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The effects of bungy weight training on muscle function and functional performance

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Eccentric strength training is thought to be important for improving functional performance. A form of training that may enhance the eccentric training stimulus is the attachment of a rubber bungy to the strength-training apparatus in such a way that the return velocity and, therefore, the force required to decelerate the load at the end of the eccentric phase are increased. To determine the effects of elastic bungy training, we performed two studies. In the first, we examined the electromyographic (EMG) and kinematic characteristics of three different squat techniques: traditional squat, non-bungy jump squat and bungy jump squat. In the second study, we examined whether jump squat training with and without the attachment of a rubber bungy to an isoinertial supine squat machine affects muscle function, multidirectional agility, lunge ability and single leg jump performance. The EMG activity of the vastus lateralis and gastrocnemius muscles was recorded. An instrumented isoinertial supine squat machine was used to measure maximal strength and various force, velocity and power measures in both studies. Participants were randomly assigned to one of three groups: a control group and two weight-trained groups, one of which performed bungy squat jumps and one of which performed non-bungy squat jumps. The two experimental groups performed 10 weeks of ballistic weight training. The kinematic and EMG characteristics of the bungy and non-bungy squat techniques differed significantly from those of the traditional squat on all the variables measured. The only difference between the bungy squat and non-bungy squat training was greater EMG activity during the later stages (70–100%) of the eccentric phase of the bungy squat condition. The 10 weeks of bungy squat and non-bungy squat jump weight training were found to be equally effective in producing improvements in a variety of concentric strength and power measures (10.6–19.8%). These improvements did not transfer to improved performance for the single leg jump and multidirectional agility. However, bungy weight training did lead to a significant improvement in lunge performance (21.5%) compared with the other groups.

Keywords: electromyography, functional performance, kinematics, power training, strength, stretch–shorten cycle.

Introduction

One factor to consider when designing strength-training programmes to optimize athletic performance is the specificity of the muscle contraction. It is recommended that athletes should perform resistance training that simulates the contraction characteristics (isometric, concentric or eccentric) of their particular event. Emphasizing the same type of contraction in training that occurs during the performance of a task should allow appropriate neural adaptation to occur (Sale and MacDougall, 1981; Hortobagyi *et al.*, 1997). Traditional strength-training techniques, in which a bar is held at the completion of the motion, have been criticized because of large decelerations during the concentric phase, proportional to the load and, therefore, velocity of movement (Elliott *et al.*, 1989; Newton *et al.*, 1996). Strength training that facilitates the projection of the load avoids this problem by allowing the athlete to accelerate the bar throughout a greater range of movement. Such training, which has been described as 'ballistic' strength training (Newton and Kraemer, 1994), has been shown to be effective in improving functional performance (Hakkinen and Komi, 1985; Wilson *et al.*, 1993; Lyttle *et al.*, 1996).

In an attempt to maximize strength, researchers have become interested in taking advantage of the greater absolute forces associated with eccentric contractions (Komi and Buskirk, 1972; Johnson *et al.*, 1976; Jones and Rutherford, 1987). It has been suggested that

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eccentric training allows greater muscular tension to be developed, which supposedly favours greater development of strength (Atha, 1981; Hakkinen and Komi, 1983; Colliander and Tesch, 1990). Researchers have speculated that, to develop eccentric muscle strength most effectively, higher loads than those used in isometric and concentric resistance training are required. However, loading the athlete to 120–150% of their maximal concentric strength is rarely performed because of potential deficiencies in basic strength, technique or equipment leading to an injury (Johnson *et al.*, 1976; Kraemer, 1992).

Another form of training that may enhance the eccentric training stimulus is the attachment of a rubber bungy to the strength-training apparatus in such a way that the return velocity and, therefore, the force needed to decelerate the load at the end of the eccentric phase are increased. Research indicates that the faster a muscle is eccentrically loaded or lengthened, the greater the resultant concentric force produced (Asmussen and Bonde-Petersen, 1974; Bosco and Komi, 1979). Cavagna and colleagues demonstrated that the slower the pre-stretch or countermovement, the greater the loss of elastic energy (Cavagna *et al.*, 1968). The magnitude of this stored elastic energy increases with the speed of the eccentric action (Bobbert *et al.*, 1987). If this is the case and higher eccentric velocities are associated with bungy training, this type of training may offer an effective means to enhance strength and functional performance. A search of the literature, however, revealed no studies that have examined the effect of bungy weight training in terms of the electromyographic and kinematic characteristics of this training stimulus. Furthermore, the effects of such training on functional performance have yet to be investigated.

The aim of our first study was to determine if there are differences between bungy, non-bungy jump and traditional squat techniques. The aim of the second study was to determine whether ballistic jump squat training performed with and without the attachment of a rubber bungy to an isoinertial supine squat machine affects muscle function and functional performance. Of particular interest to this study were the effects of training on the performance of movement tasks (lunge, single leg jump and multidirectional agility) important in small court sports such as badminton, tennis, volleyball and squash. The effect of the bungy was investigated in terms of its use as an equivalent load rather than an additional load. We rationalized that, by ensuring the load was equivalent between conditions, it was possible to disentangle the effects of the bungy as a training stimulus. Such an approach should result in a better understanding of the effects of bungy type exercise and better insight into the applications of this type of exercise as a training strategy.

Methods

Study 1: a kinematic and electromyographic analysis of squat techniques

Participants

Ten males volunteered to participate in this research. Their age and body mass were 24.2 ± 2.3 years and 80.5 ± 5.5 kg, respectively (mean $\pm s$). All the participants were experienced weight trainers with a minimum of 3 years of strength-training experience. The Human Subject Ethics Committee of the Auckland University of Technology approved all the procedures undertaken and all participants signed an informed consent form before the research began.

Equipment

Supine squat machine. The participants performed their jump squat assessment on an isoinertial supine squat machine (see Fig. 1). This machine was custom-built (Fitness Works, Auckland, NZ) and used a 300 kg pin-loaded weight stack attached to a sled to provide a resistance load. A linear transducer (P-80A, Unimeasure, Oregon; average sensitivity $0.499\ mV \cdot V^{-1} \cdot mm^{-1}$, linearity 0.05% full scale) was attached to the weight stack and measured vertical displacement relative to the ground with an accuracy of 0.1 cm. These data were sampled at 1000 Hz by a computer-based data acquisition and analysis program.

The supine squat machine was designed to allow novice and experienced participants to perform maximal squats or explosive squat jumps, with the back rigidly supported, thus minimizing the risk associated with such exercises in an upright position. The sled lay on top of an undercarriage, which enabled the sled to be pegged every 2 cm (see left-hand side of bench in Fig.

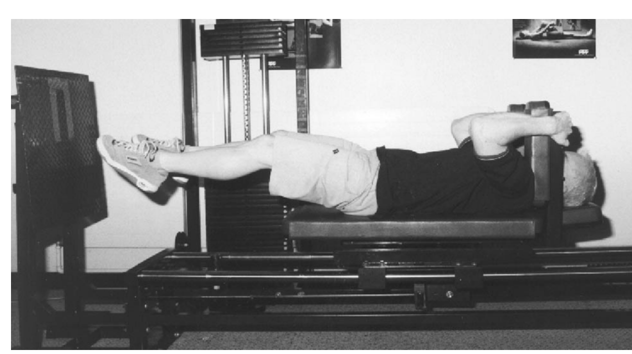

Fig. 1. Isoinertial supine squat machine.

2), allowing the start angle at the knees to be standardized according to the height of the participant. For the bungy condition, the elastic bungy ties were attached to the frame and the undercarriage of the sled (see foreground of Fig. 2). Movement of the sled away from the supine squat frame, therefore, resulted in a change of elastic resistance. At rest, the elastic bungy provided no resistance. As the sled moved from the start position (requiring a concentric contraction), the resistance provided by the bungy increased. Maximum elastic resistance was achieved, therefore, at the end of each individual's concentric phase or beginning of the eccentric (return to rest) phase. The effect of the bungy on additional resistance (as measured by a load cell; Penny and Giles Biometrics Ltd, UK) in relation to horizontal sled displacement away from the start position can be seen in Table 1. The procedures were repeated on three separate occasions, each separated by at least 1 day. If plotted, the effect of the bungy is linear across the range of displacement. The low standard deviation and coefficients of variation (s/mean $\times$ 100) indicate the consistency and stability of the system.

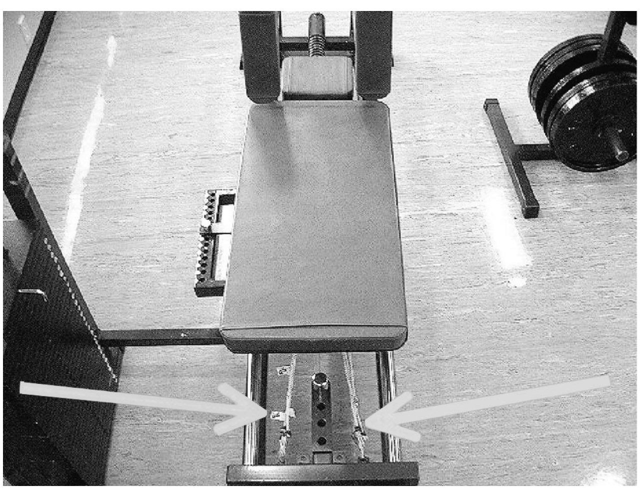

Fig. 2. Arrows indicate rubber bungy attachment from the frame of the squat machine to the undercarriage of the moveable sled.

Electromyography. For all squat conditions, electromyographic activity was recorded using self-adhesive Ag-AgCl 9.0 mm surface electrodes (3M:2259). When the skin over the muscles had been prepared by shaving, scrubbing and wiping with alcohol, two electrodes with an inter-electrode distance of 22 mm were attached over each muscle. The electrodes were placed over the belly of the vastus lateralis and gastrocnemius muscles. The reference electrode was placed on the bony part of the anterior iliac crest. The EMG signals were amplified ($\times$ 2000), band-pass filtered (5 dB down at 3 Hz and 1 kHz) and sampled at 1000 Hz.

Test procedures

Testing was performed in one session, the first part of which allowed familiarization to the three supine squat techniques and determined the maximal EMG activity of the vastus lateralis and gastrocnemius during a maximal isometric squat. In the second part of the session, kinematic and electromyographic data were collected on the three jump squat techniques using each participant's body mass as the resistance load. The three squat techniques included a traditional squat, in which the sled was moved as fast as possible in both the eccentric and concentric phases but the feet maintained contact with the foot plate at all times. The non-bungy jump squat differed from the traditional squat in that the participant and sled were projected at the end of the concentric phase (see Fig. 1). The only difference between the bungy and non-bungy squat jumps was the attachment of a rubber bungy to the sled during the squat movement. The resistance loads between the bungy and non-bungy squat conditions were equated to account for the added resistance of the bungy. For example, using Table 1, if a participant moved a sled 30 cm during the bungy squat condition, then the non-

Table 1. Force–length characteristics of the rubber bungys

Horizontal sled displacement (cm)	Test 1 force (N)	Test 2 force (N)	Test 3 force (N)	Mean $\pm s$	Coefficient of variation
5 cm from rest	53	56	52	53.7 ± 2.1	3.9
10 cm from rest	128	131	125	128 ± 3.0	2.3
15 cm from rest	215	213	216	215 ± 1.5	0.7
20 cm from rest	253	258	263	258 ± 5.0	1.9
25 cm from rest	292	291	294	292 ± 1.5	0.5
30 cm from rest	320	321	318	320 ± 1.5	0.5
35 cm from rest	358	340	349	349 ± 9.0	2.6

Note: To move sled from rest requires a concentric contraction.

bungy squat condition would need to be approximately 21 kg lighter to equate for the elastic resistance (mean resistance over that displacement). This resulted in less resistance at the inception of the concentric phase and greater resistance at the transition from the concentric to eccentric phases of the squat for the bungy squat condition. For each of the techniques, the participants were instructed to move the sled as 'explosively' as possible. The starting order of the squat techniques was randomized between participants to reduce the possible confounding effects of order and fatigue. Five repetitions of each technique were performed, from which the final two trials for each technique were used for analysis.

Data analysis

Kinematic analysis. The displacement–time data from the linear transducer were filtered using a low-pass Hamming filter with a cut-off frequency of 5 Hz. The filtered data were then differentiated using a 5-point derivative approximation (Lagrange polynomial 4th degree about each point) to determine the velocity data. The kinematic variables investigated were sled mean velocity over 10% intervals relative to total concentric or eccentric movement. For both the eccentric and concentric phases of the squats, we determined duration of contraction, mean velocity, peak velocity, time to peak velocity and when, during the movement, peak velocity occurred (time to peak velocity/duration of contraction = %).

Electromyographic analysis. The EMG collected during the supine squat was normalized to that collected during a maximal voluntary isometric contraction while lying on the squat machine with the knees at 60° from full extension. Normalization to a maximal voluntary isometric contraction is a widely used procedure and remains the most popular method when studying muscle activation (Soderberg and Knutson, 2000). To compare EMG activity over the course of the eccentric and concentric phases, each condition was divided into 10% intervals of the displacement during the eccentric and concentric movement. The root mean square values for each interval were calculated and expressed relative to the maximal voluntary isometric contraction (%MVIC). Thereafter, the %MVIC for each interval was compared across conditions. The average EMG for the eccentric and concentric phases was calculated by averaging the 10 %MVIC values recorded across the respective phases.

Statistical analysis

The results of the mean and peak eccentric and concentric velocities, the time and position of peaks and the duration of the eccentric and concentric phases for the three squat conditions were compared using a one-way repeated-measures analysis of variance (ANOVA) with Tukey *post-hoc* comparisons. A repeated-measures ANOVA with two trial factors (technique × percentage displacement) and a polynomial contrast method were used to distinguish significant differences in EMG activity and velocity profiles. The criterion level for significance was set at $P \leqslant 0.05$.

Study 2: training study

In the training study, we examined whether 10 weeks of ballistic weight training in the form of bungy and non-bungy squats affected muscle function and functional performance. Various kinematic and kinetic variables and tests of multidirectional agility, lunge ability and single leg jump performance were measured before and after the training programme.

Participants

Forty participants (28 males; 12 females) volunteered to take part in this study. The participants were involved in a wide variety of sports that predominantly involved the lower body. Their age, height and body mass were 23.1 ± 4.8 years, 1.75 ± 0.09 m and 76.3 ± 11.6 kg, respectively (mean $\pm s$).

Equipment

Supine squat machine. This device measured the displacement of the movement as previously described. The filtered data were then differentiated using a 5-point derivative approximation (Lagrange polynomial 4th degree about each point) to determine velocity and then differentiated again to determine acceleration data. Mass (participant plus sled plus resistance load) was then multiplied by the acceleration data to determine force. To determine power output over the range of motion, power was calculated by multiplying the force data by the velocity data.

Contact mat system. The contact mat system (Swift Performance, University of Southern Cross, Australia) consists of a portable battery-powered computer unit, a connecting cable and a contact mat, and was used to measure single leg jump performance. The system measures jump height (cm), flight time (ms) and ground contact time (ms). Reliability between the contact mat system and the force platform (AMTI Force Plate and Amplifier; Advanced Technology Inc., Washington, USA) revealed no significant differences between the contact mat system and force platform for flight (intraclass correlation coefficient = 0.95;

$P<0.001$) or contact times (intraclass correlation coefficient = 0.99; $P<0.001$).

Timing lights. The timing light system was a dual-beam modulated visible red-light system with polarizing filters (Swift Performance, University of Southern Cross, Australia). This system was used to measure multidirectional agility and lunge performance.

Test procedures

Testing was performed on two separate days, with at least 2 days but no more than 7 days separating the two sessions. Each session was preceded by a standardized warm-up involving multidirectional running and static stretches. The first session involved familiarization with the performance of the test items and determination of each participant's single leg concentric maximal strength (one-repetition maximum, 1-RM). Single leg jump height, lunge ability, agility and single leg concentric leg power (50% 1-RM) were assessed during the second session. The mean of the three best trials was used for analysis in each of the tests. These tests were replicated at the end of the 10 week training programme. Pilot work established the reliability of the procedures (see Table 4).

Strength and power tests. Unilateral performance was investigated. Maximal strength was established using the supine squat machine and measured as the load (kg) that each participant could lift for one repetition (1-RM) with each leg. Foot position was standardized and each participant's initial knee angle was set at approximately 90° using a goniometer aligned to the lateral malleolus, lateral epicondyle of the femur and greater trochanter of the left leg. A knee angle of 90° was selected because it was specific to the maximum angle used in lunge performance. The participants started with the 90° angle and extended the hip and knee using concentric muscle action for each trial. The procedures used to determine each participant's 1-RM were similar to those outlined by Heyward (1991). A jump squat using a load of 50% 1-RM was used to determine the power output associated with this movement task.

Single leg jump test. The participants stood on their preferred leg on the contact mat with their hands on their hips. They were instructed to perform a quick countermovement before jumping as high as possible (Young, 1995). Maximum height was recorded.

Lunge test. This test involved measuring the time taken by the participants to perform a forward lunge ($1.5 \times$ leg length) on their preferred leg and a return to the starting position as rapidly as possible. The participants stood between the beams of the timing lights, which were set at the approximate height of the lumbar spine. Their posture was upright with legs parallel and shoulder width apart. As soon as the participant moved forward, the computer began timing the movement until the participant returned to the start position. The timing was complete when the participant broke the beams during the return movement.

Agility test. A test based on the T-design of Semenick (1990) was used to assess agility. The test was modified to the dimensions shown in Fig. 3 as the smaller A–B and C–D distances were more specific to on-court conditions found in sports such as badminton and squash. Timing lights were placed at the base of the T-shape and once more the participants began within the beams. Successful completion of the test required the participant to complete the following sequence as quickly as possible: A → B → C → B → D → B → A. The participants had to touch markers C and D with a foot and place a foot in marker B when moving forward and on their return. Participants repeated the test if any of these markers were missed. Sixty seconds rest was allowed between trials.

Training programme. The participants were matched for maximal strength, weight-training experience and athletic activity and randomly assigned to a non-bungy trained group ($n=14$), a bungy weight-trained group ($n=14$) or a control group ($n=12$). Both training groups performed jump squat training. The only difference between the conditioning programmes was a series of rubber bungy straps attached to the supine squat machine when the bungy group trained. The training load for both groups was equated to account for the added resistance of the bungy. This was achieved by a load cell measuring the resistance associated with incremental changes in displacement

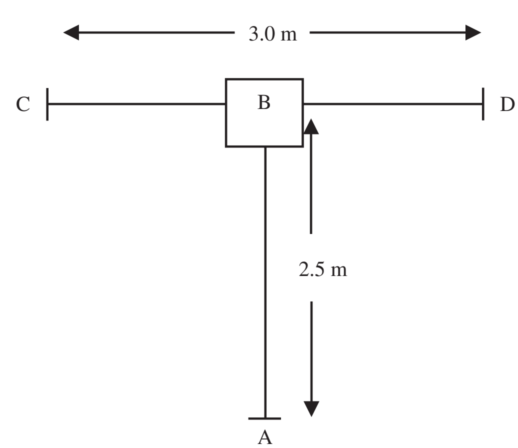

Fig. 3. Schematic representation of the agility test.

of the sled. Load was then equated relative to the sled displacement of each participant. Thus the effect of the bungy was primarily to change the magnitude of the resistance during the range of motion, with a lower resistance being experienced at the start of the concentric phase and a higher resistance being experienced at the end of the concentric phase. The bungy's resistance was checked weekly using a load cell and the bungys were replaced if decreases in the expected resistance were found (as indicated in Table 1).

An outline of the conditioning programme is presented in Table 2. The experimental groups trained twice per week; both performed a 2 week pre-conditioning phase. During weeks 3–10, the participants were instructed to move the loads as explosively as possible throughout the entire movement, irrespective of technique. The participants were retested at the end of 20 sessions (2 sessions × 10 weeks). The control group maintained normal daily activity throughout the 10 weeks of training.

Statistical analysis

The reliability of the assessment procedures (lunge, jump and agility) was assessed using two different statistical methods. A coefficient of variability (CV) was determined for all test variables to determine the similarity of measurement among trials (CV = *s*/mean × 100). Intraclass correlation coefficients were calculated to determine test–retest reliability. The interval between the two sessions was approximately 7 days.

A two-factor (time × treatment) repeated-measures ANOVA was performed to compare the pre-training and post-training means for the strength measures and performance tests across conditions. If a significant result was obtained, Tukey *post-hoc* comparisons were performed to establish which groups were significantly different. Significance was accepted at $P < 0.05$ for all statistical tests.

Results

Study 1: a kinematic and electromyographic analysis of squat techniques

No clear patterns were observed in the EMG activity of the gastrocnemius. As a result, only the EMG activity of the vastus lateralis is presented in this section. Irrespective of technique, the EMG for eccentric muscle action resulted in greater overall vastus lateralis activity as the muscle approached the transition from eccentric to concentric motion (see Fig. 4). This was to be expected, as this muscle had to brake the downward momentum of the sled. Compared with the traditional squat, greater EMG activity was observed for both the

Table 2. Conditioning programme

Phase and type of training	Sets	Reps/intensity	Type of exercise
Pre-conditioning phase (2 weeks)			
Bilateral weight training	3	15-RM	Supine squat jump* Calf extension Quad extension
Weighted vest training	2	10 (10% BM)	Front lunge Side lunge
Strengthening phase (4 weeks)			
Unilateral strength training	3	10-RM	Supine squat jump* Calf extension Quad extension
Weighted vest training	2	10 (10–15% BM)	Front lunge Side lunge
Strength/power phase (4 weeks)			
Unilateral strength and power training	3	8-RM	Supine squat jump* Calf extension Quad extension
Power training	3	50% 1-RM	Supine squat jump* Calf extension Quad extension
Weighted vest training	3	12 (10/5/0% BM)	Two step lunges Side-to-side lateral hops

Note: RM = repetition maximum, BM = body mass. *Denotes the exercises that have the rubber bungy attached.

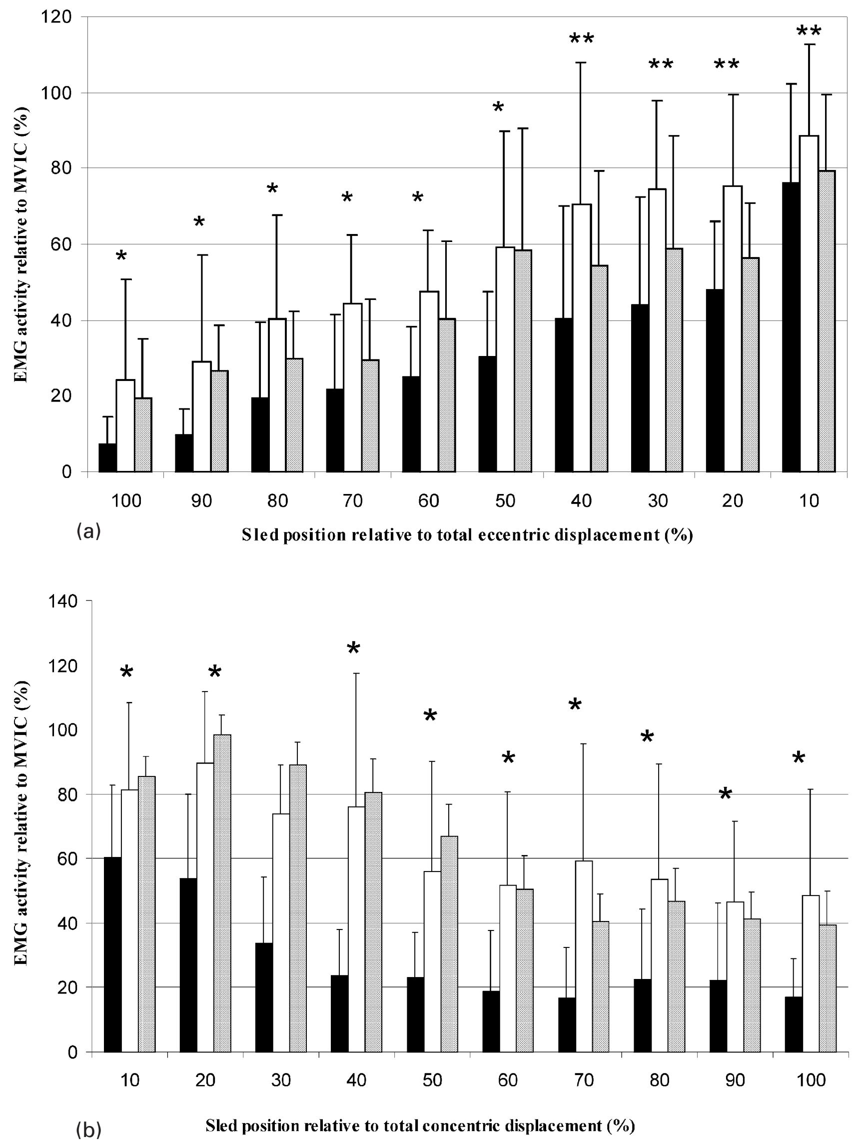

Fig. 4. EMG activity relative to the maximal voluntary contraction (%MVIC) of the vastus lateralis for traditional (■), bungy (□) and non-bungy (▒) squat techniques across different sled positions for both the eccentric (a) and concentric (b) phases. *Significant difference between the traditional squat and both the bungy and non-bungy squat techniques. **Significant difference between the bungy squat and both the non-bungy and traditional squat techniques.

bungy and non-bungy squat during the first 60% of the eccentric phase. During the final 30% of the eccentric phase, bungy EMG activity differed significantly from that of the other two squat techniques.

In contrast to the profile of the eccentric phase, the concentric EMG activity during this phase was greater at the beginning of the movement and decreased throughout the movement. Increased activity is to be expected as the muscle works to overcome the inertia of the sled and accelerate the sled. Compared with the traditional squat, significantly greater EMG activity was observed during both the bungy and non-bungy squats throughout the entire concentric phase.

The greater eccentric and concentric velocities for both ballistic weight-training techniques compared with the traditional squat can be observed in Fig. 5. The eccentric velocities begin at higher values, as the athletes are required to catch the sled after projecting themselves at the end of the concentric phase. Ballistic training of this nature probably affects the EMG activity discussed previously in both the concentric and eccentric phases. Interestingly, there was no significant difference between the two ballistic techniques in terms of the mean velocity over the entire movement for both the eccentric and concentric phases. As the bungy squat provided less

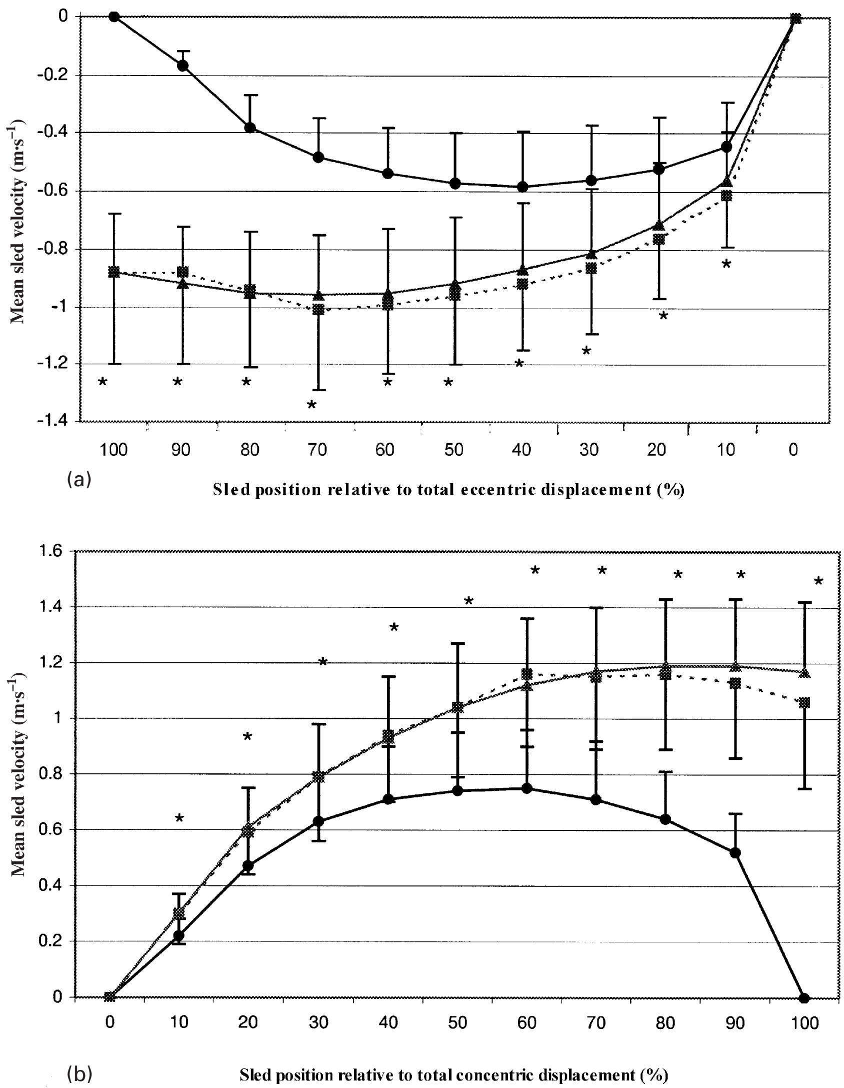

Fig. 5. Mean bar velocity for traditional (●), bungy (■) and non-bungy (▲) squat techniques across different sled positions for both the eccentric (a) and concentric (b) phases. *Significant difference between the traditional squat and both the bungy and non-bungy squat techniques.

resistance at the beginning of the concentric phase and greater resistance at the end of the concentric phase, this finding was unexpected.

Table 3 shows that, compared with the traditional squat, the ballistic squats generated greater mean and peak velocities, and shorter active phases, which were typified by higher-intensity activity (EMG). During the eccentric phase, the peak velocities occurred earlier in the contraction in the ballistic conditions. During the concentric phase, the peak velocities occurred much later during the contractions (83.0–91.3%) for the ballistic conditions, indicating that the participants were accelerating the sled for longer periods. The only significant difference between the two ballistic techniques was that the time to peak velocity occurred earlier in the bungy condition during the concentric phase.

Study 2: training study

The coefficients of variation (CV) indicate that there was very little variability (CV ≤ 4.5%) between trials for each of the dependent variables (see Table 4). The retest intraclass correlation coefficients indicate very high stability between the two sessions (intraclass correlation coefficient = 0.876–0.982). The reliability and validity of the isoinertial dynamometry used in this research to assess a variety of kinematic and kinetic variables has been reported previously (Cronin *et al.*, 2000, 2001a). In summary, the results indicate high stability between trials and sessions for the variables investigated in this study.

Ten weeks of ballistic training improved maximal and relative strength by 8.7–19.8%, which was significantly different to the control group (see Table 5). The force,

Table 3. Temporal, kinematic and EMG characteristics of the different squat techniques

	DOC (s)	MV ($m \cdot s^{-1}$)	PV ($m \cdot s^{-1}$)	TPV (s)	TPV/DOC (%)	EMG (%)
Eccentric phase						
TS	0.714 ± 0.348	0.378 ± 0.118	0.589 ± 0.180	0.337 ± 0.098	51.8 ± 8.35	34.1 ± 19.7
BS	0.423 ± 0.200*	0.679 ± 0.197*	1.02 ± 0.256*	0.158 ± 0.098*	37.3 ± 32.1*	46.1 ± 20.1*
NBS	0.432 ± 0.164*	0.638 ± 0.174*	0.988 ± 0.227*	0.077 ± 0.054*	17.8 ± 25.8*	53.3 ± 20.4*
Concentric phase						
TS	0.749 ± 0.195	0.390 ± 0.082	0.666 ± 0.163	0.421 ± 0.101	56.7 ± 5.4	29.2 ± 15.5
BS	0.459 ± 0.195*	0.650 ± 0.154*	1.13 ± 0.26*	0.381 ± 0.119#	83.0 ± 15.1*	63.5 ± 15.3*
NBS	0.472 ± 0.160*	0.609 ± 0.125*	1.14 ± 0.26*	0.431 ± 0.126	91.3 ± 6.0*	63.9 ± 22.9*

Note: TS = traditional squat, BS = bungy squat, NBS = non-bungy squat, DOC = duration of contraction, MV = mean velocity, PV = peak velocity, TPV = time to peak velocity, TPV/DOC = when peak velocity occurred, EMG = average EMG calculated over the entire phase.
*Significant difference between bungy or non-bungy squats and traditional squats.
#Significant difference between bungy squats and both non-bungy squats and traditional squats.

Table 4. Coefficient of variation (CV) and retest reliability for the performance variables

Variable	Mean ± *s*	CV%	Retest reliability
Agility performance			
Time (s)	3.77 ± 0.37	2.1	0.876 (0.001)
Lunge performance			
Duration of lunge (s)	0.784 ± 0.114	3.8	0.876 (0.001)
Jump performance			
Height (cm)	18.0 ± 4.32	4.5	0.982 (0.001)

velocity and power shown in Table 5 were calculated from the leg power assessment on the supine squat machine. The following variables improved significantly compared with the control group: peak velocity, peak force, mean power and peak power. These improvements were similar across training groups and the effect of the bungy squat was not significantly different to that of non-bungy squat weight training. The improvements from pre-treatment scores ranged from 4.3 to 14.3%. For the functional tests, the benefits of the conditioning programme led to a significant improvement in the lunge only. However, this improved lunge performance was noted only in the group that trained using the bungy attached to the supine squat machine. This group decreased the time to perform the lunge by a mean 21.5%.

Discussion

Study 1: main findings

The two ballistic weight-training techniques differed significantly from the traditional squat technique in all the variables measured (see Table 3, Figs 4 and 5). Further inspection of the results revealed that the two ballistic jump squat techniques offered a similar type of training stimulus. The only difference between the two techniques was time taken to achieve peak velocity (see Table 3) and the greater EMG activity recorded during the later stages (70–100%) of the eccentric phase (see Fig. 4). In terms of eccentric EMG activity, it would appear that the bungy and non-bungy squat conditioning provided a similar training stimulus during the initial eccentric phase. This may be attributed to the participants trying to resist or brake the greater momentum created by the elastic bungy and/or the release and return of the sled during the jump condition. The proposed greater eccentric activity from the increased resistance of the bungy in the outer ranges of the motion, therefore, does receive support from these results. Greater EMG activity was recorded later in the eccentric phase of the bungy condition, perhaps indicating that greater braking force and hence vastus lateralis activity was required for this ballistic technique.

It might be expected that the greater eccentric activation late in the bungy condition affects the concentric activation and velocities in some way. However, this was not the case. Greater and comparable concentric activation and velocities were shown for both ballistic conditions as early as the first 10% of bar movement as compared to the traditional squat. The greatest difference in velocity was found at the end of the concentric phase, as the ballistic techniques allow acceleration of a load over a greater portion of the concentric phase (83–91% *vs* 56%; see Table 3). Similar results have been reported when comparing bench press throws with traditional bench press motion (Newton *et al.*, 1997). Newton and colleagues also reported shorter contraction times, greater EMG

Table 5. Changes in performance due to training (mean and standard deviation of baseline measurements and percentage change from baseline)

Variable	Bungy training		Non-bungy training		Control	
	Mean ± s	%	Mean ± s	%	Mean ± s	%
Maximal strength (kg)	128 ± 27.5	8.7*	123 ± 28.1	19.8*	122 ± 34.1	–2.5
Relative strength (kg·body mass^{-1})	1.58 ± 0.27	12.3*	1.61 ± 0.31	16.2*	1.73 ± 0.39	–1.1
Mean velocity (m·s^{-1})	0.512 ± 0.078	4.6	0.516 ± 0.053	3.6	0.488 ± 0.070	3.8
Peak velocity (m·s^{-1})	1.13 ± 0.16	5.4*	1.14 ± 0.13	4.3*	1.09 ± 0.16	–2.8
Mean force (N)	707 ± 143	9.4	725 ± 206	2.3	711 ± 184	–1.6
Peak force (N)	939 ± 213	10.6*	963 ± 261	10.6*	925 ± 240	–2.4
Time to peak force (s)	0.467 ± 0.076	–1.8	0.450 ± 0.048	2.6	0.515 ± 0.09	–2.6
Mean power (W)	367 ± 93.8	11.4*	368 ± 96.9	12.2*	353 ± 114	–4.0
Peak power (W)	934 ± 253	14.3*	951 ± 256	11.8*	897 ± 298	–4.1
Single leg jump (cm)	17.9 ± 3.24	2.5	17.7 ± 3.78	0.6	17.5 ± 5.40	1.2
Lunge time (s)	0.807 ± 0.09	–21.5#	0.776 ± 0.104	–12.7	0.763 ± 0.146	–4.5
Agility (s)	3.75 ± 0.41	–0.7	3.78 ± 0.34	–1.4	3.88 ± 0.41	0.4

*Significantly different from the control group.
#Significantly different from the non-bungy and control groups.

activity and faster velocities for the ballistic bench press throw.

Given the different temporal and EMG characteristics of the bungy and non-bungy squat exercises, it would be interesting to ascertain whether these differences produce changes in muscle function and performance over the course of a training programme. Hence a 10 week training programme was performed, comparing the effects of bungy and non-bungy squat training in terms of muscle function and functional performance.

Study 2: main findings

Kinematic and kinetic findings

Given the relative importance of resistance training in the preparation of athletes, there is a need to determine the training stimulus that maximizes improvement of functional performance in the athlete's respective discipline. Several studies have compared the effectiveness of weight training, plyometric training and a combination of weight and plyometric training (Clutch *et al.*, 1983; Blakey and Southard, 1987; Adams *et al.*, 1992; Wilson *et al.*, 1993; Lyttle *et al.*, 1996). The training methodology used within this research was in essence a combination approach (see Table 2). As such, the weight training was predominantly ballistic irrespective of load, as was the weighted vest training.

The main results of the training study indicate that both types of ballistic training were equally effective for increasing maximal strength, relative strength, peak velocity, peak force and mean and peak power as measured on the supine squat machine. This is not surprising if taken in the context of the results described previously. Concentric measures of muscular performance were used, as previous research had shown that concentric tests were more strongly related to functional performance and were better able to effectively discriminate between good and poor performance (Pryor *et al.*, 1994; Wilson *et al.*, 1995; Young *et al.*, 1995). It might be expected that the stretch–shorten cycle (SSC) training predominantly used by this research may offer little augmentation to concentric-only performance. Indeed, some authors have suggested that while SSC training enhances performance of SSC activity, it generally does not facilitate concentric performance to the same extent (Schmidtbleicher *et al.*, 1988). The inclusion of slow SSC training (10-RM and 8-RM loading) most probably provided sufficient time under tension to ensure the contractile component contributed significantly during any given repetition. As a result, this would act as a significant concentric training stimulus. It would appear that the combination approach of fast and slow SSC training implemented in this study was equally effective as a maximal strength and power-training stimulus.

Functional performance findings

A problem associated with the assessment and development of strength and power is the limited research investigating the best methods of transferring strength and power gains to functional performance (Abernethy *et al.*, 1995). Researchers who do investigate the transference of strength gains to functional performance appear to be entrenched in two camps. One suggests that strength training needs to simulate the functional or sporting task as closely as possible in terms of movement pattern, posture, velocity, contraction type and contraction force. The other proposes that there is no need for specificity, but rather that one should train the appropriate muscle groups and use the actual practice of the specific event to tune increased strength to improved performance (Sale and MacDougall, 1981). The approach taken by this study was a compromise between these views. The supine squat training aimed to strengthen the leg musculature with little attention to specificity. However, more specific lunge and jump-type training immediately followed the supine squat training in an effort to tune the strength and power gains to improving the performance of motor tasks associated with small court sports such as badminton, tennis, volleyball and squash.

No significant changes occurred in single leg jump performance after training. As leg power and relative strength are thought to be important predictors of jump performance (Dowling and Vamos, 1993; Cronin *et al.*, 2001b), improvements in these qualities should correspond to improved single leg jump performance. However, this was not the case. Several factors may be responsible for this finding.

First, there is great variability in individual performance of the vertical jump. Dowling and Vamos (1993) studied 18 temporal and kinetic variables to identify those characteristics of good jump performance. They concluded that the large variability in patterns of force application between participants made it difficult to identify important characteristics of good performance.

Second, improvement in concentric muscle function as measured by the supine squat machine may not necessarily translate to changes in SSC function as measured by single leg jump performance. Although this appears to be the case, this is unlikely because most of the training was SSC in nature, and specific training adaptations should, therefore, reflect the nature of the stresses imposed during the training (Wilson *et al.*, 1997).

Third, perhaps the range of motion in which the participants trained was not similar enough to that of the jump task. As participants were assessed and trained at knee angles specific for improving lunge performance (approximately 90°), perhaps the improved strength and power at this range of motion did not transfer to the different angles (120–150°) associated with running and jumping (Wilson *et al.*, 1995; Young *et al.*, 1995). During this 'deep' jump squat training, the muscle is loaded for longer due to longer eccentric and concentric phases. This type of loading, therefore, is more likely to enhance lunge performance rather than jump and agility performance, which are shorter-duration SSC movements.

Fourth, it may be that the improvements achieved using the supine squat machine did not translate to improved vertical jump performance because of differences in posture. There is some evidence that posture specificity may be relevant (Sale and MacDougall, 1981; Wilson *et al.*, 1996). The posture between the single leg jumps performed on the supine squat machine and contact mat certainly differed in terms of plane (horizontal *vs* vertical) and the trunk angle (supine squat allowed no flexion–extension of the trunk). Differences in motor unit recruitment may have occurred due to more favourable leverage positions (Ter Haar Romeny *et al.*, 1984). In addition, perhaps the activation of the synergistic muscles varied as a function of joint angle, which is particularly relevant to multi-joint tests (Enoka, 1994).

Finally, Bobbert and van Soest (1994) postulated that a 20% increase in strength would translate to a 7.8 cm increase in vertical jump if jumping skill were also optimized. The same increase in strength would correspond to a 2 cm decrease if the neural control to the new levels of force production were not optimized to the jumping skill (Bobbert and van Soest, 1994). They concluded, 'muscle training exercises should be accompanied by exercises in which the athlete may practise with their changed muscle properties' (p. 1019). It may be that the improvements in strength and power were not 'tuned' to the jumping skill due to the absence of specific jump training.

The ability to quickly complete a lunge and return to the start or move off in another direction is important for success in sports such as squash, badminton, tennis and fencing. In the current study, the improvements noted on the supine squat machine only transferred to improved lunge performance for the bungy-trained group. This group decreased the time to complete a lunge compared with the non-bungy trained and control groups (see Table 5). As the only difference between training programmes was the bungy sled training, we concluded that the different training stimulus provided by the bungy was responsible for improved lunge performance. In relation to the previously described EMG and kinematic findings, we speculated that the effect of the bungy was to improve the eccentric or resistive force capability of the muscle late in the eccentric phase. Consequently, this may allow for a shorter eccentric phase and quicker eccentric–concentric transitions, which, in turn, may result in potentiation of the concentric phase (Bosco *et al.*, 1981; Komi, 1984) and ultimately quicker lunge performance.

Agility did not improve as a result of the 10 week training programme, even though strength qualities (mean power and relative strength) that were thought important for improved dynamic performance of this task increased significantly (Cronin *et al.*, 2001b).

These findings may be explained as discussed previously. The lack of specificity during training in terms of contraction type and duration, range of motion and posture may account for the non-significant gains in agility. Furthermore, the dynamic nature of agility differs greatly from that of strength training. It would appear that the strength-conditioning programme was not distinct enough to elicit specific adaptations for agility and single leg jump performance. This suggests that improved strength does not necessarily transfer to improved functional performance and emphasizes the need for training methods that improve dynamic strength and power in relation to a specific motor task.

Conclusion

Bungy and non-bungy squat exercises were found to be different to a traditional squat across several EMG and kinematic variables. The principal difference between the two ballistic techniques was the significantly greater EMG activity late in the eccentric phase of the bungy jump squat. Ten weeks of ballistic training improved several strength and power measures, but these improvements did not translate to improved SSC performance as measured by agility and single leg jump performance. Bungy training did improve lunge performance compared with the non-bungy training and control groups and this change may be associated with the greater EMG activity that occurred later in the eccentric phase of the bungy squat condition. Although the effect of bungy training remains unclear, it is certainly a training method that warrants further investigation in light of the significant improvements in lunge performance. From a practical standpoint, singular improvement in concentric or eccentric measures would appear to have little bearing on the performance of a functional task. The challenge is to develop predictor models and, therefore, assessment batteries that provide better insight into the underlying determinants of functional performance. The advent of better predictor models will enable an improved understanding of how to better develop strength and power and ensure transference of these gains to functional performance.

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