed Consent

A comparison of young female rope skippers with untrained matched controls: Description of Project

What procedures will be involved with the fitness tests?

As a volunteer participating in this project, you will be asked to perform a number of fitness tests. This will involve two visits to the UVic Sport and Fitness Center in the McKinnon Building (room 171) in October. All testing will be conducted by certified research assistants in the Sport and Fitness Center in the School of Physical Education. Prior to testing, you will be given an orientation to all test protocols to ensure that you understand the equipment and procedures to be used, the exercise intensities you will be encouraged to perform, and the possible discomforts associated with the fitness tests. You will be asked to perform to the best of your ability. It is important to understand that you maintain the right to stop and/or withdraw from the study at any time should you want to discontinue participation.

Body composition

Your height, weight and a few skinfolds (arm, body, leg) will be measured in a private section of the Sport and Fitness Center to ensure measurements are confidential.

Maturity status

Maturity status will be self-assessed to allow the researchers to understand more about how physical maturation influences physical performance. This will involve two sets of drawings (breast and pubic hair) and written descriptions, and will be explained to you by a trained female researcher. Once you understand the instructions, you will be given privacy to choose which of the drawings looks most like your development. This information will be confidential. Your name will not be placed on the forms. This information will be stored in a secured cabinet along with all other data collected. You have the right to not participate in this procedure.

Aerobic system

Maximal aerobic power will be measured using a 20-meter shuttle run test. This test involves running continuously back and forth between two lines spaced 20 meters apart on a gymnasium floor at a pace set by a 'beep' signal on a prerecorded tape in a cassette player. Each stage is one minute in duration, with an increase in speed as the test progresses. The goal of the test is to achieve the most stages possible without stopping. Your heart rate will be monitored throughout this test. You have the right to stop the test at any time. You will be stopped if you cannot keep up with the 'beep' signals. Although maximal effort is required near the end of this test, the intensity and risks involved will not be greater than that of vigorous play and/or sport performance. You will be closely monitored during the test and recovery period following the test.

Anaerobic system

A 30 second all-out sprint will be performed on a cycle ergometer ("stationary bike"). Resistance will be set based on your body weight. The resistance set will be similar to that experienced during a bike ride up a steep hill!

Muscular power and endurance

Muscular power of the legs will be measured by performing a vertical jump test. You will be asked to jump as high as possible, touching your fingers to the wall at the highest point of the jump.

Muscular endurance will be measured using push ups and a special type of sit-up called a "partial curl-up." You will be asked to do as many of each as possible.

Balance

To measure your ability to accurately jump and maintain balance while moving, you will move your way through a pattern of ten marked places on the gymnasium floor. Alternating feet, you will jump, land and balance on each mark. This will be similar to a game of hop-scotch.

Flexibility

A sit-and -reach test will measure your hamstring flexibility. In addition, active range of motion of the shoulder will be measured with a small, light instrument that will be placed near the shoulder joint. These procedures involve only light stretching of the arm and trunk.

Rope skipping training

Only the rope skipping team members will be participating in this exercise. Heart rate will be monitored throughout a full training session. The results will tell you what exercise intensity you are achieving at different paced and timed skipping routines during a typical training session.

What if you change your mind?

You have the right to withdraw from the study at any time without any negative consequences. While the research team will be in full control of the testing and equipment, it is important that you understand that you may stop at any time, during any of the tests, if you are feeling uncomfortable or are experiencing any discomfort beyond that expected. If you do choose to stop a test or withdraw from the study, the data collected to that point will be stored with all other data obtained in this study.

The informed consent

Before we begin any of the testing, you will be asked to attend an orientation session so we can familiarize you with the research team, equipment, and test protocols. After having read this description, attended the orientation session, gained a full understanding of your role as a participant in this study, and having chosen to participate, please complete the attached consent form.

Results

All data will be considered confidential. No names will be used in published results, and your results will be identified by using code numbers. Only Jill Peters and Kathy Gaul will have access to the data. All data collected will be stored in a locked cabinet at the University of Victoria and destroyed after a period of five years.

At the end of the study, you will receive a report of your personal results and an explanation of the results of the project.

It is important that all volunteer participants understand that they are free to withdraw from the study at any time. For the Island Hoppers, participation or a decision to not participate will have no influence on your relationship with your team. We would like to emphasize the importance of having as many participants as possible complete the study.

Thank you for your support and interest in this study.

Jill Peters, M. Sc. Kinesiology Graduate Student

School of Physical Education

University of Victoria

tel: 477-1953

email: jtpeters@uvic.ca

Kathy Gaul, Ph. D., Grad Supervisor

School of Physical Education faculty

University of Victoria

tel: 721-8380

email: kgaul@uvic.ca

INFORMED CONSENT FORM

As a participant I understand that I will be asked to perform a number of tasks *that I am familiar with after completing the laboratory orientation session*. I acknowledge my consent to perform the following tests:

1) My height, weight and some skinfold measurements will be taken _______

2) I will be asked to indicate my physical maturity status using a set of diagrams I will view in privacy _______

3) The 20-meter shuttle run that will become progressively more difficult and will continue until I am asked to stop or until I no longer feel I can keep going _______

4) A 30 second all-out cycle sprint _______

5) A vertical jump test _______

6) As many partial curl-ups and pushups as I can do _______

7) A balance test of jumping, landing, and balancing on one foot _______

8) I will be asked to move my arms and trunk to a comfortable stretch to measure my flexibility _______

9) *Trained rope skippers only* : My heart rate may be monitored during a regular rope skipping training session _______

I am aware of the nature of, and possible discomforts involved in, the research and realize that there are no personal risks greater than those of vigorous play and sport activities.

I am aware that to ensure anonymity and confidentiality, my name will not be kept on any data sheet and code numbers will be used to identify results obtained from all participants. No individual data will be published or used in isolation. Only Jill Peters and Kathy Gaul will have access to the data. All data collected will be stored in a locked cabinet at the University of Victoria and destroyed after a period of five years.

I am also aware that I am free to withdraw at any time during the study without any negative repercussions (ie. will not influence status on Island Hoppers Team). I understand that if I withdraw from the study, my personal data collected to that point will be stored with all other data obtained in this study.

____________________ ____________________ ____________

Name of Participant Signature Date

Age: ______ Birthdate: ______________

Address: ______________________ Telephone #: ______________

____

______________________ ______________________

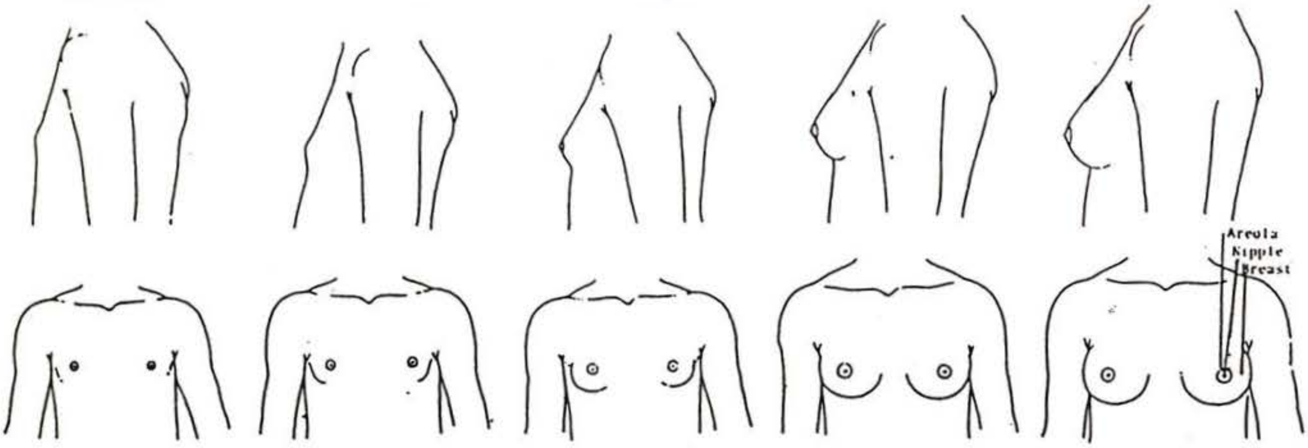
Name of Parent/guardian Signature

Appendix D

Maturity Self Assessment Form

THE DRAWINGS ON THIS PAGE SHOW DIFFERENT STAGES OF DEVELOPMENT OF THE BREASTS. A FEMALE PASSES THROUGH EACH OF THE FIVE STAGES SHOWN BY THESE SETS OF DRAWINGS. PLEASE LOOK AT EACH SET OF DRAWINGS AND READ THE SENTENCES UNDER THE DRAWING. THEN CHOOSE THE SET OF DRAWINGS CLOSEST TO YOUR STAGE OF BREAST DEVELOPMENT AND MARK IT 1. THEN CHOOSE THE DRAWING THAT IS THE NEXT CLOSEST AND MARK IT 2.

1. DRAWING A ______ 2. DRAWING B ______ 3. DRAWING C ______ 4. DRAWING D ______ 5. DRAWING E ______



1. THE NIPPLE IS RAISED A LITTLE IN THIS STAGE. THE REST OF THE BREAST IS STILL FLAT.

2. THIS IS THE BREAST BUD STAGE. IN THIS STAGE THE NIPPLE IS RAISED MORE THAN IN STAGE 1. THE BREAST IS A SMALL MOUND. THE AREOLA IS LARGER THAN IN STAGE 1.

3. THE AREOLA AND THE BREAST ARE BOTH LARGER THAN IN STAGE 2. THE AREOLA DOES NOT STICK OUT AWAY FROM THE BREAST.

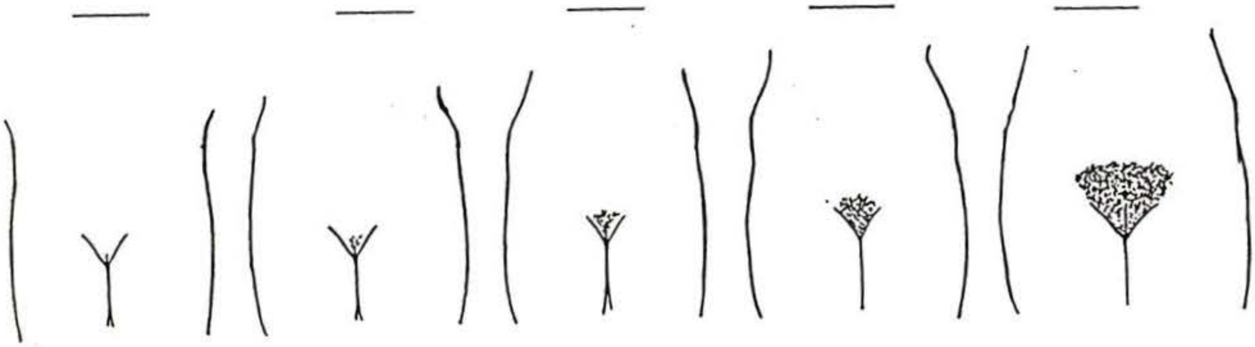
4. THE AREOLA AND THE NIPPLE MAKE UP A MOUND THAT STICKS UP ABOVE THE SHAPE OF THE BREAST. (NOTE: THIS STAGE MAY NOT HAPPEN AT ALL FOR SOME GIRLS. SOME GIRLS DEVELOP FROM STAGE 3 TO STAGE 5, WITH NO STAGE 4.)

5. THIS IS THE MATURE ADULT STAGE. THE BREASTS ARE FULLY DEVELOPED. ONLY THE NIPPLE STICKS OUT IN THIS STAGE. THE AREOLA HAS MOVED BACK TO THE GENERAL SHAPE OF THE BREAST.

***Have you had your first period? ____________________**

THE DRAWINGS ON THIS PAGE SHOW DIFFERENT AMOUNTS OF FEMALE PUBIC HAIR. A GIRL PASSES THROUGH EACH OF THE FIVE STAGES SHOWN BY THESE DRAWINGS. PLEASE LOOK AT EACH DRAWING AND READ THE SENTENCES UNDER THE DRAWINGS. THEN CHOOSE THE DRAWING CLOSEST TO YOUR STAGE OF HAIR DEVELOPMENT AND MARK IT 1. THEN CHOOSE THE DRAWING THAT IS NEXT CLOSEST AND MARK IT 2.

1. DRAWING A ______ 2. DRAWING B ______ 3. DRAWING C ______ 4. DRAWING D ______ 5. DRAWING E ______



1. THERE IS NO PUBIC HAIR.

2. THERE IS A LITTLE LONG, LIGHTLY COLORED HAIR. THIS HAIR MAY BE STRAIGHT OR A LITTLE CURLY.

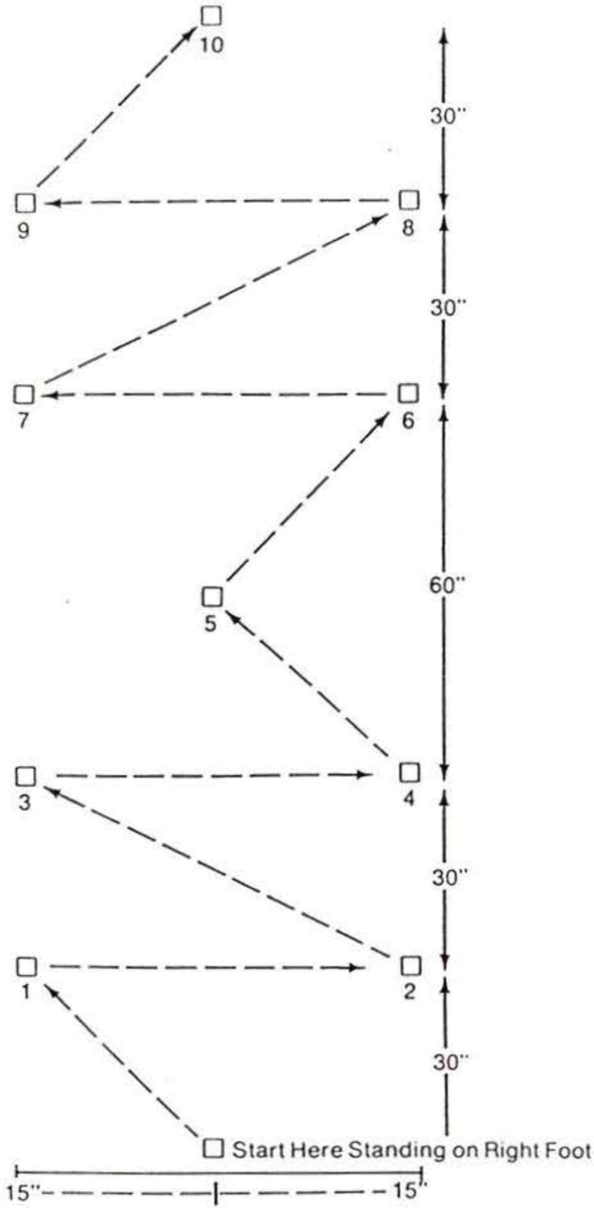
3. THE HAIR IS DARKER IN THIS STAGE. IT IS COARSER AND MORE CURLED. IT HAS SPREAD OUT AND THINLY COLVERS A LARGER AREA.

4. THE HAIR IS NOW AS DARK, CURLY, AND COARSE AS THAT OF AN ADULT FEMALE. HOWEVER, THE AREA THAT THE HAIR COVERS IS NOT AS LARGE AS THAT OF AN ADULT FEMALE. THE HAIR HAS NOT SPREAD OUT TO THE THIGHS.

5. THE HAIR NOW IS LIKE THAT OF AN ADULT FEMALE. IT ALSO COVERS THE SAME AREA AS THAT OF THE ADULT FEMALE. THE HAIR USUALLY FORMS A TRIANGULAR (▽) PATTERN AS IT SPREADS OUT TO THE THIGHS.

Appendix E

Modified Bass Test of Dynamic Balance Floor Pattern


10
30"
9
8
30"
7
6
60"
5
3
4
30"
1
2
30"
Start Here Standing on Right Foot
15"
15"

Appendix F

Heart rate response raw data of

Subject 1(Prepub) and Subject 2(Pub) rope skippers

Time (min)	Subject 1	Subject 2	Time (min)	Subject 1	Subject 2	Time (min)	Subject 1	Subject 2
1	93	93	24	112	148	47	176	134
2	92	106	25	114	145	48	167	145
3	92	113	26	108	131	49	170	141
4	143	177	27	108	133	50	171	151
5	157	193	28	112	144	51	168	128
6	131	134	29	110	141	52	158	143
7	107	197	30	112	147	53	-	144
8	108	173	31	118	159	54	-	143
9	148	138	32	121	125	55	-	135
10	142	125	33	116	146	56	-	150
11	114	118	34	111	173	57	-	152
12	121	231	35	100	172	58	-	138
13	109	238	36	104	153	59	-	121
14	125	181	37	125	151	60	-	148
15	154	138	38	133	120	61	-	120
16	151	127	39	-	144	62	-	126
17	150	114	40	145	148	63	-	159
18	112	128	41	150	150	64	-	113
19	103	127	42	137	151	65	-	109
20	104	129	43	144	147	66	-	140
21	125	148	44	148	147	67	-	160
22	113	115	45	175	146	68	-	142
23	112	134	46	180	150			
						MHR *	215	192
						Mean	126	144
						Mode	112	148

* MHR = peak heart rate obtained during the 20-meter shuttle run test

VITA

Surname: Peters **Given Names:** Jill Torrey

Place of Birth: Northampton, Massachusetts, U.S.A.

Educational Institutions Attended:

University of New Hampshire 1989 to 1993

Degrees Awarded:

B. S. Exercise Science University of New Hampshire 1993

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Title of thesis:

A Comparison of Young Female Rope Skippers with Untrained Matched Controls

Author [redacted]

Jill Torrey Peters
July 19, 1999