EXAMINATION OF THE BOSCO JUMP TEST

by

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Abstract

From the Bosco 60 s jump test, (Eur. J. Appl. Physiol., 50, p. 273, 1983) 5 variables are calculated: (1) power output (Watts/kg), (2) power output (W), (3) flight time per jump, (4) mat time per jump, and (5) percent flight time. The purpose of this study was to examine these variables when vertical jump tests were performed in four conditions: (C1) Standard Bosco test, (C2) Standard Bosco test with 10% Added Body Mass, (C3) Rapid Jumping test, and (C4) Cadence Jumping test. For the Rapid Jumping test, subjects were instructed to obtain maximum flight time and minimum mat time.

Variable	C1	C2	C3	C4
Power (W/kg)	15.4	13.0	21.0	14.6
Power (W)	1221	1122	1637	1145
T_f/jump (s)	0.41	0.37	0.42	0.38
T_m/jump (s)	0.77	0.81	0.47	0.65
$\%T_f$	34.9	31.3	48.6	37.0

The Rapid Jumping condition resulted in the highest power output. Added mass was detrimental to performance. This study demonstrates the importance of controlling jumping rate and knee angle in the Bosco jump test.

Resumé

Cinq variables sont calculees à partir du test de Saut 60 s Bosco (Eur. J. Appl. Physiol., 50, p. 273, 1983): (1) puissance de rendement (Watts/ kg), (2) puissance de rendement (W), (3) partee de saut, (4) tempo au tapis du saut, et (5) pariee du saut en pourcentage. Le but de cette etude était d'examiner ces variables sous quat ce conditions de performance des tests de saut vertical: (C1) test Bosco Standard, (C2) test Bosco Standard avec Addition de 10% de Masse Corporelle, (C3) test de Saut Rapide, et (C4) tests de Saut en Cadence. Pour le test de Saut Rapide, les sujets ont reçu l'instruction de maintenir un maximum de partée de saut et un minimum de tempo au tapis.

Variable	C1	C2	C3	C4
Puissance (W/kg)	15.4	13.0	21.0	14.6
Puissance (W)	1221	1122	1637	1145
Parée du saut (s)	0.41	0.37	0.42	0.38
Tempo au tapis de saut (s)	0.77	0.81	0.47	0.65
Partée du saut en (%)	34.9	31.3	48.6	37.0

La condition de Saut Rapide a eu pour résultat la puissance de rendement la plus élevée. L'addition de masse a été nuisible à la performance. Cette étude a démontré l'importance de contrôler la fréquence de saut et l'angle des genoux pendant le test de Saut Bosco.

Chapter I

Introduction

The evaluation of an athlete's physical potential through appropriate physiological testing provides the athlete, coach and trainer with information concerning the individual's relative physical strengths and weaknesses. Following this assessment, the development of the athlete can be enhanced with an appropriate training program resulting in an improved performance. Evaluation techniques should target the appropriate parameter.

In sports and physical activities where repeated, short duration, high-intensity muscular output is essential for successful performance, the evaluation of anaerobic power and anaerobic capacity is particularly important. One test to evaluate human anaerobic power and capacity is a continuous vertical jump test (Bosco et al. 1983b). The Bosco et al. (1983b) jumping test offers a simple method for evaluating the anaerobic (mechanical) power output from the leg extensor muscles. Subjects jump continuously for a predetermined duration, typically 15 or 60 seconds. The 15 s test is considered to provide an estimation of anaerobic (mechanical) power while the 60 s test provides an indication of anaerobic capacity (Bosco et al., 1983b). In the subsequent discussions, this test will be referred to as the "Bosco test".

A number of researchers have used jumping tests to assess anaerobic power and capacity. Several studies where the Bosco test have been used for the estimation of anaerobic power are presented in the following examples.

It has been shown (Bosco et al., 1983a) that power output scores from the 15 s Bosco Jump test correlated well with ($r = 0.86$, $p < 0.05$) the percentage of fast twitch muscle fiber obtained from the measurement of the vastus lateralis muscle. In the same study, the 60 s test demonstrated sensitivity in assessing fatigue among a group of subjects with a fast twitch muscle fibre distribution ranging from 25 to 58 percent. The Bosco test was able to differentiate among subjects with varying degrees of muscle fibre distribution.

Kirkendall and Street (1986) utilized the Bosco jumping test to assess 119 male athletes as part of their pre-season physical fitness profile. The jumping test was also used on a group of soccer players at mid-season to evaluate the effectiveness of their training program. Since power output scores improved significantly between the two evaluations, the Bosco vertical jumping test demonstrated sensitivity to changes in power output resulting from a training effect.

In an investigation of the leg extension muscles, Bosco et al. (1987) demonstrated the significance of muscle pre-stretching on mechanical efficiency. The vertical jump test was utilized to establish the differential contributions of a muscle pre-stretching on the mechanical efficiency of the leg extensor muscles.

Viitasalo et al. (1987) used the Bosco et al. (1983b) vertical jumping test to discriminate between physiological maturity levels of young athletes (8.8 to 17.1 years of age) independent of their chronological age. The jumping test demonstrated that it could group subjects according to physiological age.

Thus, the Bosco continuous jump test has been accepted by researchers as a test for estimation of human anaerobic power output in both practical and experimental settings.

1.1 Rationale for the Study

A vertical jump consists of two phases; a preparatory phase where force is applied downwards (mat time), and a flight phase (flight time) which is related to the vertical jump height. The preparatory phase consists of an eccentric component and a concentric component. The eccentric component during a vertical jump incorporates the landing, balancing and storage of potential energy by the leg extensor muscles. The concentric phase applies the generation of force from the chemo-mechanical conversion of energy and the utilization of stored elastic energy to obtain push-off from the mat. The flight phase (flight time) is a function of the power generated through the utilization of biochemical energy and the re-use of stored elastic energy from within the muscle.

Research publications using the Bosco test have reported muscle power output in Watts/kg. Power output scores are calculated from the Bosco jumping test using the formula:

$$\text{Power output (W/kg)} = \frac{g^2 \cdot T_f \cdot T_t}{4n(T_t - T_f)}$$

where (g^2) is the acceleration due to gravity,

(T_f) is flight time,

(T_t) is the duration of the test,

and (n) is the number of jumps performed during the test.

In their description of the test, Bosco et al. (1983b) do not make any reference to other variables that might be calculated from this test. These variables include; 1) flight time per jump (s), 2) percent flight time (%), 3) and mat time per jump (s).

Personal communication with researchers who have used the Bosco jump test to evaluate the muscle power output of athletes suggests interpretation of the results was a problem. An example will be used to illustrate this point.

Results for 10 athletes from the Canadian national men's water polo team are presented in Table 1. The subjects were ranked according to their performance (Watts/kg) on the Bosco vertical jump test. The subjects in Table 1 represent the top five scores (group 1) and the bottom five scores (group II) from a team of 22 players. Comparisons of the group means indicate large differences in scores even within this relatively homogenous group.

Table 1: Bosco Jump Test Results For 10 Water Polo Players.

Rank	Power Watts/kg	Power Watts	T_f/jump Seconds	$\%T_f$ Percent
1	53.2	3830	.55	70
2	43.3	3520	.49	72
3	41.0	3280	.57	66
4	39.3	3230	.54	67
5	38.0	2865	.54	65
$\bar{X}$	43.0	3345	.54	68
18	20.5	1430	.48	43
19	20.1	1804	.47	44
20	19.8	1633	.47	42
21	19.1	1463	.46	42
22	17.8	1634	.50	37
$\bar{X}$	19.5	1593	.48	42

When the groups were divided based on their mean power output score, group I averaged 43.0 Watts/kg and group II averaged 19.5 Watts/kg. The mean score of group I was 120% higher than the score of group II. The range in scores for group I was 15.2 Watts/kg and only 2.7 Watts/kg for group II. Why is the difference between means so vast when the subjects were all from a single team? Why did the top ranked individual obtain a power output score that was three times as high as the bottom ranked individual? An examination of the components of the equation may provide some answers.

When the subjects were ranked on the basis of flight time per jump, the difference between group I and group II was reduced to 13 percent. The mean percent flight time for the subjects in group I was 68% and for group II 42%. The difference between the mean percent air time for group I and group II is 62%.

For the four variables, the differences between groups I and II were 120% for power output (Watts/kg), 110% for power output (Watts), 13% for flight time per jump, and 62% for percent flight time. A possible explanation for the discrepancies seen in this data might be differences in the strategy utilized by the subject. If a subject is focused on maximizing the height of each jump, then the subject may increase the mat time to the detriment of the power score (Watts/kg) calculation because mat time is inversely proportional to power output in Bosco's formula. In contrast, another subject may focus on getting off the mat as quickly as possible. This strategy may increase the power output score in the Bosco et al. (1983b) formula, but probably would reduce the flight time per jump score.

The four treatment conditions used in this study are designed to control the strategy involved in each test. Therefore, an examination of the dependent variables associated with the measurement and calculations involved in the Bosco test can be investigated.

The purpose of this study is to examine the variables, power output (Watts/kg), power output (Watts), flight time/jump, mat time per jump, and percent flight time when the Bosco vertical jump test is performed in four conditions: (1) Standard Bosco Jump test, (2) Standard Bosco Jump test with 10% Added Body Mass condition, (3) Rapid Jumping Test, (4) Cadence Jumping Test.

1.2 Hypotheses:

1. There are no significant differences in power output (Watts/kg) between the Standard Bosco Jump test and three experimental conditions during tests of 15 and 60 second durations.

2. There are no significant differences in absolute power output (Watts) between the Standard Bosco Jump test and three experimental conditions during tests of 15 and 60 second durations.

3. There are no significant differences in flight time per jump (s) between the Standard Bosco Jump test and three experimental conditions during tests of 15 and 60 second durations.

4. There are no significant differences in percent flight time ($\%T_f$) between the Standard Bosco Jump test and three

experimental conditions during tests of 15 and 60 second durations.

5. There are no significant differences in mat time per jump (s) between the Standard Bosco Jump test and three experimental conditions during tests of 15 and 60 second durations.

1.3 Delimitations

1. Only male subjects were used in this study.
2. Generalizations and conclusions from this study can only be compared with measured variables and power output scores from the Bosco jump test.

1.4 Limitations

1. During the eccentric portion of the jump preparation phase, subjects may vary from the requested knee flexion angle of 90 degrees. Verbal feedback was provided by the researcher in order to maintain the knee flexion at 90 degrees. Performances were also videotaped to obtain standardization.
2. During continuous jumping tests, it is difficult to control lateral and vertical displacement of the feet when landing on the timing mat.
3. The fibre type of the muscle may have influenced the results of this study.

Chapter II

Review of Related Literature

This chapter presents literature related to vertical jumping as a means of evaluating human power output. The main focus of this review will be the Bosco et al. (1983b) continuous vertical jump test. Variables which influence jumping performance are also addressed in this chapter.

2.1 Introduction

In man, power output has been evaluated using several vertical jumping methods. One method is a simple vertical jump which measures the displacement of different parts of the body (i.e. preferred hand, waist, or head) from a standing position to the highest point achieved during a maximal vertical jump (Sargent, 1924; Davies & Young, 1984; Vandewalle et al., 1987). The estimation of power from the height of a vertical jump requires the calculation of work and an estimation of the jumping time (Adamson and Whitney, 1971). The performance of the jump reflects the degree in which the legs are permitted to pre-stretch (Cavagna et al., 1968) and the use of the arms in an upward movement during the positive phase of the jump (Vandewalle et al., 1987).

A second method of evaluating human power output utilizes a force platform. This has permitted the measurement of instantaneous power produced during a vertical jump (Davies, 1971; Bobbert et al., 1986; Asmussen & Bonde-Petersen, 1974). Human power output is determined by measuring acceleration at the centre of mass during the vertical jump. The acceleration is equal to the value of the force exerted on the force platform minus the subject's body weight, divided by the body mass (Vandewalle et al., 1987). The instantaneous velocity is calculated from the product of the force exerted downward on the force platform and velocity of the centre of mass during the vertical jump, thereby allowing calculation of power and average power during the vertical jump (Vandewalle et al., 1987).

A third test to measure human power was developed by Bosco et al., 1983b). This 60 s continuous vertical jumping test allowed for the storage and re-utilization of elastic energy from the leg extensors from one jump to be transferred to the next jump. The power output from the first 15 s of the Bosco test is considered to be a measure of anaerobic power and the 60 s score is an indication of anaerobic capacity or endurance.

Performance of a vertical jump (height of jump and power output) is related to the following parameters; age (Bosco and Komi, 1980; Davies & Young, 1984), sex (Komi & Bosco, 1978), muscle fibre composition (Bosco et al., 1983a), re-utilization of stored elastic energy in pre-stretched muscles (Bobbert et al., 1986; Asmussen & Bonde-Petersen, 1974), body size and external loading (Davies, 1971), muscle metabolism

(Boobis et al., 1983; Jacobs et al., 1983) and mechanical efficiency (Bosco et al., 1987a). The discussion presented in the next section reviews the literature related to vertical jumping and the effect of these variables on vertical jump performance.

2.2 Power Output from Vertical Jumping Tests

Davies (1971) utilized a force platform to examine the maximal power output achieved during the performance of a vertical jump. The power output values from the vertical jump test were compared to the power scores obtained from a stair run test and to a cycle ergometer test. The vertical jump was initiated with a countermovement followed by a maximal effort. The stair run test was administered according to the protocol established by Margaria et al. (1966). From the cycle ergometer test, aerobic power output was determined from direct measurements of oxygen consumption during the sixth to eighth minute of a maximal oxygen consumption test. The subjects were 47 adult males and 8 adult females.

The vertical jump test yielded the largest power output scores of the three tests. The mean scores for both men and women were as follows: 1) the vertical jump tests; men 5.60 $\pm$ 1.21 hp (4174 $\pm$ 905 W) and for the women 3.16 $\pm$ 0.48 hp (2353 $\pm$ 360 W); 2) the stair climb test; men 1.35 $\pm$ 0.21 hp (1613 $\pm$ 154 W) and for the women 0.91 $\pm$ 0.10 hp (727 $\pm$ 75 W);

3) the aerobic power scores for the men 0.33 ± 0.05 hp (246 ± 33 W) and for the women 0.24 ± 0.03 hp (182 ± 22 W). The author suggested that the greater power output observed in the vertical jump may be due to the re-utilization of stored elastic energy. The countermovement vertical jump protocol maximizes the pre-stretching of the knee extensor muscles prior to the upward phase of the jump. Re-utilization of elastic energy was not a major contributor to the other two experimental conditions.

Davies et al. (1984) compared peak and average power outputs from cycling and vertical jumping in five male subjects. Each subject performed three single jumps with a countermovement. Force-time data were collected before, during and after the jump for a total duration of five seconds. The cycling was performed on a constant velocity ergometer at a pre-determined speed for 10 seconds. The subjects were required to pedal as rapidly as possible for this duration. Strain gauges were connected to each pedal to measure force output. The frequency of pedalling was increased by the investigators until the subject could no longer safely maintain any further increases.

The average peak power outputs for the maximal cycling test were significantly greater than the power output values from the jumping test. However, the two methods were closely related ($r = 0.74$ $p < 0.01$) and provided a simple and accurate measure of power in humans.

Bosco et al. (1983b) developed a simple method for the evaluation of mechanical power by utilizing a vertical rebound jump series. The test required the subjects to perform vertical jumps with maximal effort for 60 s. The first 15 s of the test was used to calculate the anaerobic power output. The anaerobic capacity score was the average power output for the 60 s test. During the test, flight time was monitored by a timer connected to a mat which is triggered when the feet of the subject leave the mat. The time is stopped when the feet make contact with the mat. The Bosco test evaluates the ability to sustain power output for a period of time with stored elastic energy contributing to the total power output.

The Bosco Jump test was compared to Wingate tests of 15 and 60 second duration, the power output from the Margaria stair climb test, and a 60 m sprint (Bosco et al., 1983b). Male subjects between 16 and 30 years of age participated in the study. The subjects were from three groups: basketball players (n = 12), volleyball players (n = 12) and school boys (n = 14) who were not specifically involved in any single activity. Power output scores of 19.8, 21.6 and 22.2 W/kg were obtained for groups one, two, and three, respectively for the 60 s Bosco test. The mean mechanical power output obtained in the 60 s jumping test demonstrated a higher value (20 W/kg) than the power score obtained in the 60 s Wingate test (7 W/kg) or the Margaria stair climb test (14 W/kg).

The first 15 s of the Bosco test correlated closely with the 15 s Wingate test (r = 0.87) and with the 60m sprint (r = 0.84). The 60 s Bosco test was closely associated with the 60 s Wingate test, (r = 0.80). The Margaria stair climb test correlated poorly with both time intervals of the Bosco jump test (15 s: r = 0.12 and 60 s: r = 0.03), respectively. The Bosco jump test had a test re-test correlation of r = 0.95 and thus was considered a reliable test.

Bosco et al., (1983b) suggests that the greater power output scores obtained in the jumping test were due to the additional release of mechanical energy stored in the elastic elements of the muscles and tendons. The re-use of the stored potential energy in the muscles and tendons, plus the contribution of power from the chemomechanical conversion allow for greater total power outputs than power tests which do not utilize the elastic component of the muscles.

To evaluate the average power of 119 male athletes, Kirkendall and Street (1986) employed the Bosco et al., (1983b) 60 s anaerobic vertical jump test. The subjects were representative of seven different athletic activities and the Bosco test was used as a pre-participation evaluation. The average power output score for the subjects was 20.37 W/kg. This was similar to the value obtained by Bosco et al. (1983b). Ten indoor soccer players were used in a test-retest program to evaluate any changes in average power due to training. After four months of training, their average power output increased by 17% from a pre-season score of 20.8 W/kg to 24.3 W/kg at mid-season. The Bosco test was found to be reliable and sensitive in detecting changes in power output due to training.

Bosco et al. (1983c) investigated the relationship between isokinetic performance and ballistic movements of the leg extensor muscles in 12 male subjects. The experimental conditions were: 1) leg extension through complete range of motion measured on a Cybex II isokinetic dynamometer at velocities of 0.5, 1.0, 2.1, 3.14, 4.2, and 5.2 rad/s., 2) a vertical jump beginning from a 90° static flexion in the legs, 3) a vertical jump with a countermovement, 4) a vertical jump after different stretch loads that were given to the leg extensor muscles by letting the subject drop onto a platform from heights of 20, 40, 60, 80, and 100 cm, and 5) the Bosco et al. (1983b) 60 s continuous power jump test.

The mean and standard deviation scores from the static vertical jump, the countermovement jump and best drop jump performance were 37.1 ± 2.7 cm, 44.0 ± 2.6 cm, and 42.1 ± 3.4 cm, respectively. The countermovement vertical jump and best drop jump yielded higher scores than the static position jump. Bosco et al. (1983c) attributed this difference to the storage and re-utilization of elastic energy in the leg extensor muscles during jumps with dynamic flexion prior to the jump.

The power outputs ($\bar{X} \pm SD$) recorded from the Bosco jump test during the first 15 s and at the end of the 60 s continuous test were 22.9 ± 2.9 W/kg and 19.2 ± 3.9 W/kg respectively. The power output from the isokinetic dynamometer performance yielded a mean score of 6.45 ± 1.04 W/kg. The differences in power output between the Bosco 60 s jump test and the isokinetic performance were attributed to the following four reasons. The first was the fact that only one leg was used during the isokinetic performance testing. The second reason was that the isokinetic test evaluated only the knee extensors while the jumping involved both the ankle and the knee extensors. Thirdly, at the highest angular velocities, there was insufficient time to reach full activation of the muscles at angles greater than 0.25 rad/s where the isometric torques are highest. Lastly, no elastic energy could be stored during the isokinetic test.

Both the ballistic activities and anaerobic power test demonstrated the highest relationship with peak torque respectively at 3.14 and 4.2 rad/s. Peak torque was significantly correlated to the static vertical jump ($r = 0.71$, $p < 0.01$); to the countermovement jump ($r = 0.74$, $p < 0.005$); to the best drop jump ($r = 0.60$, $p < 0.005$); to the 15 s anaerobic power test ($r = 0.70$, $p < 0.01$), and to the 60 s anaerobic power test ($r = 0.68$, $p < 0.01$). Bosco et al. (1983c) concluded that both the jumping test and the isokinetic dynamometer performances are useful tests for determining mechanical power output. The isokinetic apparatus evaluated the instantaneous power output while the continuous jump test measured the average mechanical power output.

2.3 Age and Jumping Performance

Bosco and Komi (1980) investigated the influence of age on the ability of the leg extensor muscles to generate force and height of jump. A total of 226 subjects (113 females and 113 males), ranging in age from 4 to 73 years of age were studied. The subjects were grouped into age categories. Subjects performed maximal vertical jumps on a force platform using three methods of jumping. The first method had the subjects jump from a static position with legs flexed at 90°. No preparatory countermovement was utilized in this condition. The second method used a preparatory countermovement. Subjects started from an erect standing position on the force platform with the end of the eccentric phase identical to the beginning phase of the static jump. The third method altered the stretch load by dropping the subjects onto the force platform from varying heights (20 to 100 cm). The children and more senior participants were not tested at high stretch-loads.

The results showed that generally the height of the jump, the force produced during the jump, and the power output performance from the jump peaked for the group aged 19 to 29 years. A decline in the power output was observed with increasing age. The male subjects tended to obtain greater values than the females in all three conditions with both groups obtaining their best performance in the 50 cm condition. The decrease in performance was attributed to a possible decrease in fast twitch muscle fibres with increasing age and a reduction in muscle and connective tissue elasticity of the leg extensor muscles (Bosco & Komi, 1980).

2.4 Sex and Jumping Performance

Komi and Bosco (1978) examined the utilization of stored elastic energy in leg extensor muscles by men and women. The authors suggested that an alternating cycle of eccentric-concentric contractions in locomotion represent a sequence where storage and subsequent utilization of elastic energy takes place. It was hypothesized that the storage capacity and utilization depends on the stretch-loads of activated muscles, and that sex differences may be present in these phenomena. To examine this hypothesis, three groups were tested: Female physical education students (n = 25), male physical education students (n = 16), and players from the Finnish National Men's Volleyball Team (n = 16). The subjects performed three methods of vertical jumps on a force platform. The first consisted of a jump from a static position in which no preparatory countermovement was allowed.

The angle at the knee was 90° and maintained for three to five seconds before jumping. The second method permitted a countermovement where the subjects started from an erect position, flexed their legs to 90° and then initiated the jump. The third method consisted of having the subjects dropped from heights between 20 to 100 cm onto a force-platform followed immediately by a vertical jump. The subjects kept their hands on their hips during the jumping conditions.

A comparison of the average values of the maximum height jumped showed that females generally performed 54 to 67% below both male groups in all conditions. The volleyball players displayed a performance level which was 2 to 8% higher than the male physical education students.

In the three different jumping conditions, the least efficient method was the one which began from a static position as compared to the performances in the countermovement jumps or the drop jumps. There was no significant difference between the performances on the countermovement jumps and the drop jumps.

The drop height influenced performance in all three groups studied. In males, the height of rise of the centre of gravity improved when drop height was increased from 26 cm to 62 cm. Similarly, the female subjects showed increases from 20 cm to 50 cm. The authors concluded that the degree of stretch load of a muscle prior to contraction augments performance to a certain level. Beyond that level detriments in performance were observed. This study also indicated that male subjects can sustain much higher stretch-loads than their female counterparts. However, they also suggested that females compared to males are able to utilize a greater portion of the stored elastic energy in both the countermovement and drop jump conditions. Female subjects were able to re-utilize 90% of the stored elastic energy transferred from the eccentric portion of the jump to the concentric phase of a countermovement jump. The male groups in the same experimental condition re-utilized between 48.8 to 50.0% of the stored elastic energy. Therefore, it appears that jumping conditions with a pre-stretching component are more likely to achieve a maximal vertical jump. Although the males sustained greater stretch loads on muscles, the females were able to re-utilize greater percentages of the stored elastic energy. No explanation was provided for this difference (Komi & Bosco, 1978).

2.5 Muscle Fibre Composition and Jumping Performance

Bosco et al. (1986) investigated the recoil of elastic energy in subjects with different muscle types during large amplitude vertical jumps before and immediately after fatigue induced by short high intensity exercise. Fourteen male track and field athletes were divided into two groups depending upon their percentage of fast twitch muscle fibres in the vastus lateralis. Fibre composition was determined by a needle biopsy technique. Subjects performed three countermovement jumps and three static jumps approximately 15 s before and again after a 60 s continuous jump test (Bosco, 1983b). The countermovement jumps and the static jumps were executed with an angular displacement of approximately 90°. Knee flexion was measured with an electrogoniometer attached to the lateral side of the knee. The execution of large amplitude jumps does not allow fast stretching movements (e.g. 2 rad/s) which are approximately 15% of the maximal speed recorded in drop jumps. Vertical jumps with a large angular displacement allow for an extended coupling time for muscle fibres which favours the characteristics of slow twitch muscle fibres (Bosco et al., 1986).

The results showed that the slow twitch muscle group used a greater percentage of elastic energy before fatigue than did the fast twitch group (28.3% vs 22.8%, respectively). However, after exercise-induced fatigue, the fast twitch muscle group demonstrated a greater percentage of re-utilization of elastic energy than the slow twitch muscle group (32.0% for fast twitch subjects vs 22.5% for slow twitch subjects). The slow twitch muscle fibres can retain their elastic energy longer before detachment of their cross bridges. The shorter crossbridge connection times of the fast twitch muscle fibres prevent significant retention of elastic energy in vertical jumps at slow stretching speeds

(Bosco et al., 1986). However, after fatigue, a greater percentage of fast twitch fibres were recruited by the subjects in the fast twitch muscle fibre group, which might have induced a decrease in the time of the cross bridge attachment-detachment cycle. A decrease of the cross bridge cycle rate might allow the re-use of elastic energy during the concentric phase of the countermovement jump, despite increased coupling time due to the fatigued state of the muscles.

Bosco et al. (1983a) investigated the relationship between muscle fibre distribution of the vastus lateralis muscle and performance on a 60 s Bosco anaerobic power test. Ten male track and field athletes were used as subjects. Their muscle fibre composition ranged from 25 to 58% fast twitch fibres. Mechanical power output was calculated at every 15 s interval for the 60 s test. The relationship between the mechanical power for the first 15 s interval correlated highly with the percentage of fast twitch muscle fibres ($r = 0.86$, $p < 0.005$). The correlation dropped with increasing time spent on the test until the relationship became non-significant after 30 s. Sensitivity to fatigue was demonstrated by the reduction in power during the 60 s jumping interval. The percentage of fast twitch muscle fibres and rate of fatigue correlated highly ($r = 0.73$, $p < 0.01$). The authors concluded that the 60 s continuous jumping test is sensitive in assessing fatigue patterns.

Bosco and Komi (1979) investigated the influence of skeletal muscle fibre composition on the mechanical performance of human skeletal muscle under dynamic conditions. The muscle fibre composition was determined by a needle biopsy technique. The vastus lateralis muscle was selected for biopsy. Histochemical analysis provided by staining for myofibrillar ATPase was used to classify fibres into categories of fast and slow twitch. Subjects (n = 34) performed maximal vertical jumps from two different positions. The first method was initiated from a static position (knee flexed at 90°) without a preparatory countermovement. The second procedure allowed for a preparatory countermovement in which the subjects began from a standing position initiated with a 90° knee flexion followed immediately by a maximal vertical jump. In both procedures, the subjects kept their hands on their hips to prevent any additional lift from the upward movement of the arms effecting the jump.

The results indicated that the countermovement jump significantly increased height of centre of gravity compared to jumps from the static position. The mean scores and SD for the groups were: 41.0 ± 6.1 cm for the countermovement jumps, and 35.9 ± 4.7 cm for the static jump group. The authors suggested that the stored elastic energy in the leg extensors contributed to the improved performance during countermovement jumps.

The degree of fast twitch muscle fibre distribution in the vastus lateralis muscle ranged from 19 to 76% ($\bar{x}$ = 50.7%; SD = 15.1%). The percentage of fast twitch fibres demonstrated a significant positive relationship with the height of jump in both static jump performance ($r = 0.37$, $p < 0.05$) and with countermovement jump performance ($r = 0.48$, $p < 0.01$).

2.6 Body Size and External Loading

The effects of external loading on short-term power output measured on a force platform has been examined by Davies and Young (1984). The subjects included ten children (11.8 $\pm$ 0.4 years) and four adults (22.7 $\pm$ 1.5 years). They performed single countermovement vertical jumps on a force platform and a cycling test to evaluate power. In the cycling test an optimal pedal frequency was established for each subject. During the maximal cycling test the peak force was taken as the maximal value recorded during a single revolution during the first 5 s of the test. Cycling velocity, average power and peak power were calculated for each revolution. Following the control measurement period, the subjects performed vertical jumps with varying degrees of external loading. The loading was evenly distributed over the subject's body by inserting small flat steel weights into specially designed overalls. The external loading represented approximately 5, 10, 15, 20, 25, and 30 percent of the children's body weight and 5, 10, 15, 30, and 40 percent of the adult's body weight.

The results demonstrated that under controlled (unloaded) conditions the absolute peak power output (W) achieved by children and adults was 572 W and 765 W respectively. Cycling produced peak power values which were 45% and 25% higher than jumping, for both the children and adults respectively. External loading decreased both the average and peak power outputs due to a reduction in velocity immediately prior to take-off.

2.7 Re-utilization of Stored Elastic Energy

To investigate the extent that the leg extensors are activated during a vertical jump, Van Soest et al. (1985) compared one-legged and two-legged vertical countermovement jumps in 15 male volleyball players. They recorded ground reaction forces, cinematographic and electromyographic data. The mean jump height from the single non-preferred leg was 58.5% of that of a two-legged jump. The mean net torques in the hip and ankle was higher in the single-legged vertical jumps. The net power output of a single-legged jump accounted for more than 50% of that of the two-legged total. Electromyographic data from this study showed an increased activation of the gastrocnemius and vastus medialis muscles, suggesting that when a vertical jump is performed from both legs simultaneously, the leg extensors and plantar flexor muscles are not activated maximally.

Bobbert et al. (1986) investigated the explosive movements involving the lower extremity elastic recoil and transportation of power from knee to ankle via the gastrocnemius muscle. This was associated with a power output about the ankle that rendered values over and above the maximal power output of the plantar flexors. The authors examined the relative power and work contributions of these two components for the push-off phase in one-legged jumping. Ten trained male subjects performed one-legged countermovement jumps with their non-preferred leg. Ground reaction forces and cinematographic data were recorded. The relative contributions of muscle fibres, tendinous structures, transfer of elastic energy on the total power output of the triceps surae muscle were calculated. The power output at the ankle closely resembled the curve obtained by the summation of the power output calculated from muscle fibres, tendons and the transferred energy (energy transferred from knee to ankle). The percentage contributions of the muscle fibre, tendons and transferred energy just prior to toe-off (50 ms) were 27, 53 and 27 percent respectively. Bobbert et al. (1986) concluded that elastic recoil and transferred energy are important components for high levels of performance during a vertical jump.

Cavagna et al. (1971) demonstrated that the power output from the knee extensor muscles during a vertical jump was significantly greater when the muscle was pre-stretched prior to contraction. The subjects in this study were five men and two women who performed three different methods of vertical jumping on a force platform. The first method was initiated without any preparatory countermovements before the upward movement phase of the vertical jump. The subjects chose the degree of flexion in their legs such that they felt it would produce a maximal jump. The position was held for three to five seconds to insure that the effect of pre-stretching was minimized. The second method allowed a countermovement which was characterized by a flexion in the knees prior to the upward phase of the vertical jump. The countermovement provides the knee extensors with the pre-stretch before contraction. The degree of knee flexion was chosen by the subjects to produce a maximal effort. The final method consisted of two consecutive jumps with the vertical jumps performed in the same manner as the subjects in the second group.

The results showed that the countermovement jump and consecutive jump produced significantly greater power outputs than the method with no pre-stretching of the knee extensors. The countermovement vertical jump produced 2.737 hp (2040 W) vs. 1.614 hp (1204 W) for the static jumping method. The authors concluded that pre-stretching which occurred in methods two and three was a major contribution to the greater power output observed in the non-stretching method. The energy cost for maintaining the active muscle was believed to be less in the pre-stretched muscle due to re-utilization of elastic energy during the positive jump phase (Cavagna et al., 1971).

The potential of muscles absorbing and temporarily storing mechanical energy in the form of elastic energy for subsequent utilization in a post-storage activity was investigated by Asmussen and Bonde-Petersen (1974). Using a force platform, 19 subjects performed three types of jumps: 1) a jump from a flexed static position; 2) a jump with a countermovement; and 3) a jump from drop heights of 0.23, 0.40 and 0.69 m. The performances of the countermovement jumps and the drop jumps were compared to those initiated from the flexed, static starting position. Compared to jumps from the flexed static starting position, the mean height of jumping increased 22.9% with a countermovement jump, 13.2 % with a drop height of 0.23 m, 10.5 % with a drop height of 0.40 m, and 3.3 % with a drop height of 0.69 m. The countermovement jumps and the drop jumps provided significantly greater jump heights than jumps without pre-stretching.

2.8 Muscle Metabolism and Energy Utilization

Muscles use chemical energy to perform physical activity whereby biological work is accomplished (Brooks and Fahey, 1984). The energy producing biochemical processes of the human body yield adenosine triphosphate (ATP), which is used by the tissues of the body to derive energy and heat. ATP is produced by three energy systems: (1) the ATP-CP system (or phosphagen system); (2) the anaerobic glycolysis system (or lactate system); and (3) the oxidation of fat, carbohydrate and protein molecules (the oxygen system). The oxidative or aerobic system is not fully activated until activity has persisted for several minutes (Green, 1982). The energy systems which are of main concern to this paper are the anaerobic systems. During the first few seconds of all-out exercise, the ATP-CP system is essentially depleted (Thoden et al., 1982) and thus the anaerobic breakdown of glycogen becomes increasingly prominent.

Boobis et al. (1983) investigated anaerobic metabolism during a brief supramaximal cycle ergometer test. Four subjects attempted to pedal as quickly as possible against a pre-set load (75 g/kgBW) for 30 s. The rotation of the flywheel was constantly monitored with the power output calculated for each second of the test. Peak power occurred between three and six seconds.

Muscle biopsy samples were taken from the quadriceps before and immediately after exercise on two occasions. The first muscle biopsy was sampled after 6 s of supramaximal exercise and the second after 30 s. The results showed an elevation in glycolytic intermediates and a decrease in glycogen within 6 s of exercise which indicates that the glycolytic processes were initiated early in the exercise.

Jacobs et al. (1983) investigated the post-supramaximal exercise lactate levels after 10 s and 30 s bouts of exercise. Twenty-two physical education students (15 males and 7 females) participated in this study. The supramaximal exercise task was the Wingate anaerobic test. Resistance was standardized so that one pedal revolution produced a power output of 4.90 W/kg. Subjects performed two all-out tests of 30 s and 10 s duration. Immediately after the completion of these tests, a muscle biopsy sample was taken from the vastus lateralis muscle. The 10 s lactate concentration, compared to exercise of 30 s duration, was 59% for the males and 46% for the females. The male subjects produced significantly greater lactate levels than female subjects after both 10 s and 30 s. The results demonstrate that substantial lactate accumulation from elevated rates of glycogenolysis occurs during supramaximal exercise of 10 s duration.

The usefulness of the ATP-CP system lies in the rapid availability of energy rather than the quantity. Lactic acid accumulates when there is an inadequate amount of oxygen available at the cellular level (Brooks and Fahey, 1984). When the ATP-CP system is substantially depleted, ATP is produced through the breakdown of glucose into lactic acid.

Fox (1979) compared the percentage of ATP contributed by the three energy systems in relation to performance time and power output. In activities in which the lactic acid system is important, at least one of the other two systems also is a significant contributor of ATP supply. Furthermore, it is important to note that the three energy systems cannot be thought of as isolated processes which operate independently during exercise; all three systems contribute concurrently (Brooks and Fahey, 1984).

Fox (1979) stated that the ATP-CP system dominates in activities less than 30 s while the oxygen system is predominant in events exceeding three minutes. Between 30 s and three minutes, the lactate system combines with the ATP-CP system and the oxygen system to provide the energy to perform the activity.

The duration of recovery periods recommended by Fox (1979) to obtain 100% resynthesis of the ATP-CP system is shown in Table 2.

Table 2: Duration of Relief Interval and ATP-CP Resynthesis

Relief Interval(s)	ATP-CP Restored (%)
less than 10	very little
30	50
60	75
90	88
120	94
more than 120	100

Saltin (1973) stated that the ATP-CP energy system does not play a major role in meeting energy requirements for repeated exercise bouts unless rest periods are at least one minute in duration. The significance of phosphagen replenishment has been questioned by several investigators. Saltin et al. (1977) reported that the energy available from ATP and CP concentrations of 5 and 20 mmol kg of wet skeletal muscle, respectively, could provide the energy for high intensity exercise of 5-15 s duration provided that the phosphagen stores are fully resynthesized to normal levels during the recovery periods.

Saltin and Essen (1971) examined the reloading of the phosphagens during the recovery period. Three subjects performed intermittent exercise for 30 minutes at a supramaximal load of 2400 kpm/min (392 W). The work and recovery periods were: 1) 10 s:20 s, 2) 20 s:40 s, 3) 30 s:60 s, and 4) 60 s:120 s. The ATP-CP depletion was most marked with the longer work periods. When the recovery periods lasted more than 20 seconds, a significant increase in the ATP-CP was observed in the muscle. It was concluded that reloading of ATP-CP during recovery periods of less than 20 s, plays, from a quantitative standpoint - an insignificant role in energy supply during intermittent exercise.

2.9 Mechanical Efficiency

The significance of pre-stretching a muscle and its effect on the mechanical efficiency of human skeletal muscle was investigated by Bosco et al. (1987). The focus of this study was to determine the contribution of the elastic recoil component to activities which utilized a stretch-shortening cycle compared to those that did not. Six male runners participated in three experimental conditions. The first was a run on a motor-driven treadmill for four to five minutes at a speed of 3.33 m/s. Foot contact time on the treadmill belt was measured with a special capacitive sole connected to an electronic digital timer. This provided a measure of the positive workphase from the total foot contact time. The second and third conditions utilized a 60 s continuous vertical jumping test (Bosco et al., 1983b) with and without an interruption between jumps. This was characterized by one condition in which the subjects were permitted to use a rebound between jumps such that the concentric work was immediately preceded by pre-stretching during the eccentric work phase. The second continuous vertical jump condition was executed with no rebound phase between jumps. The eccentric and concentric phases were separated by a 0.5 s pause which prevented the storage of elastic energy. Both series were performed with knee angular displacement of approximately 90° and executed on a force-platform sensitive to vertical ground reaction force.

The net mechanical efficiency ($\bar{x}$ and SD) for the running, rebound and non-rebound continuous vertical jumping was 54.5 ± 9.1%, 27.8 ± 5.3% and 17.2 ± 2.7%, respectively. In the jumping conditions, the rebound method was significantly more efficient than the non-rebound condition. The increased mechanical efficiency in the rebound condition above that achieved during the non-rebound condition was attributed to the delivery of stored elastic recoil which was transferred to the concentric contraction of the leg extensors via the elastic elements (Cavagna et al., 1974).

The extra work found in this study was greater in magnitude than in other studies using exercises similar to rebound jumping (Asmussen & Bonde-Petersen, 1974). The magnitude of the positive work delivered in this study was significantly greater than the calculated potential elastic energy stored within leg extensor muscles (Bosco et al., 1987). In running and rebound jumping, when active muscles utilize elastic energy, the contraction time is reduced. The re-utilization of stored elastic energy reduces the chemical energy needed to accomplish the activity. The mean times required to perform positive work in both rebound jumps ($\bar{x}$ = 282.5 ms) and running ($\bar{x}$ = 128.7 ms) were significantly shorter than the time in no rebound jumps ($\bar{x}$ = 372.2 ms). The contraction time during positive work demonstrated a strong relationship with the mechanical efficiency found in both jumping exercises and running performance.

The effect of pre-stretching a muscle on subsequent muscle economy has been studied by Bosco et al. (1987). The mechanical efficiency of 13 subjects during two different series of vertical jumps performed with and without pre-stretch was investigated. Both continuous jumping series were completed for 60 s at a frequency and jump height that the subjects felt they could maintain for the duration of the test.

In the first condition, jumping was performed continuously such that the subjects rebounded from one jump into another. This allowed storage and subsequent re-utilization of elastic energy to be transferred into the following jump. The second condition reduced the storage and re-utilization of elastic energy by placing a pause (approximately one second) between each jump. Both vertical jump series were executed with large knee angular displacement (approximately 90°). For the two vertical jump series, mechanical efficiency was defined as the percentage of the output of energy to the input of energy. The net input energy was taken as the chemical energy expended and the output energy as the mechanical work required to move the mass of the body upwards. Muscle economy was represented as a ratio of the efficiency of muscular work performed during pre-stretch and non-stretch conditions.

The net efficiency of positive work ($\bar{x}$ and SD) was 18.7 ± 2.7 and 27.3 ± 4.3 percent for non-rebound and rebound series, respectively. Bosco et al. (1987a) attributed part of the difference in net efficiency between the two conditions as the recoil of elastic energy in the rebounding condition, although the difference between the two conditions was not solely due to the elastic recoil phenomenon. The enhanced efficiency during a stretch-shortening cycle is also due to the observation that previous stretching decreased the time in which positive work is done during the next shortening cycle (Bosco et al., 1987). The re-use of elastic energy during positive work is dependent upon the amount of elastic energy stored during the eccentric phase and the duration of the coupling time. Therefore, depending upon the duration of the activity, subjects possessing higher percentages of slow twitch or fast twitch muscle fibres will store different quantities of elastic energy. Subsequently, if coupling time is longer than a few milliseconds, some of the fast twitch fibres are detached and their elastic potential lost. This is probably why the economy of jumping is higher in subjects with a high percentage of slow twitch fibres when jumping at slow and moderate rates (Bosco et al., 1987).

Chapter III

Methods

3.1 Subjects

Twenty-six male physical education students volunteered to participate as subjects. The subjects ranged in age from 19 to 37 years. They were physically active at differing levels of recreational and competitive sport.

3.2 Treatment of Subjects

Each subject performed the Bosco et al. (1983b) jumping test as well as three variations with each experimental condition performed for durations of 15 and 60 seconds. This experimental design is illustrated in Figure 1.

Test Condition	Measurement Interval	
	15 seconds	60 seconds
Standard Bosco Jump Test		
Cadence Jumping Test		
Rapid Jumping Test		
Standard Bosco Jump Test With 10% Added Body Mass Test		

Figure 1: Experimental Design

Prior to the commencement of the testing sessions, the subjects were instructed on the jumping protocols used for the four experimental conditions. The subjects were provided with demonstrations of each test and were permitted practice time. All tests were randomly performed over a one week period. Two trials (one 15 s trial and one 60 s trial) were performed on a single day with adequate recovery time (5 minutes) between trials. The 15 s test was always performed first to minimize the effect of fatigue on the subsequent 60 s trial. A five minute recovery time was chosen because it allowed for sufficient time to restore the depletion of energy following the first trial. (Fox, 1979; Saltin et al., 1977).

The subjects arrived for testing in proper athletic attire and were asked to refrain from eating, drinking (except water), and smoking for two hours prior to their testing. All subjects read and signed an informed consent document before the first testing session. A warm-up period was performed by the subject before each testing session. The warm-up consisted of light cycling and stretching of the quadricep and hamstring muscles.

3.3 Standard Bosco Jump Tests

The Bosco et al. (1983b) vertical jump test was used to evaluate mechanical power and capacity by measuring the flight time (T.) of consecutive vertical jumps during time intervals of 15 and 60 seconds. Flight time (T_f) was recorded with a digital timer (±0.01) that was connected to a resistive (or capacitive) mat. The timer was activated when the subject's feet were released from the mat (toe-off) and subsequently deactivated with the landing of the subject's feet (touch-down). The total time (T_t) of the test (15 or 60 s) was measured with a stopwatch (±0.01 s). Timing began when the toes of the subject left the mat and continued until contact was made with the mat immediately following the completion of the pre-determined time interval. The number of jumps during the test were counted.

During each jump, knee angular displacement was standardized at 90 degrees. Subjects received feedback from the researcher to indicate the position of legs during the test. To familiarize the subjects with the test, subjects were given practice trials which reduced the horizontal and lateral displacement during the test. The additional upward lift from the arms during the jump was eliminated by having the subjects place their hands on their hips throughout the testing.

The formula derived by Bosco et al. (1983b), for calculation of the average mechanical power is:

$$\text{Power (W/kg)} = \frac{g^2 \times T_f \times T_t}{4n(T_t - T_f)}$$

- g^2 is the acceleration due to gravity
- T_f is the flight time recorded by a digital timer

- T_t is the duration of the test
- n is the number of jumps performed during the test interval

Mechanical power output scores for test durations of 15 s and 60 s were reported in absolute (Watts) and relative terms (Watts/kg). The absolute score was obtained by multiplying the relative power output score by the subject's mass.

Bosco et al. (1983b) have evaluated the reliability of the jumping test by measuring the power output for every 15 s interval of a 60 second test. Volleyball players (n=12) repeated the jumping test on two successive days. The test-retest reliability correlation was $r = 0.95$ ($p < 0.001$).

The validity of the Bosco et al. jumping test was demonstrated by its strong correlation to the Wingate cycling test when both tests were conducted within a similar time frame. The 15 s Bosco et al. test was related to the 15 s modified Wingate test ($r = 0.87$) and the 60 s Wingate test associated closely with the 60 s Bosco et al. vertical jumping test ($r = 0.80$).

3.4 Cadence Jumping Tests

The Cadence Jumping tests were conducted similar to the Standard Bosco et al. test for the 15 s test, the subjects performed 15 jumps at a self-selected cadence. The subjects were not permitted to pause between jumps. The timing of this condition was continued until the feet of the subject touched down on the mat at the end of the 15^{th} jump.

For the 60 s test, the subjects jumped continuously at a pace of one jump per second. The cadence was presented to the subjects by a metronome set to a signal of one cycle per second. The test was terminated when the feet landed on the mat following completion of the 60^{th} jump.

3.5 Rapid Jumping Tests

The Rapid Jumping tests (15 s and 60 s) were administered in the same way as the Standard Bosco Jump tests with one exception. This condition differed in the instructions to the subjects before execution of the test. The instructions were: "Today, you will perform the Rapid Jumping test for 15 s (or 60 s). You should flex your legs to 90° with each jump and have a minimum amount of time on the mat but still attempt to obtain maximum flight time." During this test, no verbal feedback was given to the subjects pertaining to the degree of knee flexion. Hence, it was expected that some subjects would chose a knee angle less than 90° in order to minimize mat time.

3.6 Standard Bosco Jump Test with 10% Added Body Mass Condition

In this condition, the Standard Bosco Jump test was performed for 15 s and for 60 s with subjects externally loaded with 10% of their body mass (±0.01 kg). Subjects wore a vest that contained the appropriate mass. The additional mass was evenly distributed in the pockets of the vest which was secured to the torso of the subject.

3.7 Statistical Analysis

The statistical procedure was a single sample repeated measures analysis of variance (S X A). A series of planned comparisons were conducted to analyze the five dependent variables, between the Standard Bosco Jump test and each of the three experimental conditions. The dependent variables were, power output (W/kg), power output (W), flight time per jump (s), percent flight time (%), and mat time per jump (s). Univariate F-tests were conducted to determine if a comparison was statistically significant at the 0.05 level.

Chapter IV

Results

This chapter is divided into the following six sections:

4.1 Subjects' Characteristics

4.2 Descriptive Data for the 15 s Tests

4.3 ANOVA Results for the 15 s Tests

4.4 Descriptive Data for the 60 s Tests

4.5 ANOVA Results for the 60 s Tests

4.6 Pearson Product Correlations

4.1 Subjects' Characteristics

The subjects for this study were 26 male physical education students from McGill University. A summary of their physical characteristics (age, mass, and sum of five skinfolds) are presented in Table 3.

Table 3: Characteristics ($\bar{X}$ ± S.D.) of the Subjects (n = 26)

Variable	$\bar{X}$	S.D.
Age (years)	23.9	3.8
Mass (kg)	78.8	6.7
Sum of Skinfolds (mm)	48.5	17.9

4.2 Descriptive Data for the 15 s Tests

Table 4 shows the results for the five calculated variables: power output (W/kg), power output (W), flight time per jump (s), mat time per jump (s), and percent flight time. The test conditions are identified by numbers in Table 4.

Table 4: Results ($\bar{X}$ ± S.D.) for the Four Experimental Conditions of the 15 s Bosco Jump Test (n = 26)

Condition	1	2	3	4
Variable				
Power(W/kg)	20.8 ± 4.7	17.9 ± 3.2	24.9 ± 7.7	22.3 ± 6.2
Power(W)	1635 ± 376	1544 ± 294	1954 ± 560	1748 ± 462
T_f/J (s)	0.48 ± .07	0.44 ± .05	0.47 ± .05	0.50 ± .07
T_m/J (s)	0.61 ± .12	0.67 ± .13	0.45 ± .13	0.62 ± .12
T_f (%)	43.9 ± 5.7	39.9 ± 5.2	52.0 ± 8.8	44.8 ± 6.2

Condition 1 = Standard Bosco Jump Test

Condition 2 = 10% Added Body Mass Condition

Condition 3 = Rapid Jumping Test

Condition 4 = Cadence Jumping Test

4.3 ANOVA Results for the 15 s Tests

A series of planned comparisons were conducted, contrasting the Standard Bosco Jump test with the 10% Added Body Mass Condition, the Rapid Jumping test, and the Cadence

Jumping test. The design was a single sample repeated measures analysis of variance (S X A). The dependent variables were: power output (W/kg), power output (W), flight time per jump (s), mat time per jump (s) and percent flight time (%).

ANOVA results for the five dependent variables in the 15 s test are presented in tables 5, 6, 7, 8 and 9. The planned comparisons that are made in these tables are identified using the numbers associated with each test.

Condition 1 = Standard Bosco Jump Test

Condition 2 = 10% Added Body Mass Condition

Condition 3 = Rapid Jumping Test

Condition 4 = Cadence Jumping Test

Table 5: Analysis of Variance (Planned Comparisons) for Power Output (W/kg) Over 15 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	244.3	1	12.4	25	19.7	<.01
1 vs 3	417.4	1	35.6	25	11.7	<.01
1 vs 4	51.1	1	49.8	25	1.0	<.32

Table 6: Analysis of Variance (Planned Comparisons) for Power Output (W) Over 15 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	289146.0	1	76423.0	25	3.8	<.06
1 vs 3	241677.7	1	208066.4	25	11.6	<.01
1 vs 4	252948.5	1	292610.7	25	0.9	<.36

Table 7: Analysis of Variance (Planned Comparisons) for Flight Time per Jump (s) Over 15 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	.0291	1	.003	25	8.5	<.01
1 vs 3	.0003	1	.003	25	.02	<.90
1 vs 4	.0174	1	.007	25	2.3	<.14

Table 8: Analysis of Variance (Planned Comparisons) for Mat Time per Jump (s) Over 15 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	.008	1	.009	25	12.4	<.01
1 vs 3	.617	1	.026	25	24.0	<.01
1 vs 4	.009	1	.017	25	0.3	<.60

Table 9: Analysis of Variance (Planned Comparisons) for Percent Flight Time (%) Over 15 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	495.6	1	11.8	25	42.5	<.01
1 vs 3	1526.0	1	74.8	25	25.4	<.01
1 vs 4	4.5	1	46.5	25	.10	<.76

The following comments summarize the statistical analysis in Tables 5-9 for the 15 second tests. There were significant differences between the Standard Bosco test and the 10% Added Mass Condition for four dependent variables - power output (W/kg), flight time per jump (s), mat time per jump (s), and percent flight time (%). Compared to the

Standard Bosco test, there was a significant ($p < 0.05$) decrease in power (W/kg), decrease in flight time per jump (s), a decrease in percent flight time (%), and an increase in mat time per jump (s) when the 10% Added Mass Condition was performed. When the power output was expressed in watts, there was no significant difference between the Standard Test and the 10% Added Mass Condition.

When the Standard Bosco test was compared to the Rapid Jumping test, there were significant differences for four dependent variables - power output (W/kg), power output (W), mat time per jump (s), and percent flight time (%). Compared to the Standard Bosco test, there was a significant ($p < 0.05$) increase in power output (W/kg), an increase in power output (W), an increase in percent flight time (%), and a decrease in mat time per jump (s). There was no significant difference between the Standard Bosco test and the Rapid Jumping test for the variable flight time per jump (s).

There were no significant differences between the Standard Bosco test and the 15 s Cadence Jumping Test for any of the five dependent variables

4.4 Descriptive Data for the 60 s Tests

Table 10 displays the results for the five calculated variables: power output (W/kg), power output (W), flight time per jump (s), mat time per jump (s), and percent flight time (%).

Table 10: Results ($\bar{X}$ ± S.D.) for the Four Experimental Conditions of the 60 s Bosco Jump Test

Condition	1	2	3	4
Variable				
Power(W/kg)	15.4 ± 2.7	13.0 ± 2.0	21.0 ± 7.5	14.6 ± 2.2
Power(W)	1221 ± 221	1122 ± 183	1637 ± 556	1145 ± 180
T_f/J (s)	0.41 ± .04	0.37 ± .05	0.42 ± .05	0.38 ± .04
T_m/J (s)	0.77 ± .15	0.81 ± .14	0.47 ± .17	0.65 ± .05
T_f (%)	34.9 ± 5.4	31.3 ± 4.1	48.6 ± 11.1	37.0 ± 3.4

Condition 1 = Standard Bosco Jump Test

Condition 2 = 10% Added Mass Jump Condition

Condition 3 = Rapid Jumping Test

Condition 4 = Cadence Jumping Test

4.5 ANOVA Results for the 60 s Tests

For the 60 s tests, a single sample repeated measures analysis of variance (S x A) design was used for data analysis. The dependent variables for the 60 s test were the same as for the 15 s test conditions. The ANOVA results for the 60 s tests are located in Tables 10, 11, 12, 13, and 14 for the five dependent variables: power output (W/kg), power (W), flight time per jump (s), mat time per jump (s), and percent flight time (%), respectively.

Table 11: Analysis of Variance (Planned Compar'sons) for Power Output (W/kg) Over 60 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	163.4	1	4.50	25	36.3	<.01
1 vs 3	763.5	1	39.7	25	19.3	<.01
1 vs 4	21.8	1	4.1	25	5.29	<.03

Table 12: Analysis of Variance (Planned Comparisons) for Power Output (W) Over 60 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	294262.0	1	30231.2	25	9.7	<.01
1 vs 3	4337216.2	1	193622.5	25	22.4	<.01
1 vs 4	177915.8	1	25553.5	25	7.0	<.01

Table 13: Analysis of Variance (Planned Comparisons) for Flight Time per Jump (s) Over 60 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	.005	1	.001	25	29.0	<.01
1 vs 3	.000	1	.002	25	.17	<.70
1 vs 4	.030	1	.002	25	19.5	<.01

Table 14: Analysis of Variance (Planned Comparisons) for Mat Time per Jump (s) Over 60 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	.03	1	.02	25	2.0	<.15
1 vs 3	2.35	1	.04	25	64.2	<.01
1 vs 4	.38	1	.02	25	17.9	<.01

Table 15: Analysis of Variance (Planned Comparisons) for Percent Flight Time (%) Over 60 s

Comparison	Hypoth.MS	df	Error MS	df	F	P
1 vs 2	537.8	1	21.4	25	25.1	<.01
1 vs 3	4243.7	1	102.7	25	41.3	<.01
1 vs 4	33.7	1	24.6	25	1.4	<.25

The following comments summarize the statistical analysis in Tables 10-15 for the 60 second tests. There were significant ($p < 0.05$) differences between the Standard Bosco test and the 10% Added Mass Condition for four dependent variables - power output (W/kg), power output (W), flight time per jump (s), and percent flight time (%). Compared to the Standard Bosco test, there was a significant decrease in power (W/kg), power (W), flight time per jump (s), and percent flight time (%). There was no significant difference between the conditions for the variable, mat time per jump (s).

When the Standard Bosco test was compared to the Rapid Jumping test, there were significant differences for four variables. Compared to the results for the Standard Bosco test, the Rapid Jumping test produced increased power output (W/kg), increased power output (W), increased percent flight time (%) and decreased mat time (s). There was no significant difference between the conditions for the variable, flight time per jump (s).

When the Standard Bosco test was compared to the Cadence Jumping test, there were significant differences for the four variables. Compared to the results for the Standard Bosco test, the Cadence Jumping test produced significantly lower power output (W/kg), lower power output (W), lower flight time per jump (s), and lower mat time per jump (s). There was no significant difference between the conditions for the variable, percent flight time (%).

4.6 Pearson Product Correlations

When the Bosco Jump Test is performed, frequently the results are expressed by a single variable - power output (W/kg). In Table 16, the variable, power output (W/kg) is correlated with the four other dependent variables for both the 15 s and the 60 s tests.

Table 16: Pearson Product Correlation Coefficients Between Power Output (W/kg) at 15 and 60 s With the Dependent Variables from the Standard Bosco Jump Test

Power Output (W/kg) versus	15 s Test	60 s Test
Power (Watts)	.94	.86
Flight Time/Jump	.95	.89
Mat Time/Jump	-.40	-.41
Percent Flight Time	.83	.73

For a sample size of n = 26, the results from the Pearson Product Correlation at the 0.05 level of probability produced these relationships. For both the 15 s and 60 s tests, there is a good correlation between the power output (W/kg) and the variable - power output (W/kg), flight time per jump (s), and percent flight time (%).

Chapter V
Discussion

In this study, four experimental conditions were used: Standard Bosco Jump test, a 10% Added Body Mass condition, a Rapid Jumping test, and a Cadence Jumping test. For comparisons between the present study and other studies which have used the Bosco jump test only results from the Standard Bosco test will be used. Comparisons between the Standard Bosco Jump test and the three treatment conditions are also made in this chapter.

5.1 Condition 1: The Standard Bosco Jump Test

The power output scores produced in this study tended to be lower than those cited in other studies which used the Bosco Jumping test protocol. Table 17 displays the power scores (W/kg) from the present study, and studies using the Bosco Jump test (Bosco et al., 1983b; Kirkendall and Street, 1986; Viitasalo et al., 1987; Bosco et al., 1986). In this study, the mean power scores were 20.4 W/kg over 15 s and 15.4 W/kg over 60 s. Bosco et al. (1983b) reported power output for 15 s tests of 24.7 and 26.8 W/kg for basketball players and volleyball players respectively. For the 60 s tests, the power output was 19.8 W/kg for the basketball players, 21.6 W/kg for the volleyball player and 22.2 W/kg for the school boys.

Table 17: Comparison of Power Output (W/kg) from Various Studies Using the Bosco Jump Test

Group	n	Power Output (W/kg) 15 s	60 s	Reference
Basketball players	12	24.7	19.8	Bosco et al. 1983b
Volleyball players	12	26.6	21.6	Bosco et al. 1983b
School boys	14		22.2	Bosco et al. 1983b
Ballet Dancers	12		18.1	Kirkendall & Street 1986
College Wrestlers	24		18.6	Kirkendall & Street 1986
Football Players	19		20.8	Kirkendall & Street 1986
Soccer Players	19		20.9	Kirkendall & Street 1986
Indoor Soccer Players	22		21.5	Kirkendall & Street 1986
Amateur Bobsledders	7		21.9	Kirkendall & Street 1986
Basketball Players	16		22.2	Kirkendall & Street 1986
Young Athletes	35	21.4		Viitasalo et al. 1987
Track Athletes				
Fast Twitch Group	8	26.2		Bosco et al. 1986
Slow Twitch Group	6	21.5		Bosco et al. 1986
University Students				
Standard Bosco test	26	20.8	15.4	Present study
10% Added Mass test	26	17.9	13.0	Present study
Rapid Jumping test	26	24.4	21.0	Present study
Cadence Jumping test	26	22.3	14.6	Present study

In a study by Kirkendall and Street (1986) power output was measured with the Bosco et al. (1983b) protocol. The subjects were participants in six athletic teams and ballet dancers (n = 119). The calculated power output (W/kg), from each of the seven groups in Kirkendall and Street's (1986) study were higher than the power output scores obtained by subjects in the present study.

Bosco et al. (1986) calculated power output (W/kg) from fourteen track athletes. The athletes were placed into two groups; one group possessing a high percentage of fast twitch muscle fibres and a second group with a lower percentage of fast twitch muscle fibres. The results from a 15 s duration Bosco Jump test produced power outputs of 26.2 and 21.5 W/kg for groups I and II respectively. The group with the higher percentage of fast twitch fibres generated higher power output scores than the present study. However, the power output obtained from the group with the low percentage fast twitch fibres produced power output scores comparable to the scores of the present study.

There may be three explanations for the discrepancies found between the power output cited in other studies and the power output from the present study. (1) Other studies (Bosco et al., 1983b; Kirkendall and Street, 1986; Bosco et al., 1986) used subjects from various athletic teams who were probably better and more specifically trained than the physical education students in this study. (2) Since the percentage of fast twitch muscle fibre is a significant contributor to overall power output (Bosco et al., 1986), it is possible that the subjects from this study possessed a low mean percentage of fast twitch muscle fibres. The group of subjects with a low percentage of fast twitch muscle fibres in the study by Bosco et al. (1986) demonstrated similar results to those obtained in this study. (3) The Bosco Jump test protocol states that a standard knee angle of 90° be achieved during the eccentric and concentric phase of landing. The degree of knee flexion during the jump test was closely observed during the testing in this study. If the degree of knee flexion is not closely controlled, then power output may increase due to the reduction of mat time between jumps. The degree of knee flexion may not have been as strictly imposed on the subject in other studies. An example of this may be shown in a study by Bosco et al. (1983b). In this study the power output (W/kg) and the number of jumps for two groups were reported. One group, a men's basketball team (n = 12) performed the Bosco jump test for 60 s and produced a mean power output of 19.8 W/kg. The mean number of jumps for this group was 56.8 jumps for 60 s. A second group, consisting of school boys (n = 14) produced a mean power output score of 22.2 W/kg. The mean number of jumps for the second group was reported to be 63.2 for 60 seconds.

The expectation that a group of school boys would obtain higher mean power output (W/kg) than a group of adult male basketball players seems unlikely. However, if a comparison between the number of jumps is made for each group it is seen that the school boy group had 6.4 more jumps during a 60 s test than the basketball players. This suggests that the degree of flexion at the knee may not have been controlled between jumps. This would reduce mat time per jump and increase power output. This may account for the difference between the power output scores by the two groups and suggest a reason for the higher power output obtained by the school boy group.

5.2 Condition 2: Added Body Mass Condition

This condition was designed to investigate the effect of increased body mass on the production of power output. The subjects were required to carry 10% of their body mass secured to their torso while performing the Standard Bosco Jump test. Power output in relative terms (W/kg) and absolute units (W) were calculated for test durations of 15 and 60 seconds.

When power output was calculated in relative terms (W/kg), the magnitude of the power was significantly lower than in the other experimental conditions. However, when power output was expressed in absolute terms, it was found that no significant differences existed between the Standard Bosco test values and the 10% Added Mass condition over 15 s. In the 60 s tests, the Added Mass condition produced significantly lower power output compared to the Standard Bosco test.

An explanation for the lower calculated power output was suggested by Davies and Young (1984). They used a force platform to measure force during single countermovement vertical jumps when the subjects were externally loaded with 0, 5, 10, 15, 20, 25, and 30 percent of their body weight.

They found that external loading decreased both the average and peak power output. This finding was attributed to a reduction in velocity immediately prior to take-off.

In a study conducted by Van Soest et al. (1985) a comparison was made between single and double legged jumps. The variables measured were jump height and power output from both a single (non-preferred) leg and from both legs. The results from this study showed that the mean net torques in the hip and ankle were higher in the single-legged vertical jump. The mean jump height from the single non-preferred leg was 58.5% of that of a two-legged jump. The net power output of a single-legged jump accounted for more than 50% of that from the two-legged total. This study found increased muscle activation in the vastus medialis muscle and gastrocnemius muscle during the single leg jumps. The authors suggested that when a jump is performed with both legs simultaneously, the leg extensor muscles and plantar flexor muscles are not activated maximally.

In this study it was found that for the 15 s tests, the relative power output (W/kg) from the Standard Bosco test was 14% higher than the power (W/kg) from the 10% Added Mass condition. When expressed in relative terms (W) the difference decreases to 5.6% between the two tests over 15 s. When power output is calculated using the Bosco formula, heavier subjects may obtain a lower power output scores if the score is expressed in W/kg. However, when the scores are presented in absolute terms for the 15 s test, the difference between the tests is decreased if the subjects carry additional mass. For the shorter duration test (15 s), additional body mass is less of a hinderance during performance than in a longer test (60 s). This study cannot determine whether the 10% Added Body Mass condition increased activation of the leg extensor muscles and gastrocnemius muscles. It appears that for a reciprocal jump test, a duration of 15 s is too short to effect tne power output when expressed in absolute terms.

For the 60 s test, there were significant differences between the Standard Bosco test and the 10% Added Mass condition for both relative (W/kg) and absolute (W) power output. The lower power output for both W/kg and W can be attributed to fatigue. Due to the lack of specific training, many subjects had difficulty in completing the 60 s test. The fatigue from the 60 s test was increased in the Added Mass condition.

Added mass has been shown to significantly decrease flight time per jump for tests of 15 and 60 s durations (Davies and Young, 1984). Added mass may increase mat time per jump because: (1) the subjects require additional time to stabilize and balance while reaching a knee angle of 90°, (2) require increased time for the chemo-mechanical conversion of energy to compensate for the additional load, and (3) the elastic recoil potential may have been exceeded and its effect reduced (Cavagna et al., 1971; Asmussen and Bonde-Petersen, 1974; Saltin, 1973; Bosco et al., 1987). The summation of lower flight times per jump and increased mat time would account for a significantly lower percent flight time for the Added Mass condition.

5.3 Condition 3: Rapid Jumping Test

The Rapid Jumping condition was designed to measure power output when the subjects were given specific instructions to maximize flight time and reduce mat time. This condition was the only condition where feedback to obtain 90° at the knee was withheld. The Rapid Jumping condition demonstrated the highest relative (W/kg) and absolute (W) power output scores among the four tests. The power output in the Rapid Jumping condition was significantly higher than that achieved from the Standard Bosco test condition. The Rapid Jumping test was the only experimental condition that obtained power output scores comparable to those cited in Table 17.

The formula for power output derived by Bosco et al. (1983b) is:

Power Output W/kg = $\dfrac{9.8^2 \times T_f \cdot T_t}{4(n)\ (T_t - T_f)}$. Since flight time is located in the numerator and mat time in the denominator, a strategy which produces high flight time and low mat times would influence the power output scores. In this study, a reduction in mat time in the Rapid Jumping condition produced the highest power output values. Since the subjects were not corrected for knee flexion, it was found that they jumped more frequently during the tests at both test durations (15 and 60 s). Although the subjects jumped more frequently, they produced a similar score for the variable - flight time per jump in the Rapid Jumping condition compared to the Standard Bosco jump test. The instructions provided to the subjects were to minimize mat time. In the 15 s test, mat time per jump decreased from .61 s per jump in the Standard Bosco jump condition to .45 s per jump for the Rapid Jumping condition. For the 60 s test, the mat time decreased from .77 to .47 s/jump.

The Rapid Jumping condition demonstrated the influence of strategy on the power output scores and the need to standardize the instructions given to the subjects. It is also necessary to insure that when the subjects perform the Bosco jump test, that the correct knee angle is achieved between each jump. If knee angle is not closely observed, subjects who select a better strategy in relation to the Bosco formula will achieve higher power output scores.

5.4 Condition 4: Cadence Jumping Test

The purpose for the Cadence Jumping test was to examine power output when the number of jumps the subjects performed was held constant. Tests using 15 jumps and 60 jumps represent the typical frequency of jumping for tests of 15 and 60 seconds duration. The 15 jump test was performed at a self-selected pace. The test duration therefore was different for each subject. When subjects selected their own jump frequencies, the 15 jump test produced similar power output scores as the Standard Bosco test. The flight time per jump, mat time per jump, and percent air time were similar to that obtained in the Standard Bosco test. When the subjects chose their own cadence for 15 jumps and maintained a knee flexion angle of 90°, there was no significant difference between the 15 jump test and the Standard Bosco test.

The 60 s jump test was performed at a frequency of one jump per second for 60 jumps. The relative power output (W/kg) and absolute power output (W) were significantly lower than the Standard Bosco test. The variables - mat time per jump and flight time per jump were both significantly different from the Standard Bosco test. The flight time per jump and mat time per jump were both lower than the Standard Bosco test. Adherence to a cadence of one jump per second was restrictive and prevented subjects from obtaining a high power output, even though the mat time per jump was lower in this condition than in the standard test. The pre-selected pace reduced the mean flight time jump in the Cadence Jumping condition. Placing subjects on this cadence frequency was not beneficial for the production of higher power output scores.

5.5 Variable Correlations

The variables T_c/J, T_s/J, and % T_f were correlated with the power output scores at 15 and 60 s. The relationship between the 15 s and the 60 s power output scores for the Standard Bosco test was .70. The correlations for $T_f/5$ and % T_f with the 15 s power output (W/kg) scores was .95 and .83 respectively. For the 60 s test the relationship between T_f/J and % T_f with power output (W/kg) was .89 and .72 respectively.

The high correlation between T_f/J and % T_f with power output suggest that these variables are representative of the power production in these subjects.

Chapter VI

Summary, Conclusions and Recommendations

6.1 Summary

The purpose of this study was to examine the variables, power output (W/kg), power output (W), flight time per jump (s), mat time per jump (s), and percent fight time (%) when the Bosco jump test was performed under four conditions:

1) the Standard Bosco Jump Test
2) the 10% Added Body Mass Condition
3) the Rapid Jumping Test
4) the Cadence Jumping Test

The Standard Bosco Jump test was administered to subjects as described by Bosco et al. (1983b). The 10% Added Body Mass condition consisted of the subject performing the Standard Bosco Jump test while wearing a vest containing 10% of their body mass (± 0.01 kg) securely fastened to their torso. For the Rapid Jumping condition, the subjects were instructed to maximize flight time and minimize mat time during the test. The Cadence Jumping test was implemented by the subjects jumping at a self selected cadence for 15 jumps in the first test condition. For the second test condition, a frequency of one jump per second for 60 jumps was performed. Each of the four test conditions was performed at test durations of 15 s (or 15 jumps) and 60 s (or 60 jumps).

The subjects were 26 physical education students from McGill University and were not part of a specific sports team. The subjects performed a total of eight tests. Four tests were conducted at a duration of 15 s (or 15 jumps in the cadence test). The remaining four tests were performed by the subjects for a duration of 60 s (or 60 jumps in the cadence test). Each test session consisted of a 15 s test, a five minute rest and a 60 s test. The order of the tests were randomly assigned with a 15 s test always preceding a 60 s test.

The statistical procedure was a one-way analysis of variance with repeated measures. A series of planned comparisons were conducted to analyze the five dependent variables between the Standard Bosco Jump test and the three experimental conditions.

The first hypothesis of this study stated that there would be no significant differences in power output (W/kg) between the Standard Bosco test and the three experimental conditions during tests of 15 and 60 second duration. The one-way analysis of variance for the comparisons at 15 s between the Standard Bosco test and the 10% Added Body Mass condition revealed a F-ratio of 19.7 which was significant at the 0.05 level. In this comparison, the Standard Bosco test generated higher power output values (W/kg) than the 10% loaded condition. The second comparison was made between the Standard Bosco test and the Rapid Jumping condition. The

Rapid Jumping condition produced power output values which were significantly ($F = 11.7$; $p < 0.05$) greater than the Standard test. For the comparison between the Cadence Jumping test and the Standard test, no significant difference was found. The power output (W/kg) achieved in the 60 s test in the 10% Added Mass condition, the Rapid Jumping test, and Cadence Jumping test were all significantly different from the scores produced by the 60 s Bosco test. F-values of 36.3, 19.2 and 5.3 were found for each respective comparison.

The second hypothesis of this study stated that there would be no significant differences between the absolute power output (W) from the Standard Bosco test and the three experimental conditions during tests of 15 and 60 s duration. For the comparison between the Standard Bosco test and the 10% Added Body Mass condition, an F-value of 3.8 was produced. This value was not significant at the 0.05 level. The Rapid Jumping test produced significantly (F-ratio = 11.6) greater power output values (W) than the Standard Bosco test. There was no significant difference in power output values between the Cadence Jumping test and the Standard Bosco test.

The third hypothesis of this study stated that there would be no significant difference in flight time per jump (s) between the Standard Bosco Jump test and the three experimental conditions during tests of 15 and 60 s in duration. When the Standard Bosco test was compared to the

10% Added Body Mass condition, an F-value of 8.5 was obtained for the 15 s test. Flight time per jump was lower in the 10% Added Body Mass condition than in the Standard Bosco test. For the comparisons between the Standard Bosco test with the Rapid Jumping test and the Cadence Jumping test there were no significant differences for the variable, flight time per jump.

The fourth hypothesis of this study stated that there would be no significant differences in mat time per jump between the Standard Bosco Jump and the three experimental conditions during tests of 15 and 60 s durations. There were significant differences between the Standard Jump test with (1) the 10% Added Body Mass condition and (2) the Rapid Jumping condition with F values of 12.4 and 24.5 respectively. The Cadence Jumping test did not differentiate significantly from the Standard Bosco Jump test.

The fifth hypothesis stated that there would be no significant difference in percent flight time (%) between the Standard Bosco test and the three experimental conditions during tests of 15 and 60 second durations. Analysis of this variable revealed that the 10% Added Body Mass condition and the Rapid Jumping test condition were significantly different from the Standard Bosco test (F-values of 42.0 and 20.4 respectively). The Cadence Jumping test was not statistically different from the Standard test for the variable, percent flight time.

6.2 Conclusions

Within the limitations of this study the following conclusions are warranted:

1) Compared to the Standard Bosco test, the Rapid Jumping test had a higher power output (W and W/kg), a higher T_f (%), a lower Tm/Jump, and similar T_f/Jump for 15 seconds.

2) Compared to the Standard Bosco test the Rapid Jumping test had a higher power output (W and W/kg), a higher T_f (%), a lower T_m/Jump, and similar T_f/Jump for 60 seconds.

3) Compared to the Standard Bosco test, the Cadence Jumping test had a similar power output (W and W/kg), T_f/Jump, T_m/Jump, and T_f (%) for the 15 second test.

4) Compared to the Standard Bosco test, the Cadence Jumping test had a lower power output (W and W/kg), a lower T_f/Jump, a lower T_m/Jump, and similar T_f (%) for the 60 second test.

5) Compared to the Standard Bosco test, the 10% Added Body Mass condition had a lower relative power output (W/kg), similar absolute power output (W), lower T_f/Jump, lower T_f (%), and higher T_m/Jump for the 15 second test.

6) Compared to the Standard Bosco test, the 10% Added Mass condition had a lower relative and absolute power output (W/kg), lower T_f/Jump, lower T_f (%), and similar T_m/Jump for the 60 second test.

6.3 Recommendations

1) Whenever the Standard Bosco test is administered, it is important to interpret such variables as T_f/Jump, T_m/Jump and T_f (%) in addition to power output (W and W/kg). If knee flexion is not maintained at 90° between each jump, then decreasing mat time will increase the power output score.

2) Since added mass was shown to be detrimental to performance of the Bosco test, the Body composition of the athlete must be considered when interpreting the power output score and the T_f/Jump scores.

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