THE EFFECT OF BILATERAL AND VERTICAL PLYOMETRIC TRAINING ON VERTICAL AND HORIZONTAL MOVEMENT IN COLLEGE-AGED MALES

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Abstract

The purpose of this study was to examine the effect of bilateral and predominantly vertical plyometric (BV) training on vertical jump (VJ) and sprint (SP) performance. Seventeen moderately-trained males were randomly assigned to either a plyometric training group (n=9; TG) or a no-training control group (n=8; C). The TG subjects trained twice weekly for eight weeks. Countermovement jump (CMJ), two-step jump (2SJ), right foot jump (RFJ), left foot jump (LFJ) and SP speed over 5, 10, 15, 20 and 36m were measured at weeks 0, 4 and 8. TG subjects improved their CMJ and 2SJ height from weeks 4 to 8 ($p<0.05$) and from weeks 0 to 8 ($p<0.05$) beyond the C subjects. No significant improvements were observed in RFJ, LFJ or any SP speed measures. The results suggest that a specific BV training program improves performance in activities that have primarily BV components but has no transfer to activities with predominantly unilateral or horizontal components.

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Dedication

This project is dedicated to Kama, to Zeke and to all of the warm and loving people that I had the pleasure to meet in Victoria.

Chapter 1

Introduction

Many athletes involved in sports that demand powerful actions, such as a two-foot vertical jump (VJ), participate in plyometric training. Plyometric training involves exercises that typically require repeated stretch-shortening cycle (SSC) activation and high power outputs, such as drop jumping or bounding. The SSC is characterized by an initial rapid eccentric stretch of muscle that facilitates the force generated by a subsequent concentric contraction (Bosco, Viitasalo, Komi & Luhtanen, 1982). Performances of the VJ and sprint (SP) stride are both influenced by SSC action. The landing of the SP stride facilitates the concentric push-off by eliciting SSC activity. Although the VJ can be performed as a static jump (SJ) where the performer initiates the jump from a semi-squat position, it is typically performed as a countermovement jump (CMJ; Komi, 1984). A CMJ is characterized by a brief period of unloading - achieved through hip flexion, knee flexion, and ankle dorsiflexion - followed immediately by a jumping action. Comparison of the CMJ and SJ reveal that a jumper can achieve greater height with a countermovement (Asmussen & Bonde-Petersen, 1974; Bosco, Tarkka & Komi, 1982). This performance difference can be explained by the facilitation of the CMJ by the SSC. The mechanisms by which the SSC potentiates concentric contraction include elastic energy utilization, reflex potentiation and improved tendon and fibre interaction (Huijing, 1992).

Interest in plyometrics began in the 1970s as East European athletes began to dominate gymnastics, weightlifting and track and field jumping events. Investigation of the training practices of these athletes revealed that they were involved in what is now known as plyometric exercise (Chu, 1992). The ability of plyometric training to improve SSC action, power output, and ultimately VJ performance, has been observed in controlled studies. Blakey and Southard (1987) found significant improvements in dynamic leg strength and Margaria Anaerobic Power Test scores after eight weeks of drop jump and regular jump training. In an investigation of unskilled male jumpers involved in an eight-week plyometric training program, Bartholemew (1985) observed mean VJ increases of 10.2 and 11.7cm for drop jumping and regular jumping, respectively.

The association of plyometric training with VJ improvement has led to the incorporation of plyometric training into a range of sports. Many athletes have adopted plyometrics to develop other components of sport that rely on high power output, such as running speed and agility. Although the inference that plyometric training may improve running speed is theoretically sound, controlled examination of the efficacy of plyometric training for improving the speed of horizontal movement is limited (Rimmer & Sleivert, in press; Stannard, 1996). Therefore, the purpose of this study was to examine the effect of plyometric training, performed bilaterally and in the vertical plane (BV), on VJ and SP performance.

Hypotheses and Research Questions

The study attempted to answer the following research questions:

1. Will the change in performance of CMJ (ΔCMJ), two-step jump (Δ2SJ), left foot jump (ΔLFJ) or right foot jump (ΔRFJ) differ between groups of university-aged, moderately active subjects after eight weeks of either BV plyometric training or no training?

Ho_1: $\mu_{TG;\Delta CMJ} = \mu_{C;\, \Delta CMJ}$

Ho_2: $\mu_{TG;\Delta 2SJ} = \mu_{C;\, \Delta 2SJ}$

Ho_3: $\mu_{TG;\Delta LFJ} = \mu_{C;\, \Delta LFJ}$

Ho_4: $\mu_{TG;\Delta RFJ} = \mu_{C;\, \Delta RFJ}$

2. Will the change in performance of 0-5m SP (ΔSP0-5) or 0-36m SP (ΔSP0-36) differ between groups of university-aged, moderately active subjects after eight weeks of either BV plyometric training or no training?

Ho_5: $\mu_{TG;\Delta SP0\text{-}5} = \mu_{C;\ \Delta SP0\text{-}5}$
Ho_6: $\mu_{TG;\Delta SP0\text{-}36} = \mu_{C;\ \Delta SP0\text{-}36}$

Limitations

Force plate measurements were not feasible at the time of study. Force plate recordings would have allowed for observation of jumps with no countermovement (static jumps). By comparing static jump measures to CMJ heights, the relative contribution of the SSC to jump performance can be determined. Additionally, qualitative analysis of pre- and post-training force plate data, and of EMG recordings of the lower body musculature may have offered valuable insight into the factors associated with VJ improvement.

Delimitations

The subjects involved in this study were university-aged males enrolled in physical education classes or involved in intramural athletics. Although the aim of the study was to examine the effect of BV plyometric training on VJ and SP performance, generalizations to all athletes involved in sports that demand high VJ or SP performance may not be appropriate. Kraemer and Newton (1994) identified maximum force, maximal rate of force development and neural co-ordination as the determining factors of VJ height. Consideration of these factors and the difference in training state between the moderately active subject sample and a population of elite athletes could supercede any generalizations to an elite population. The effect of the training, or lack thereof, in the moderately trained subjects may have been a product of factors of

VJ height that may be different in a highly trained population. Furthermore, the magnitude of transfer to SP performance may also depend on the individual factors of VJ performance. Since neither the loci of any training effect nor the transferability of improvements in individual factors of VJ height can be assured, generalization to the elite population is inappropriate.

A similar disparity in training state is possible between an untrained and/or very young population and the moderately trained subject sample. Consequently, generalizations of the study to these populations may also be inappropriate.

Furthermore, consideration should be given to the potential for improvement in either a highly-trained or in an untrained population and may further suggest that generalizations to these groups should be avoided.

Operational Definitions

Countermovement jump (CMJ) – Refers to a maximal jump with a preliminary countermovement, a two-foot take-off and a predominance of movement straight upwards.

Static Jump (SJ) – A vertical jump performed from a semi-squatting start position with no preliminary countermovement.

Drop Jumping Exercises – Exercises that involved an initial drop from a 37cm step.

Stretch-shortening cycle (SSC) - The SSC action of muscle is characterized by a rapid eccentric action followed by a brief period of supramaximal tension and a concentric contraction (Bosco, Viitasalo, Komi & Luhtanen, 1982).

Volume – the volume for each training session was the product of sets and repetitions (total foot contacts).

Chapter 2

Research Methods

Subjects

Seventeen male volunteers (mean age 23 SD 4 yr; height 1.82 SD 0.07 m; and weight 81.0 SD 9.0 kg; Appendix A) completed the study. All subjects were enrolled in physical education classes, competed in intramural sports, or both. All subjects were tested for the ability to front squat 125% of their body weight before beginning training as recommended by Allerheilegen (1994). Subjects who had participated in lower body plyometric training and/or lower body injury within the previous six months were excluded from the study. Subjects were randomly assigned to either a BV plyometric training group (n=9; TG) or to a no training control group (n=8; C). Two subjects could not complete the program owing to injury not related to the training program.

Approval was obtained from the University of Victoria Human Ethics Committee before any testing or training were administered. All subjects completed an informed consent form (Appendix C) before participating in testing or training.

Testing

Testing sessions were conducted during weeks zero (pre-test), four (mid-test) and eight (post-test) of the eight-week training period. Training volume was slightly reduced for the last session in an attempt to control the potential effect of cumulative fatigue from the training on the final testing session. A rest period of 72-96h was allotted between the final training day and the post-training test session. Sprint tests preceded jump tests at every test session. For all performance tests the highest of three trials was recorded. Rest intervals of approximately 30 s and 2 min separated the jump and sprint tests, respectively. The following measures were taken:

1. *Height (cm) and weight (kg)*
2. *Countermovement Jump (CMJ)* – Subjects were instructed to stand with the right shoulder to the wall and reach up with the right hand. The height of the middle finger was recorded and considered 'stand-and-reach' height. Subjects jumped maximally off two feet with a preliminary countermovement. No limitation was placed on the countermovement executed by each subject to allow the most unconstrained performance of the jump. The highest mark made on the wall with the pre-chalked fingers of the right hand was considered 'jump-and-reach' height. Jump height was determined by subtracting stand-and-reach height from jump-and-reach height.
3. *Two-step jump (2SJ)* – Subjects positioned themselves at a 45° angle and approximately six to ten feet from the jumping wall. Two steps (left foot then right) were taken toward the wall, followed by a maximal two-foot jump-and-reach with countermovement. All jumps were attempted from the left side of the wall.
4. *Left foot jump (LFJ)* – Subjects positioned themselves at a 45° angle and approximately four to eight feet from the left side of the jumping wall. With the right foot planted, a single long step was taken toward the wall, followed by a maximal left foot jump-and-reach.
5. *Right foot jump (RFJ)* – Performed as above with a right foot jump from the right side of the wall.
6. *Sprint speed* – sprints were executed on an indoor course. Subjects began from a standardized start to control for any rocking motion. Subjects were instructed to start with feet staggered and parallel and with the head above the front foot and to sprint 36m as fast as possible. The times at 5 and 36m were recorded with timing lights (Brower

Timing Systems Model #175; sensitive to one hundredth of a second) for analysis. The times at 10, 15 and 20m were recorded for discussion purposes.

Training

All groups were asked to refrain from beginning any supplementary sprint, plyometric or lower body resistance training for the duration of study. The TG subjects were scheduled to train twice per week for eight weeks. Subjects were instructed to perform a 10-minute low-intensity aerobic warm-up before each training session followed by five minutes of static lower-body stretching. A set consisted of five repetitions of each exercise. The rest time between repetitions was the time for the subject to return to the starting point of the exercise (approximately 3-5s). Sets were interspersed with 60-90 s rest periods. Pre-study performance of the TG program revealed that the adoption of shorter rest periods interfered with the maintenance of maximal VJ height in the later sets of the session. The rest periods were selected to allow for achievement of maximal performance during the last sets of each training session. Subjects were instructed to perform five minutes of static stretching at the end of each session.

TG plyometric exercises

All landings and jumps were performed with two feet. The landing floor was either hardwood or thinly carpeted. The exercises were preceded by twenty submaximal two-foot warm-up jumps over a 30cm bench. Subjects performed drops from a 37cm step. The number of sets of each exercise prescribed for each training session is outlined in table 1.

1. Drop, no rebound – subjects dropped from the step to the floor and attempted to land with the knees flexed at 90° (Figure 1). This exercise generates high eccentric tension in the lower body musculature. Although 90° knee flexion is greater than is achieved

in most sport-related VJ performance, this protocol was incorporated to increase the intensity of each repetition.

Table 1. Numbers of sets of each exercise in the TG training sessions.

Week	1		2		3		4		5		6		7		8	
Session	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TG training session																
Drop, no rebound	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Step jump	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4
Rebound Jump	2	2	3	3	4	5	5	6	6	7	7	8	8	9	9	7
Total Sets	6	6	9	9	10	11	11	12	12	13	14	15	15	16	16	14
Total Foot Contacts*	30	30	45	45	50	55	55	60	60	65	70	75	75	80	80	70

Adapted from Bartholomew (1985)
* The number of repetitions per set remained at five for the duration of the training period.

2. Step jump – Subjects dropped from the step and immediately jumped onto another step (Figure 2). 90° knee flexion was attempted with each landing.
3. Rebound jump – Targets were placed at 2cm intervals were placed on the wall. Subjects dropped from the step and immediately performed a maximal VJ upon landing (figure 3). Subjects were instructed to reach for the highest target possible.

Twelve cool-down jumps, identical to the warm-up jumps, were performed after the exercises and before the post-session stretching.

Statistical Analysis

A one-way ANOVA was used to determine if the groups were significantly different on any of the pre-training performance measures. The only significant difference between the groups was in the LFJ measure, where the mean of the TG subjects group exceeded that of the C group ($p<0.05$). Consequently, a 3 x 2 ANCOVA was applied to the *difference in LFJ* measures with pre-test LFJ height as the covariate, the LFJ test differences (pre to mid, mid to post, pre to post) as a measurement factor and treatment (TG or control) as a training factor. For all other measures a 3 x 2 ANOVA was used with the aforementioned factors.

Figure 1. Drop, No Rebound exercise– TG subjects dropped to the floor and attempted to land with 90° knee flexion.

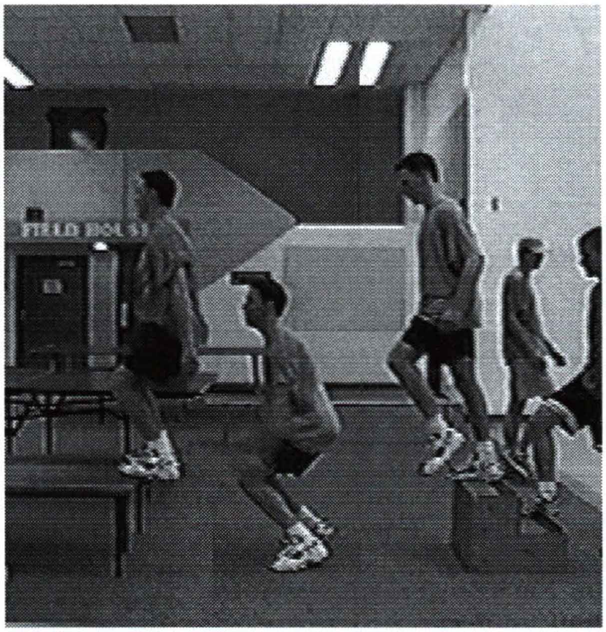

Figure 2. Step Jump exercise – TG subjects dropped from the step and immediately jumped onto another step. 90° knee flexion was attempted with each landing.

Figure 3. Rebound Jump exercise – Subjects dropped from the step and immediately performed a maximal VJ upon landing.

Chapter 3

Results

TG subjects attended a mean of 13.3 sessions per subject (83%; range 12-15 sessions) of the sixteen total training sessions. None reported injuries from training. Two TG subjects could not complete the program owing to injuries sustained from other activities. Consequently, their data were not included in the analysis. Mean CMJ performance increased from 54.6 (SD 5.3) to 60.3 (SD 5.1cm) in the TG subjects and from 51.8 (SD 8.6) to 52.4 (SD 8.8cm) in the control subjects from pre-test to post-test (figure 4). Mean CMJ performance increased from 56.4 (SD 5.8) to 60.3 (SD 5.1cm) in the TG subjects and decreased from 53.1 (SD 7.8) to 52.4 (SD 8.8cm) in the control subjects from mid-test to post-test (figure 4). The change in mean CMJ performance was significantly greater ($p<0.05$) in the TG group than in the C group from pre-test to post-test and from mid-test to post-test (figure 6). Mean 2SJ performance increased from 59.7 (SD 5.8) to 66.6 (SD 5.6cm) in the TG subjects and from 55.1 (SD 8.7) to 56.3 (SD 9.6cm) in the control subjects from pre-test to post-test (figure 5). Mean 2SJ performance increased from 61.7 (SD 5.9) to 66.6 (SD 5.6cm) in the TG subjects and decreased from 56.6 (SD 8.5) to 56.3 (SD 9.6cm) in the control subjects from mid-test to post-test (figure 5). The change in mean 2SJ performance was significantly greater ($p<0.05$) in the TG group than in the C group from pre-test to post-test and from mid-test to post-test (figure 7). Mean LFJ performance increased from 57.7 (SD 7.8) to 62.7 (SD 8.5cm) in the TG subjects and from 45.9 (SD 12.2) to 47.4 (SD 14.5cm) in the control subjects from pre-test to post-test (table 2). Mean LFJ performance increased from 61.2 (SD 8.5) to 62.7 (SD 8.5cm) in the TG subjects and from 46.9 (SD 12.2) to 47.4 (SD 14.5cm) in the control subjects from mid-test to post-test (table 2). Although the mean LFJ performance was significantly ($p<0.05$) different between groups at all testing sessions, the change in mean LFJ performance was not significantly different between the groups at any test session. Mean RFJ performance increased from 52.4 (SD 4.8) to 56.4 (SD 6.9cm) in the TG subjects and from 47.3 (SD 7.3) to 49.1 (SD 9.8cm) in the control subjects from pre-test to post-test (table 2). Mean RFJ performance increased from 53.8(SD 3.6) to 56.4 (SD 6.9cm) in the TG subjects and from 48.9 (SD 6.9) to 49.1 (SD 9.8cm) in the control subjects from mid-test to post-test (table 2). The changes in mean RFJ performance were not significantly different between the groups at any test session. The mean 0-5m SP time decreased in the TG group from 0.83s (SD 0.01s) at the pre-training test session to 0.82s (SD 0.01s) at the mid-training test session and to 0.78s (SD 0.03s) at the post-training test session (table 3). The mean 0-5m SP time in the C group was 0.84s (SD 0.01s) at the pre-training and mid-training test sessions and decreased to 0.83s (SD 0.01s) at the post-training test session (table 3). The changes in mean 0-5m SP performance were not significantly different between the groups at any test session. The mean 0-36m SP time decreased in the TG group from 4.98s (SD 0.31s) at the pre-training test session to 4.96s (SD 0.35s) at the mid-training test session and to 4.90s (SD 0.40s) at the post-training test session (table 3). The mean 0-36m SP time decreased in the C group from 5.05s (SD 0.27s) at the pre-training test session to 5.03s (SD 0.29s) at the mid-training test session and to 5.01s (SD 0.27s) at the post-training test session (table 3). The changes in mean 0-36m SP performance were not significantly different between the groups at any test session.

Table 2. Mean and standard deviation (SD) countermovement jump (CMJ), two-step jump (2SJ), left foot jump (LFJ) and right foot jump (RFJ) heights for TG and control subjects at weeks 0 (pre), 4 (mid) and 8 (post).

				Jump Measure				
Group	CMJ (cm)	F Value	2SJ (cm)	F Value	LFJ (cm)	F Value	RFJ (cm)	F Valu
TG								
Pre	54.6 (5.3)	0.67	59.7 (5.8)	1.69	57.7 (7.8)*	5.77	52.4 (4.8)	2.91
Mid	56.4 (5.8)	0.95	61.7 (5.9)	1.93	61.2 (8.5)*	7.79	53.8 (3.6)	3.39
Post	60.3 (5.1)*	4.84	66.6 (5.6)*	6.81	62.7 (8.5)*	6.56	56.4 (6.9)	2.99
Control								
Pre	51.8 (8.6)	0.67	55.1 (8.7)	1.69	45.9 (12.2)*	5.77	47.3 (7.3)	2.91
Mid	53.1 (7.8)	0.95	56.6 (8.5)	1.93	46.9 (12.2)*	7.79	48.9 (6.9)	3.39
Post	52.4 (8.8)*	4.84	56.3 (9.6)*	6.81	47.4 (14.5)*	6.56	49.1 (9.8)	2.99

* indicates a significant between-group difference ($p<0.05$)

Table 3. Mean and standard deviation (SD) 0-5 and 0-36m sprint times for TG and control group subjects at weeks 0 (pre), 4 (mid) and 8 (post).

Group	0-5m	F Value	0-36m	F Value
TG				
Pre	0.83 (0.01)	0.01	4.98 (0.31)	0.02
Mid	0.82 (0.01)	0.47	4.96 (0.35)	0.16
Post	0.78 (0.03)	1.39	4.90 (0.40)	1.35
Control				
Pre	0.84 (0.01)	0.01	5.05 (0.27)	0.02
Mid	0.84 (0.01)	0.47	5.03 (0.29)	0.16
Post	0.83 (0.01)	1.39	5.01 (0.27)	1.35

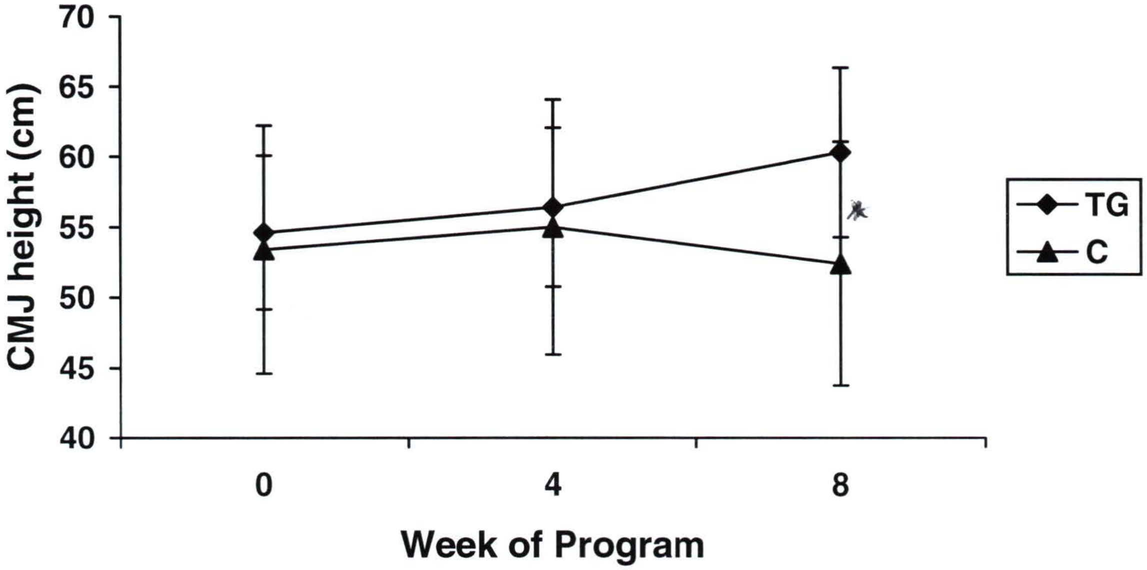

Figure 4. Mean countermovement jump (CMJ) height for training group (TG) and control (C) subjects at weeks 0, 4 and 8. * indicates a significant between group difference ($p<0.05$). Error bars represent standard deviation.

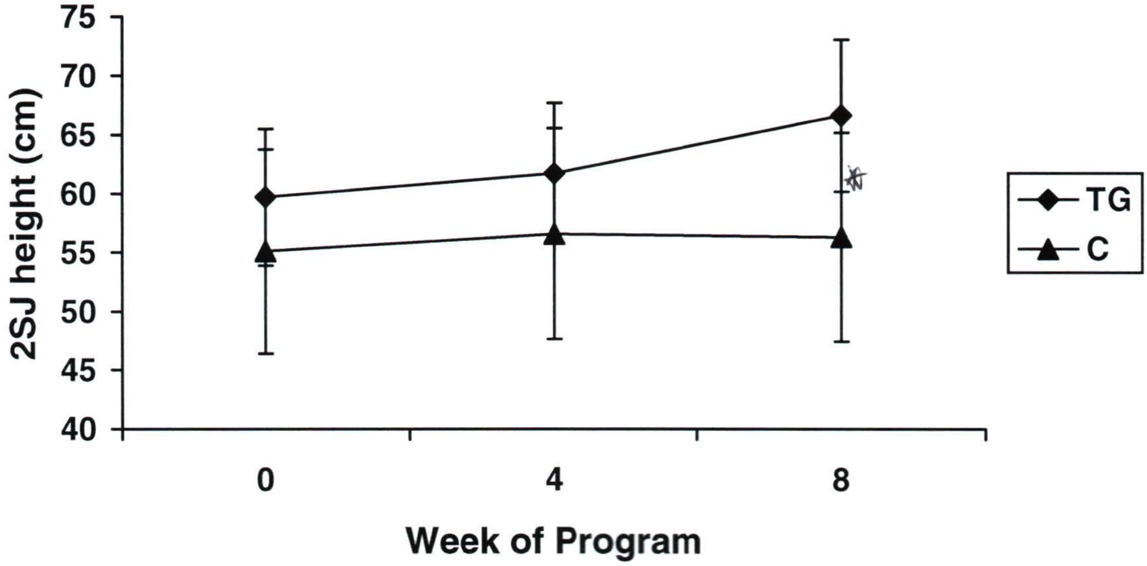

Figure 5. Mean two-step jump (2SJ) height for training group (TG) and control (C) subjects at weeks 0, 4 and 8. * indicates a significant between group difference ($p<0.05$). Error bars represent standard deviation.

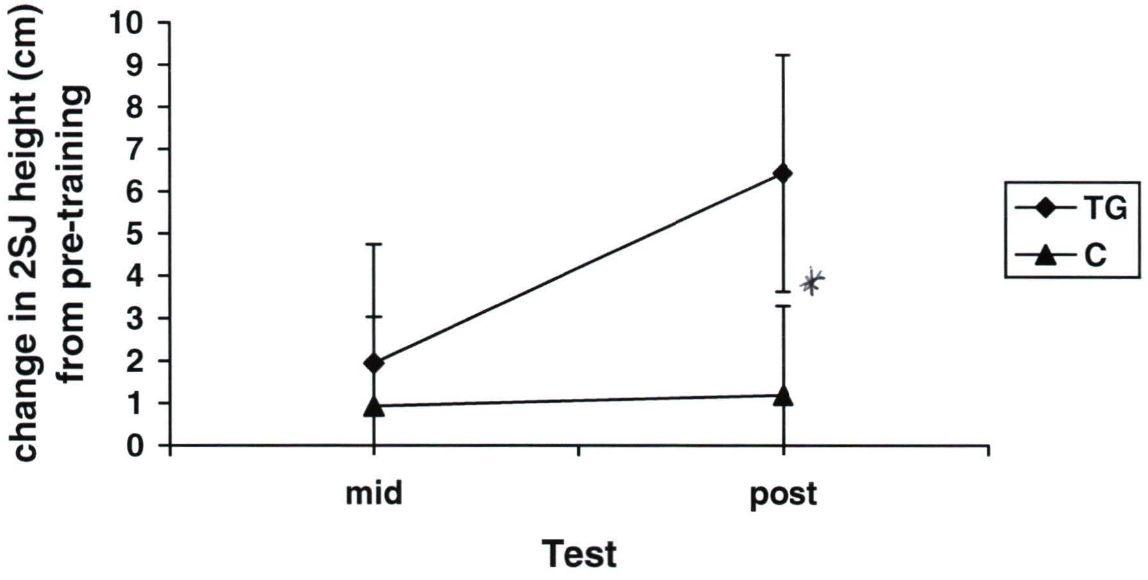

Figure 6. Change in mean countermovement jump (CMJ) height from pre-training values for training group (TG) and control (C) subjects at mid-training and post-training test. * indicates a significant between group difference (p<0.05). Error bars represent standard deviation.

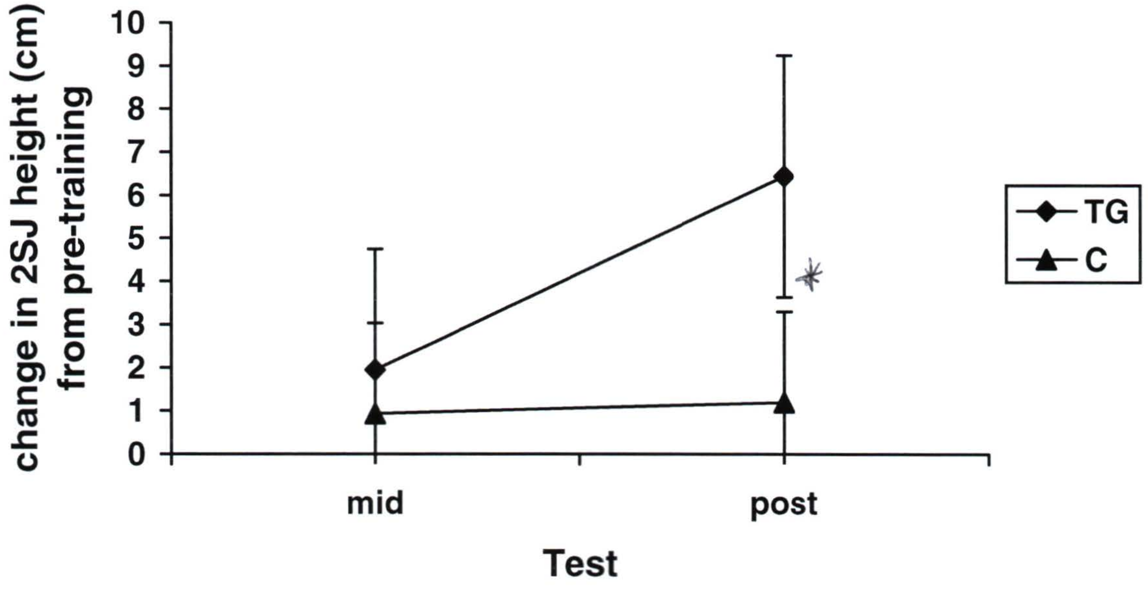

Figure 7. Change in mean two-step jump (2SJ) height from pre-training values for training group (TG) and control (C) subjects at mid-training and post-training test. * indicates a significant between group difference (p<0.05). Error bars represent standard deviation.

Chapter 4

Discussion

The purpose of this study was to examine the effect of BV plyometric training on VJ and SP performance. The results of this study demonstrated that the training group improved CMJ and 2SJ jumping performance beyond the no training control group, with no difference found in one-foot jumping (RFJ or LFJ) or sprint speed measures. Previous investigations of plyometric training have revealed a similar positive relationship between BV-type plyometric training and CMJ. Adams, O'Shea, O'Shea and Climstein (1992) measured VJ in twelve male physical education students before and after six weeks of drop jump training twice weekly. The observed VJ increase (mean 3.8cm; $p<0.05$) was comparable to the training group in this study (mean 5.5cm; $p<0.05$). Miller (1982) examined the effect of one drop jump session per week for eight weeks on the VJ performance of twelve females and found a mean increase of 5.0cm ($p<0.05$). The observation of increases in CMJ and 2SJ performance from BV plyometric training could have resulted from improvements in maximal muscle force (MMF), maximal rate of force development (RFD) and/or neural coordination, as identified by Kraemer and Newton (1994).

Unfortunately, no measurements of lower body MMF were taken for analysis in this study. Subjective reports of post-training muscle soreness suggests that the adaptive processes that occur in response to traditional weight training may have been present in some of the subjects. However, it is unlikely that the improvement of CMJ and 2SJ in this study could be completely accounted for by an increase in the MMF of training subjects. During examination of a computer simulated jumping model Bobbert and Van Soest (1994) found that an isolated strength increase was unable to improve VJ performance. It seems likely that RFD and neural coordination developments were involved in the observed improvements.

The product of muscular force and movement velocity is muscular power. Movement velocity is positively related to RFD. The positive relationship between muscular power and VJ performance has been well documented (Hay, Dapena, Wilson, Andrews & Woodworth, 1978; Kraemer & Newton, 1994; Luhtanen & Komi, 1980). In an examination of bilateral isometric RFD in trained ski jumpers and in an untrained control group, Viitasalo and Komi (1978) provided evidence to support the notion that athletes may be able improve the rate of force development through training. The ski-jumping group, which trained with powerful exercises, exhibited the ability to achieve higher RFDs. A velocity-specific training response to resistance training, where high-velocity training improves high-velocity movement beyond low-velocity training, has been demonstrated in other studies (Coyle et al., 1981; Duchateau & Hainaut, 1984).

In addition, high-velocity training may have improved RFD by increasing premovement silence in the active musculature (a brief period where all or most fibres are inactivated; Sale, 1992). This adaptation could improve RFD in two ways: a) the premovement silence may bring all motoneurones into a non-refractory state and allow for more synchronous recruitment, and b) a SSC condition may be induced through a decreased resistance of the musculotendinous system so that an eccentric load can be developed at a faster rate (Sale, 1992). In accordance with these observations, electromyographic (EMG) investigation of subjects involved in 'explosive' jump training has revealed specific increases in the onset of motor unit activation (Hakkinen, Komi & Alen, 1985). Subjects in the same study also demonstrated improvements in the maximum motor unit firing rate (Hakinen et al., 1985). Although no measurements of muscular power were collected in the present study, the potential for power improvements resulting from the high velocity BV training must be considered.

Enhanced neural coordination may also have contributed to the increases in CMJ and 2SJ in the training group. VJ height is determined by the vertical velocity of the centre of gravity (VVCG) at the instant of take-off (Hay et al., 1978), a physical product of neuromuscular control. An important factor involved in maximizing vertical velocity is the sequential attainment of peak vertical velocities by body segments (upper body, upper legs, lower legs, feet) to optimize the use of energy released from the muscles (Bobbert & Van Ingen Schenau, 1988). This concept is supported by Luhtanen and Komi (1978) who showed that the mechanical efficiency (% use of available mechanical energy) of jumping can be increased by shortening the time difference between the acceleration maxima of the different contributing body segments. The importance of muscular control development to VJ performance was demonstrated with a computer simulated jumping model manipulated for strength and muscular coordination (Bobbert & Van Soest, 1994). It was observed that stronger musculature only improved VJ performance if the strength increase was accompanied by the appropriate muscular recruitment pattern. The nature of the BV exercises in this study provided the training subjects with an opportunity to repeatedly perform VJ actions. Since jump training was novel to the subjects (none of the training subjects had engaged in plyometric training previously), it seems possible that a repetitive concentration on jumping could improve the ability to coordinate the skill.

A change in the interaction of muscle reflexes is another possible neuromuscular adaptation to plyometric training that could facilitate VJ performance. A heightened muscle spindle response could result in agonist facilitation by amplifying the concentric portion of the SSC during the rapid stretch phase of the countermovement (Foss & Keteyian, 1998). A decrease in the Golgi tendon organ response would augment the SSC contribution to jump performance by reducing inhibition of the active musculature during the high load portion of the countermovement (Foss & Keteyian, 1998). Indeed, investigation of EMG recordings of gastrocnemius muscle during drop jumps revealed that plyometric-trained subjects responded to high eccentric stretch loads with a period of agonist facilitation whereas untrained subjects responded with a period of agonist inhibition (Schmidtbleicher & Gollhofer, 1982 as cited in Sale, 1992).

In this study, observation of improvement in bilateral measures (CMJ and 2SJ) with no corresponding increase in any unilateral measure (LFJ, RFJ or SP) suggests that the TG subjects experienced neuromuscular adaptations specific to bilateral training. The development of a specific bilateral training response is in accordance with reports from Secher (1975) who found that bilateral resistance training could reduce or eliminate the bilateral deficit (difference between two-leg force and the sum force of each isolated leg). Sale (1992) suggests that a reduction of the bilateral deficit can be considered a neural adaptation that manifests itself as an increased ability to activate agonists in a bilateral movement. The observation that performance improvement in the training group did not transfer to the vertical one-leg jumps (RFJ and LFJ) suggests that a specific response to two-foot training was discernable.

The absence of TG improvement in sprint performance suggests that adaptations to BV movements may not transfer to unilateral and horizontal actions. Unilateral actions place greater loads on each limb, relative to bilateral actions. Consequently, the forces achieved in the musculature are larger and there is a greater possibility of stimulating the Golgi tendon organs (Komi, 1992). An increase in Golgi tendon organ activity would reduce muscle stiffness and result in decreased power and mechanical efficiency (Komi, 1992). BV-type training may not have provided the muscle reflexes with the stimulus to adapt for the higher loads associated with unilateral movements. Additionally, given the importance of horizontal force and stride frequency to sprint speed (Delecluse, 1997), the minimal horizontal force and absence of stride training involved in this study is a likely factor in the lack of SP performance improvement.

Significant improvements in CMJ and 2SJ were observed over the last four weeks of the program, but not over the first four weeks. This could be a consequence of a delay in the training effect. However, the possibility exists that the lower volume (total foot contacts) in the first four weeks, relative to the last four weeks, was less than optimal as a training stimulus.

The actions of the CMJ and 2SJ tests are very similar, suggesting a possible overlap of these measurements. The CMJ measure is a common measure used in studies involving vertical jumping and, consequently, served as a reliable reference for comparison to other research. Alternatively, the 2SJ test provided a closer approximation to the jumping that is performed in sports such as basketball and volleyball, where stepping often precedes jumping. The extra stepping increases the preload that can be placed on the lower body musculature and consequently increases the SSC contribution of the subsequent jump. In the present study 2SJ height (mean = 59.5cm) was higher than CMJ height (mean = 54.8cm) in both groups at all testing sessions. This supports the notion that the CMJ and 2SJ movements are distinct and advocates the inclusion of both measures.

A test that may have been useful in the present study is a measure of a jump performed from a semi-squatting start position with no countermovement (static jump;SJ). It has been presumed that the SJ is a measure of concentric muscular power only, and that the CMJ is a product of concentric muscular power and SSC activity (Sale, 1991). Correspondingly, SSC contribution can be inferred from the difference between CMJ and SJ measures. Discernment of the relative contribution of power and SSC activity to each jump may have provided insight into the locus of training improvement. However, SJ measurements were not included in the present study. Application of an SJ protocol during the pre-testing period revealed challenges to the validity of the test. The foremost threat involved control of the SJ test. Consideration was given to the presence of countermovement as well as to isometric tension developed by subjects in the semi-squat position that could have affected power output (Fukashiro & Komi, 1987). Visual observation proved to be an unreliable method of controlling SJ performance. Consequently, the SJ measure was considered invalid and the data were not included in the analysis of the study. Future research should attempt to incorporate this measure by monitoring ground force electronically.

Given the importance of lower body MMF to VJ performance, a test of this variable would have been beneficial to this study. Pre- and mid-training testing sessions included a test of the maximum number of times that a subject could perform a front squat with a load equal to 125% of their body weight. However, the front squat was a novel exercise for many of the subjects and difficulty with the exercise jeopardized both the control of the test and the safety of the subjects. Consequently, the test was excluded from the post-training testing sessions and the data have not been reported.

Using a program that closely approximated the training in the present study, Bartholomew (1985) found a CMJ increase of 10.0 cm ($p<0.05$). The disparity between the improvements observed by Bartholomew and those in the present study may be related to the length of time between training days. To accommodate the timetables of the subjects, sessions were scheduled for Tuesday and Thursday evenings, which allowed for two and five day rest intervals. Two days between sessions may not have been of sufficient length for optimal recovery. Although no available research has examined inter-session rest length in isolation, there is evidence to support the implication that the fatiguing SSC exercise associated with plyometric training may interfere with subsequent jump performance. Horita, Komi, Nicol and Kyrolainen (1999) found that regulation of muscle stiffness (the rate of change in muscle force divided by a change in muscle length; Hutton 1992) and pre-landing motor control were detrimentally affected for two days after exhaustive SSC exercise. Avela and Komi (1998) suggest that a reduction in muscle stiffness, which is associated with decreased reflex sensitivity, could result in weakened muscular performance following exhaustive SSC exercise. In the present study some subjects did comment on the presence of delayed muscle soreness during the Thursday training session, suggesting that the rest interval between sessions was too short to allow for complete muscular recovery. However, the occurrence of muscle soreness and/or performance decrement is not a reliable indicator of the quality of the training stimulus. Until further investigation reveals reliable inter-session rest parameters, explanation is restricted to speculation.

Conclusion

The results of this study indicate that BV plyometric training is an effective mode for improving bilateral and vertical movement, but not for unilateral action such as single-leg jumping or unilateral and horizontal movement such as sprinting. The possible factors associated with this improvement are increases in MMF and RFD, and neuromuscular adaptations that include improved segmental coordination and a training response specific to bilateral and vertical movement. The potential for a specific response to BV plyometric training suggests that attention should be given to alternative plyometric exercises to develop power capabilities for movements performed unilaterally or horizontally. Future research could focus on determining which, if any, performance attributes would benefit from unilateral and predominantly horizontal (UH) plyometric training. As a point of reference, a UH plyometric program that approximates the TG program in this study is included in appendix D. The test measurements of a subject who completed the eight week program is presented in appendix E. Considerable improvements were observed in 2SJ, LFJ and RFJ performance and in 0-5 and 0-36m SP performance. These observations suggest that further investigation of UH plyometric training could lend insight into the most effective exercises for improving a range of ballistic movements and consequently benefit the training practices of athletes who aspire to improve UH power.

Chapter 5

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Appendix A

Table 4. Mean and standard deviation (SD) height and body mass for TG and control subjects at weeks 0 (pre), 4 (mid) and 8 (post).

Table 4. Mean and standard deviation (SD) height and body mass for TG and control subjects at weeks 0 (pre), 4 (mid) and 8 (post).

Group	Body mass (kg)	F Value	Height (cm)	F Value
TG				
Pre	82.1 (9.0)	0.18	186.8 (6.3)*	8.87
Mid	82.4 (9.1)	0.0	✓	
Post	83.5 (9.5)	1.23	✓	
Control				
Pre	80.1 (11.2)	0.18	178.2 (5.6)*	8.87
Mid	81.3 (10.0)	0.0	✓	
Post	80.6 (10.0)	1.23	✓	

* indicates a significant between-group difference ($p<0.05$)

✓ height measurements were only taken at week 0.

Appendix B

Table 5. Mean and standard deviation (SD) 0-5, 5-10, 10-15, 15-20, 20-36 and 0-36m sprint times for TG and control group subjects at weeks 0 (pre), 4 (mid) and 8 (post).

Table 5. Mean and standard deviation (SD) 0-5, 5-10, 10-15, 15-20, 20-36 and 0-36m sprint times for TG and control group subjects at weeks 0 (pre), 4 (mid) and 8 (post).

			Sprint (s)			
Group	0-5m	5-10m	10-15m	15-20m	20-36m	0-36m
TG						
Pre	0.83 (0.01)	0.80 (0.02)	0.70 (0.03)	0.65 (0.02)	2.00 (0.09)	4.98 (0.31)
Mid	0.82 (0.01)	0.81 (0.02)	0.68 (0.02)	0.63 (0.03)	2.02 (0.10)	4.96 (0.35)
Post	0.78 (0.03)	0.81 (0.02)	0.68 (0.02)	0.64 (0.02)	1.99 (0.10)	4.90 (0.40)
Control						
Pre	0.84 (0.01)	0.82 (0.02)	0.71 (0.02)	0.65 (0.02)	2.03 (0.08)	5.05 (0.27)
Mid	0.84 (0.01)	0.81 (0.02)	0.69 (0.03)	0.64 (0.02)	2.05 (0.09)	5.03 (0.29)
Post	0.83 (0.01)	0.82 (0.01)	0.69 (0.02)	0.64 (0.02)	2.03 (0.09)	5.01 (0.27)

Appendix C

Informed consent form

Informed consent for the research project:

The effects of plyometric training on horizontal and vertical movement

This research project has been designed to observe the effects of two different types of plyometric training on vertical jump and sprint performance. Plyometric exercises involve high-impact, powerful movements such as jumping after a 40cm drop or bounding. There is no significant cardiovascular stress associated with this type of exercise. To ensure that subjects have the lower body strength to safely participate in plyometric training, a pre-study squat test will be administered. Subjects will be divided into three groups: a) a two-foot "jumping" training group, b) a one-foot-at-a-time "bounding" training group and c) a control group which will not participate in training. Your height, weight, vertical jump and 30m sprint speed will be measured before, and after, an eight-week training period. These testing sessions will require about 40 minutes each. The training groups will meet twice per week for eight weeks. Each training session will involve light basketball drills, stretching and plyometric exercises and will last about 75 minutes. Early training sessions may cause some muscle soreness, but this will diminish as training progresses. The results will be reported to the department of Physical Education and may be published in a scholarly journal.

Your participation is voluntary and you can withdraw from the study at any time, without explanation or penalty. Upon withdrawal all of your data will be destroyed. Whether you participate or choose not to participate will have no bearing on your academic standing.

Any data collected in the study will remain confidential. Your name will not be attached to any published results and your anonymity will be protected by using code number to identify results obtained from individual subjects. All data will be kept in a locked office. Computer data will be password protected. Only the researcher and his supervisor, Dr. David Docherty will have access to any of the data.

By signing this form you acknowledge that you understand the nature and conditions of the study. Your signature releases the University of Victoria and all personnel involved with the research project from liability for injury sustained during participation in the study.

Participant name: Participant signature:

Participant phone #: Date:

Researcher: Aron Wilson (250) 385-4967

Supervisor: Dr. D. Docherty (250) 721-8375

Appendix D

An eight-week unilateral and horizontal plyometric training program

UH Plyometric Exercises

The warm-up exercise for subject UH consisted of approximately sixty submaximal one-foot steps with alternating feet over 10cm obstacles arranged in series. All exercises were performed with a one-foot landing and take-off. All sets were performed with five repetitions with each foot. The number of sets prescribed of each exercise is outlined in table 4.

1. Drop, no rebound – The subject dropped 15cm from a step and performed a one-foot landing. This was repeated with the other foot. 75° knee flexion was attempted with each landing.
2. Drop stride – Five 15cm steps were arranged in series and staggered by approximately twenty feet. The subject dropped from the first step, landed on the left foot and performed an immediate stride toward the next step. After a brief pause, this exercise was repeated over the five-step course. At the end of the five steps, the subject turned and completed the set with the opposite foot.
3. Two-step bound – A pre-determined starting point was approached at a slow jogging pace. Two alternate maximal strides were performed from the starting point. The subject was instructed to perform an exaggerated sprint stride with each step and to alternate the starting foot with each repetition. Distance targets were placed 10cm apart on the floor and the subject attempted the longest possible steps without interrupting horizontal motion.

Each training day was completed by performing a cool-down that approximated the warm-up.

Table 6. Number of sets of each exercise in the UH training sessions.

Week	1		2		3		4		5		6		7		8	
Session	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
UH training session																
Drop, no rebound	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Drop stride	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4
Two-step bound	2	2	3	3	4	5	5	6	6	7	7	8	8	9	9	7
Total Sets	6	6	9	9	10	11	11	12	12	13	14	15	15	16	16	14
Total Foot Contacts	30	30	45	45	50	55	55	60	60	65	70	75	75	80	80	70

Appendix E

A quantitative description of subject 01: participation in an eight-week unilateral and predominantly horizontal plyometric training program.

Subject 01

Gender: Male
Training status: Involved in intramural sports (volleyball)
Height: 181cm
Weight: 82.5kg
Number of Sessions attended: 14

Table 6. Performance measures for subject UH at week 0 (Pre), week 4 (Mid) and week 8 (Post) of an eight week UH plyometric training program.

Measure	Pre	Mid	Post
CMJ (cm)	63.0	67.0	65.0
2SJ (cm)	67.0	64.0	76.0
LFJ (cm)	71.5	67.5	76.0
RFJ (cm)	59.5	62.5	66.0
0-5m sprint (s)	1.14	0.82	0.74
5-10m sprint (s)	0.77	0.75	0.82
10-15m sprint (s)	0.66	0.77	0.66
15-20m sprint (s)	0.64	0.61	0.58
20-36m sprint (s)	1.89	1.89	1.99
0-36m sprint (s)	5.10	4.84	4.79

Table 7. Performance change in Subject UH (UH) and mean performance change in BV plyometric training group from pre- to mid-test, mid- to post-test and pre- to post-test.

Test interval	Pre- to mid-test		Mid- to post-test		Pre- to post test	
Measure	UH	BV(mean)	UH	BV(mean)	UH	BV(mean)
CMJ (cm)	+4.0	+1.8	-2.0	+3.9*	+2.0	+5.7*
2SJ (cm)	-3.0	+2.0	+12.0	+4.9*	+9.0	+6.9*
LFJ (cm)	-4.0	+3.5	+8.5	+1.5	+4.5	+5.0
RFJ (cm)	+3.0	+1.4	+3.5	+2.6	+6.5	+4.0
0-5m sprint (s)	-0.32	-0.01	-0.08	-0.06	-0.40	-0.07
5-10m sprint (s)	-0.02	-0.01	+0.07	-0.01	+0.05	-0.02
10-15m sprint (s)	-0.03	0	-0.11	+0.01	0	+0.01
15-20m sprint (s)	+0.11	-0.01	-0.03	0	-0.06	-0.01
20-36m sprint (s)	0	0	+0.10	0	+0.10	0
0-36m sprint (s)	-0.26	-0.03	-0.05	-0.06	-0.31	-0.09

* Indicates a significant ($p<0.05$) improvement in the BV group (TG) beyond a no training control group.

Appendix F

Related Literature

Appendix F

Related Literature

Two-foot vertical jump (VJ) and sprint (SP) performance are fundamental to many sports, such as basketball, rugby and American football. Execution of power-oriented movements such as jumping and sprinting is dependent on the magnitude and rate of force produced by the active musculature. Plyometric exercises are often included in the training of athletes involved in power-oriented sports. These exercises typically demand maximal power output and repeated stretch-shortening cycle (SSC) activation. The following review of related literature will focus on the SSC and its associated factors, studies that have investigated plyometric training, drop jump technique and the risks of plyometric training.

The Stretch-Shortening Cycle

Muscle action can be divided into three types: concentric (the muscle length shortens during tension development), isometric (the muscle maintains constant length during tension development), and eccentric (the muscle lengthens during tension development). However, most sport-related movements do not involve one muscle action type only. More typically, a combination of muscle action types produces the resultant action, such as a vertical jump (VJ) or throwing movement.

The SSC involves the forced lengthening of active muscle (eccentric action) followed immediately by a concentric contraction. The concentric contraction is enhanced by the preceding eccentric contraction (Bosco, Viitasalo, Komi, & Luhtanen, 1982). The eccentric portion of the SSC is linked to the concentric portion by a brief supramaximal isometric contraction. Joint moments reach their highest values during this phase (Fukashiro & Komi, 1987). Svantesson, Grimby, and Thomee (1994) report that isometric action alone (no eccentric action) will potentiate subsequent concentric action, but to a lesser extent than the eccentric action involved in the SSC.

Performances of the VJ and sprint (SP) stride are both influenced by SSC action. The landing of the SP stride facilitates the concentric push-off by eliciting SSC activity. Although the VJ can be performed as a static jump (SJ) where the performer initiates the jump from a semi-squat position, it is typically performed as a countermovement jump (CMJ; Komi, 1984). A CMJ is characterized by a brief period of unloading - achieved through hip flexion, knee flexion, and ankle dorsiflexion - followed immediately by a jumping action. Comparison of the CMJ and SJ reveal that a jumper can achieve greater height with a countermovement (Asmussen & Bonde-Petersen, 1974; Bosco, Tarkka & Komi, 1982). This performance difference can be explained by the facilitation of the CMJ by the stretch-shortening cycle.

Three mechanisms help to explain the efficacy of the SSC: storage and utilization of elastic energy, reflex potentiation, and the interaction of tendon and fibre length.

Storage and Utilization of Elastic Energy

It has been well documented that muscles and tendons can absorb and briefly store mechanical energy in the form of elastic energy (Alexander & Bennet-Clark, 1977; Asmussen & Bonde-Petersen, 1974; Belli & Bosco, 1992; Bosco, Tarkka, & Komi, 1982; Bosco, Viitasalo, Komi & Luhtanen, 1982; Cavagna, Dusman & Margaria, 1968; Cavagna, Saibene & Margaria, 1965; Fukashiro and Komi, 1983; Huxley & Simmons, 1971; Thys, Faraggiana & Margaria, 1972). The term "series elastic component" (SEC) describes the elastic elements that are responsible for the elasticity of muscular and tendinous structures (Huijing, 1992).

In the muscle fibres, actin and myosin cross-bridges exhibit elastic properties. Huxley and Simmons (1971) suggest that heads of stretched myosin filaments can be rotated backwards, against their natural tendency, to a position of higher potential energy. If coupling time (time for the switch from eccentric to concentric action) is short enough, this potential energy can be used to potentiate the concentric action (Komi, 1984). However, if coupling time is too long, the concentric action may be compromised because stored mechanical energy may be lost as heat (Cavagna, Saibene, & Margaria, 1965) or sarcomere slipping may occur (Flitney & Hirst, 1978).

Reflex Potentiation

Electromyographic analysis of the musculature that is active during VJ performance has revealed that reflex potentiation is an additional contributor to SSC performance (Bosco, Tarkka, & Komi, 1982; Bosco, Viitasalo, Komi, & Luhtanen, 1982; Hakkinen & Komi, 1985; Yamazaki, Mitarai, & Mano, 1983). The reflex contribution to the SSC has been estimated at 50% in the ankle dorsiflexors (Sinkjaer, Toft, Andreassen & Hornemann, 1988). It is suggested that the high motor unit activation and simultaneous rapid increase in force associated with the eccentric contraction of SSC movement increases the stiffness of the muscle and may enhance the facilitatory influence of the muscle spindles (Bosco, Viitasalo, Komi, & Luhtanen, 1982).

Bosco, Tarkka, and Komi (1982) compared the EMG activity of the gastrocnemius and soleus muscles of five subjects performing CMJ and SJ. For all five subjects myoelectrical activity during the concentric action of CMJ was beyond that of the SJ. This difference was attributed to muscle spindle facilitation.

The strength of the muscle spindle response is related to the rate of muscle stretch (Yamazaki et al., 1983). However, the muscle is not capable of withstanding unlimited stretch. Hakkinen and Komi (1985) report that potentiation of concentric force may reach a breaking point where the facilitatory contribution of muscle spindles is exceeded by the inhibitory effects of the Golgi tendon organ reflex mechanism.

The reflex potentiation of the SSC appears to be related to muscle stiffness (the ratio of change in muscle force divided by a change in muscle length; Hutton, 1992). Walshe and Wilson (1997) observed that subjects with greater muscle stiffness did not perform as well under drop jumping conditions as subjects with more compliant muscles. It was hypothesized that upon ground contact the stiff group transmitted relatively greater force from the skeleton to the muscle, which resulted in greater reflex inhibition from the Golgi tendon organs.

It has been suggested that fatigue may increase muscle stiffness (Komi, 1992; Gollhofer, Komi, Miyashita & Aura, 1987). Gollhofer et al. (1987) found that fatiguing exercise reduced the reflex contribution to SSC action, which supports the association between fatigue, stiffness, and reduced reflex potentiation.

Interaction of Tendon and Fibre Length

In addition to elastic energy utilization and reflex potentiation, the interaction of tendinous tissues and fibre length can influence SSC action (Ettema, Van Soest, & Huijing, 1990; Huijing, 1992). Changes in force affect the length of the tendinous tissues, which in turn affect muscle fibre length and rate of contraction.

The increased force associated with SSC action will increase the length of tendinous tissues in a given muscle-tendon complex. This translates into shorter muscle fibre lengths (compared to the same muscle-tendon complex with shorter tendinous tissues). This relationship works in reverse when forces drop rapidly. If force drops as a result of a high shortening velocity tendinous tissue length will decrease and fibre length will decrease less than if the tendinous tissue did not lengthen (Huijing, 1992).

With an increased drop of force additional elastic energy is released from the tendon which will increase its contribution to the shortening velocity of a given muscle-tendon complex. The tendon acts as an 'energy pool' and allows muscle fibres to operate more forcefully by slowing the contraction velocity of the fibres (according to the force-velocity relationship of muscular action; Huijing, 1992).

Additionally, tendon-dependent changes in fibre length may increase or decrease work output. Depending on the fibre action in relation to optimal length and rate of contraction, the changes imposed by tendinous tissues may bring a fibre closer to, or further from, optimal length-tension conditions (Huijing, 1992).

Plyometric Training

The goal of plyometric training is to improve ballistic action performance. Exercises typically involve high power outputs and SSC activation. A thorough review of plyometric exercises was completed by Chu (1992). The exercise most commonly employed in studies of plyometric training is drop jumping which involves dropping from a raised surface and immediately performing a maximal VJ (Bobbert, 1990). Since drop jumping was introduced by Verhoshanski in 1966 it has been integrated into the training programs of a broad range of sports (Bobbert, 1990). Unfortunately, no controlled studies available have investigated the optimal volume, frequency, or rest for drop jump training programs.

Hakkinen and Komi (1985) observed the progression of ten male subjects involved in a 24-week jump training program. A series of jump exercises were performed three times per week with and without extra weight. Two observations led to the conclusion that the jump training elicited neuromuscular adaptations. First, the jumpers exhibited significant improvement in the high velocity portion of the force-velocity curve. This suggests that subjects had learned to improve the speed of fibre recruitment. Second, improvements in SJ height (21.2%) were significantly greater than the observed increase in maximal squat strength (6.8%). Increased integrated electromyographic (EMG) activation of the vastus lateralis and medialis muscles during SJ performance was considered to be evidence that increased neural activation is a significant adaptation to jump training.

Sale (1992) reported that a trained jumper may exhibit increased muscle spindle facilitation and decreased Golgi tendon organ inhibition while jumping. Schmidtbleicher, Gollhoffer, and Frick (cited by Sale, 1992) observed that subjects involved in four weeks of drop jump training demonstrated reduced EMG inhibition during jumping. It is proposed that a decrease in inhibition enhances stretch potentiation of concentric activity.

It has also been suggested that high velocity training may increase premovement silence in the active musculature (a brief period where all or most fibres are inactivated; Sale, 1992). This adaptation could increase the rate of force development in two ways: a) the premovement silence may bring all motoneurones into a non-refractory state and allow for more synchronous recruitment, and b) a SSC condition may be induced through a decreased resistance of the musculotendinous system so that an eccentric load can be developed at a faster rate (Sale, 1992).

In contrast, EMG analysis of the drop jump has revealed that the muscles involved are activated before contact, and to a different degree, depending on the expected load (Avela, Santos, & Komi, 1996). Kyrolainen, Komi, and Kim (1991) reported that after 16 weeks of plyometric training subjects were able to pre-activate leg extensor muscles earlier before impact. Avela, Santos, Kyrolainen, and Komi (1994) reported that this pre-activation is related to the peak angular velocity in the ankle joint. The importance of the peak angular velocity of the ankle to VJ execution suggests that an increase in muscle pre-activation could contribute to VJ improvement (Hay et al, 1978).

Although drop jumping can increase the load with which plyometrics are performed, it has been reported that drop jumping is no more effective at improving VJ than regular jump training (Clutch, Wilton, McGown, & Bryce, 1983; Bobbert, 1990). One possible explanation for this is that the muscle pre-activation associated with drop jumps (Kyrolainen et al., 1991) and the pre-movement silence associated with high velocity training (Sale, 1992) interfere with each other.

Although muscular strength is an important aspect of VJ and SP performance, it does not appear that plyometric training increases maximal concentric strength (Wilson et al., 1996; Wilson et al., 1993). However, exhausting SSC exercise appears to cause muscle damage similar to that experienced from strength training (Nicol, Komi, Horita, Kyrolainen, & Takala, 1996) and an associated loss of function (Smith, 1991). It is likely that this damage and loss of function is a result of the high eccentric loads associated with plyometric training.

Drop Jump Technique

The physical demands of the drop jump are dictated by the drop height and the type of jump performed. Considering the large individual differences in VJ performance (Fowler, Lees,

& Reilly, 1994; Hubley & Wells, 1983), these factors should be considered in the control of a training program.

When determining drop jump height it is important to consider that a higher drop is not necessarily better. As drop height increases, so does landing force, ground contact time, and coupling time. An increase in coupling time may increase elastic energy loss (Cagvagna et al., 1965; Flitney & Hirst, 1978) and compromise the SSC contribution to the subsequent jump. Allerheiligen (1994) reports that a drop of 1.2m increases the coupling time to a point of interfering with the jump. Asmussen and Bonde-Petersen (1974) report that jump height increased in drops up to 40 cm and Bobbert, Huijing, and van Ingen Schenau (1987) advise a limit of 20-40 cm for drop height. Schmidtbleicher (1992) recommends that the drop height be set at the highest point where the jumper's heels do not touch the ground during the contact phase.

The two techniques of the drop jump are the bounce drop jump (BDJ) and the countermovement drop jump (CDJ; Bobbert et al., 1987; Bobbert, 1990; Bobbert et al., 1996; Sale, 1991). The BDJ involves an immediate jump upon ground contact and the CDJ involves a more gradual deceleration with a greater downward displacement (Sale, 1991). Biomechanical analysis of the two techniques reveals that the BDJ is associated with greater joint moments and power (Bobbert et al., 1987; Bobbert et al., 1996). The lower power values associated with the CDJ may be a result of less elastic energy being stored as a result of the larger amplitude countermovement (Bosco, Tihanyi, Komi, Fekete, & Apor, 1982; Blakey and Southard, 1987; Gollhofer, Komi, Fujitsuka, & Miyashita, 1987).

Bosco, Tihanyi, Komi, Fekete, and Apor (1982) report that jumpers with a higher percentage of slow twitch (ST) fibres in the vastus lateralis muscle may reuse more elastic energy (24%) in a CDJ than jumpers with a lower percentage of ST fibres (17%). The suggested mechanism for this is the difference in cross-bridge life times between fibres. The ST fibre may retain cross-bridge activation longer and be better suited for elastic recoil following an extended coupling time. No studies presently available have looked at the difference in VJ adaptations to the techniques, but the greater moments and power that can be realized with a BDJ suggest that it may be a more effective technique for eliciting increases in power capabilities.

The Risks of Plyometric Training

It has been suggested that plyometric training is too stressful on the musculotendinous system and that it may increase an athlete's risk of injury (Brzycki, 1986). Bobbert, Mackay, Schinkelshoek, Huijing, and van Ingen Schenau (1986) measured the peak force transmitted to the achilles tendon during jumping and found that drop jumping (3.2-7.0 X body weight) does indeed place greater strain on the musculotendinous systems than CMJ (1.5-2.7 X body weight). Schmidtbleicher (1992) recommends that an athlete should be able to squat 150% of their body weight before engaging in plyometric training. Unfortunately, the frequency of injury is not reported in any of the reviewed literature.

Stone (1988) suggests that load bearing and intensity are the most important factors for connective tissue and bone adaptations. Plyometrics involves both heavy load bearing and intense action. This may suggest that the progression of training intensity (exercise, drop height, extra load) and volume (repetitions X sets) should be gradual to take advantage of possible connective tissue and bone adaptations and reduce the risk of musculotendinous injury.

Conclusion

The current literature suggests that plyometric exercises are effective at improving power producing capabilities and SSC activity. Specific adaptations to ballistic movement may include increased muscle spindle facilitation, decreased golgi tendon organ inhibition, increased neural activation, and increased pre-movement silence. Unfortunately, the training variables associated with optimal plyometric training can not be ascertained from the available literature. Further study directed at establishing efficient plyometric training variables may prove valuable to the power-training athlete.

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