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ORIGINAL ARTICLE

A comparison of the kinematics, kinetics and muscle activity between pneumatic and free weight resistance

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Abstract Pneumatic devices provide a resistance comprising minimal mass, possibly affording greater movement velocities, compared to free weight, while reducing the influence of momentum. Thirty men completed three testing sessions [free weight (FW), ballistic (BALL) and pneumatic (P)] each consisting of a one repetition maximum (1RM) and six sets (15, 30, 45, 60, 75 and 90% 1RM) of four explosive repetitions of a bench press. Dependent variables were expressed as mean and as a percentage of the concentric displacement. Significant differences ($P < 0.05$) were evaluated using two way repeated measures ANOVAs with Holm–Sidak post hoc comparisons. On average, the mean and peak *P* velocity were 36.5 and 28.3% higher than FW, and 22.9 and 19.1% higher than the BALL movements. The FW and BALL peak force were both significantly higher than the *P* (26.3 and 22.7% for FW and BALL, respectively). BALL mean power output was significantly higher than the FW and *P* at loads of 15 and 30% 1RM; however, between loads of 60–90% 1RM the highest mean power was produced with a *P* resistance. A 15% 1RM load maximized the peak power for each condition and no significant differences were found between the *P* and BALL. For loads of 45–90% 1RM the force, power and muscle activity were higher during the last 10–20% of the concentric displacement when subjects employed the *P* resistance. In summary, pneumatic resistance may offer specific advantages over loads comprising only mass (FW and BALL), although not without its own limitations.

Keywords Ballistic · Free weight · Pneumatic · Power · Velocity

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Introduction

Newton's second law of motion describes the acceleration of an object, as being directly proportional to the magnitude of the net force, in the same direction as the net force and inversely proportional to its mass ($a = F/\mathrm{m}$). With respect to linear motion, mass is a numerical representation of an object's inertia, or its resistance to change in its state of motion and is directly proportional to the magnitude of an object's momentum at any given velocity ($p = \mathrm{m} \times v$). All motion is governed by these relationships, independent of the exercise being performed or the contraction type being used, however, the degree to which this governance affects the associated kinetics, kinematics and muscle activity is dependent on the resistance type.

Dynamic exercise performed with free weight resistance necessitates the production of peak forces in excess of 190% of the weight of the load to produce the higher accelerations associated with lighter lifts (Cronin et al. 2003; Newton et al. 1996). As a result, momentum is increased, which leads to subsequent decreases in force, relative to the weight of the load and an extended deceleration phase during the later stages of the concentric contraction (Alamasbakk and Hoff 1996; Cronin et al. 2003; Elliott et al. 1989; Newton et al. 1996). Well trained athletes may spend up to 52% of the duration of a concentric contraction decelerating a load in order to compensate for the momentum produced during the initial 3% of the concentric displacement (Elliott et al. 1989), which results in a concomitant decrease in the activity of the agonist and synergist musculature (Newton et al. 1996). Training of this nature May have negative implications for sports characterized by high velocity, high power actions. Athletic movements are governed in part by body segment lengths and maximum force capabilities; however, an athlete's ability to sequence the muscle activity of the entire kinetic chain may lead to superior performance.

A number of attempts have been made to overcome these inherent limitations of free weight resistance, via accommodating (Hislop and Perrine 1967; Holt and Pelham 1992; Hortobagyi et al. 1989; Telle and Gorman 1985) and variable resistances (Harman 1983; Smith 1982), however, such approaches are not without their own problems specific to their mechanics. Accommodating resistances, such as hydraulics and isokinetics, allow for maximal efforts to be produced throughout the concentric phase, however to achieve this, velocity is held constant and acceleration is zero. Variable resistance devices have traditionally offered a training mode in which the resistance varies according to the mechanical leverage experienced at specific joint angles with the intent of maintaining a maximum muscular effort, but have typically involved lever or cam based machines and do not accommodate for individuality. To improve upon the degree of sport specificity attained through free weight resistance training, velocity and acceleration profiles likely need to be similar to those produced during athletic movements. Therefore, strategies that minimize the acceleration or make attempts to control the movement velocity (Hislop and Perrine 1967) may not be conducive to improving athletic performance. Furthermore, limiting oneself to single joint, machine based efforts, reduces the permissible movement directions from six in natural movements to just one, thereby reducing the synergistic and stabilizing requirements implicit in most human motion.

More recently, ballistic movements, denoting accelerative, of high velocity, with projection into free space (Newton and Kraemer 1994), have been introduced as a potentially superior form of free weight resistance training because the athlete is no longer limited by having to decelerate the load at the end of the concentric contraction (Newton et al. 1996). Consequently, a greater portion of the concentric phase can be spent accelerating, thereby increasing the mean and peak velocity and power, in comparison to a non ballistic equivalent (Newton et al. 1996). However, in order to facilitate such movements, a Smith machine is frequently used (Baker 2001, 2002; Baker et al. 2001; Cronin et al. 2003; Thomas et al. 2007), which may compromise the contraction velocity and synergist involvement, while restricting motion of the barbell to a fixed vertical path (Cotterman et al. 2005). Furthermore, because ballistic motion involves the projection of a mass, inertia and momentum may still limit the movement velocity that can be achieved or the force, power and muscle activity produced towards the end of the concentric phase; although such a contention has yet to be investigated.

Given the notion of velocity specificity (Caiozzo et al. 1981; Izquierdo et al. 2002; Kanehisa and Miyashita 1983; McBride et al. 2002) and the possible limitations of overcoming the inertia associated with free weight resistance, a technology has been developed whereby the external load is composed primarily of a resistive force manufactured from air pressure (pneumatic resistance). It has been asserted that pneumatic resistance training devices may avoid the inherent limitations of free weight by providing a load/resistance that is not subject to inertia to or momentum (Keiser 1981). Consequently, the forces required to elicit movement should remain more consistent during the entire concentric phase and when using an equivalent load greater velocities should theoretically, be attainable. Furthermore, the resistance is supplied via a cable, thereby maintaining the six degrees of freedom and allowing any natural movement to be reproduced. It is these attributes that may afford a superior velocity specific training response, however the authors are unaware of any experimental evidence to support such a contention.

The objectives of this investigation given information were to (1) examine the kinematics, kinetics and muscle activity between explosive upper body movements performed with free weight and pneumatic resistance; (2) compare the kinematics, kinetics and muscle activity between ballistic and non ballistic explosive upper body movements; (3) identify the optimal training load for mean and peak power development for each resistance and movement type; and, (4) evaluate the force and velocity contributions to mean and peak power and concluding as to the possible implications for athletic performance.

Methods

Subjects

Thirty men with a minimum of 12 months of resistance training experience and a maximum bench press greater than their body weight volunteered to participate in this investigation. The subjects' mean (±SD) age, height, body mass and resistance training experience were 24.9 (4.9) years, 1.79 (0.06) m, 80.6 (9.8) kg and 5.6 (3.8) years, respectively. Prior to the commencement of testing, all subjects read and signed an informed consent and filled out a health questionnaire approved by the Human Ethics Committee of the University.

Movement selection

A bench press movement was used to examine the mechanical differences between resistance types with the intention of reducing between subject variability and to limit the body mass component of the system. Less moveable mass ensured that the lighter pneumatic loads were comprised primarily of pneumatic resistance. Further, this model has been used in previous research (Cronin et al. 2003; Newton et al. 1997) and so comparisons to these published results would be possible.

Instrumentation

A squat rack (Fig. 1), instrumented with pneumatic technology (Half Rack, Keiser®, Fresno, CA, USA) was used for all pneumatic testing purposes. Resistance was generated via an air compressor (1022, Keiser®, Fresno, CA, USA) by depressing '+' and '−' foot pedals located at the base of the rack. A detailed explanation of the technology involved has been reported previously (Keiser 1980, 1981). The pneumatic rack permitted a traditional bench press to be executed with a pneumatic load while maintaining all six permissible movement directions. Resistance was supplied by way of cables (Fig. 1a, iii), which extended from a pulley system free to move in the horizontal direction along tracks at the base of the rack (Fig. 1a, iv). The cables were then attached to a lightweight 2.5 kg barbell (Keiser®, Fresno, CA, USA; Fig. 1a, ii), specifically designed for use with the pneumatic squat rack. The grip diameter was identical to that of a standard Olympic barbell. A digital screen displayed the pneumatic load (lb) as calculated by software within the system. Through pilot testing, the reliability of the pneumatic rack was found to be high at all loads within its useable range (ICCs = 1.00).

Free weight testing was performed inside a standard power rack equipped with a magnetic particle brake (Fig. 1b, vi) (Fitness Technology, Adelaide, SA, Australia), which prevented any eccentric motion of the barbell subsequent to the point of release, during the ballistic testing condition. A bench was secured to the centre of a portable 0.92 by 0.92 m force plate (Quattro Jump Model 9290AD, Kistler, Switzerland) using a customized steel bracket (Fig. 1b, ix). Foot pegs extending horizontally from the end of the bracket were used to accommodate various foot positions so subjects were not obliged to place their feet on the bench or the floor, thus maintaining a degree of comfort and ensuring an accurate reading from the force plate. Prior to each testing session the force plate was calibrated and zeroed with the weight of the participant and the bench.

A linear position transducer (PT5A-150, Celesco, Chatsworth, CA, USA) with a signal sensitivity of 0.244 mV/V per millimeter was secured to a wood plank and positioned approximately 1.5 m directly above the centre of the barbell (Fig. 1b, vii). The transducer was zeroed at the commencement of each repetition as the acquisition software recorded the initial displacement as 0.000 m.

During the ballistic condition, two, 0.30 m ribbon switches (151-BBW, Tapeswitch, NY, USA) with a pressure sensitivity of 2 N, were fastened to the underside of the barbell. Using a common power supply of 5 V, the two switches were connected in parallel and wired so that the voltage would remain low unless both were released. This equipment was used as a means of identifying the exact

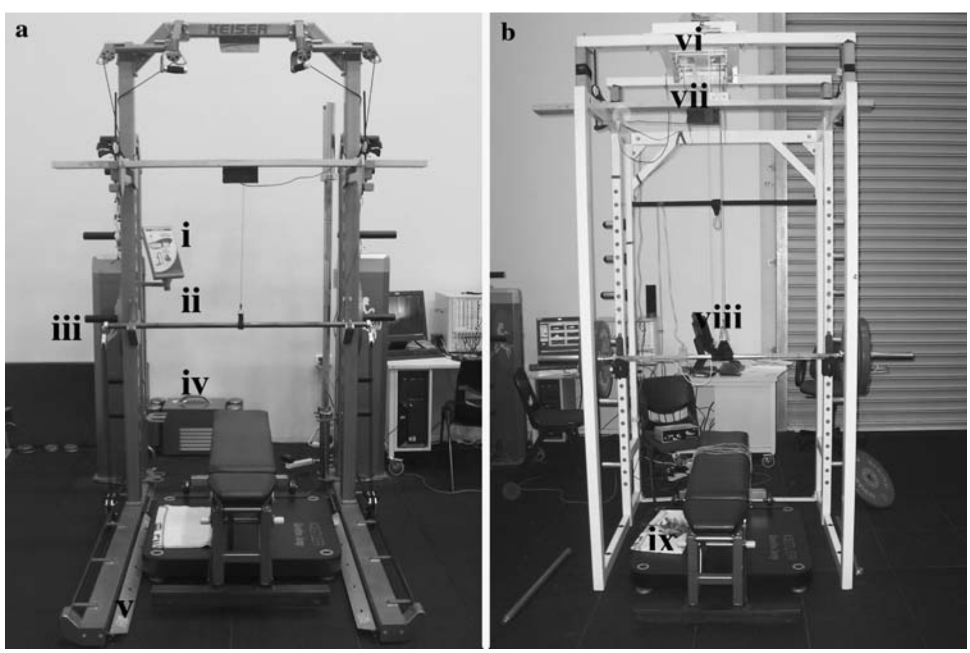


Fig. 1 The experimental setup for the: **a** pneumatic; and, **b** free weight and ballistic conditions. The pneumatic resistance was set by depressing foot pedals located at the base of the rack (*v*), loaded onto the lightweight barbell (*ii*) via cables (*iii*) and displayed on a digital indicator (*i*). An air compressor (*iv*) controlled the ratio of pressure to resistive force. The magnetic particle brake (*vi*) controlled downward movement of the barbell by way of a steel cable attached with two Velcro straps (*viii*). Displacement and vertical force were measured with a position transducer (*vii*), fastened to the centre of the barbell, and portable force plate (*ix*), respectively

point of barbell release and hypothesized to be a more accurate representation of motive kinematics and kinetics than previous methods used (Frost et al. unpublished).

Electromyographic signals were acquired with a Model 12 Neurodata Aquisition System (Grass Instrument Division, Astro-Med Inc., West Warwick, RI, USA), amplified with a gain of 1,000 and passed through a frequency window of 10–1,000 Hz prior to A/D conversion. The common mode rejection ratio of the amplifiers was 80 dB at 50 Hz. All raw analogue signals (position, force, EMG and switch) were A/D converted using a 16 bit data acquisition (DAQ) board (PCI-6220, National Instruments, Sydney, NSW, Australia) and sampled simultaneously at 2,000 Hz. Original Labview™ software (Version 8.1, National Instruments, Austin, TX, USA) acquired, displayed and stored all data for further analysis.

Pairs of Ag/AgCl surface electrodes (Meditrace 200, Mansfield, MA, USA), were placed at five sites on the right hand side of the body, in accordance with the locations outlined in Freeman et al. (2006); latissimus dorsi—0.01 m lateral to the inferior border of the scapula; pectoralis major—on an angle midway between the anterior aspect of the humeral head and the nipple, over the muscle belly; long head of the biceps brachii—midway between the anterior aspect of the humeral head and the elbow joint; lateral head triceps brachii—angled medial and inferior over the muscle belly; anterior deltoid—between the lateral border of the clavicle and the deltoid tuberosity on the humerus, over the muscle belly. One ground electrode was placed on the olecranon process of the ulna. All electrodes were placed in parallel with the muscle fibres at an inter-electrode distance of 0.02 m and subsequently marked with permanent ink. Prior to application, each site was shaved if necessary, gently abraded and cleansed with an alcohol swab. The impedance between each pair of electrodes was measured to ensure that the resistance was below 5 kΩ.

Testing procedures

Each subject attended one familiarization session and three testing sessions separated by a minimum of 72 h and a maximum of 1 week. The familiarization protocol consisted of six sets of four repetitions with pneumatic resistance using loads of 20, 30, 40, 50, 60 and 70% of an estimated free weight one repetition maximum (1RM), followed by three sets of four ballistic efforts using absolute loads of 20, 40 and 60 kg; each separated by three minutes of rest. Subjects were permitted to self select their grip and foot width, however, the distances were measured, marked with tape and maintained during all future assessments. A closed grip, with which the fingers and thumb were wrapped in opposite directions around the barbell, was used for the duration of testing. Testing sessions involved the completion of four maximum voluntary isometric contractions (MVIC), a 1RM test and six sets of four repetitions performed at loads equating to 15, 30, 45, 60, 75 and 90% of the previously determined 1RM. The order of testing was standardized in the following order for all subjects: free weight (FW), ballistic (BALL) and pneumatic (P), although four individuals were asked to complete the P session prior to the BALL due to complications with the magnetic brake and between—session time constraints. Four minutes of rest was given between the completion of the MVICs and the beginning of the 1RM test. An additional 10 min of rest was given before performing the sub-maximal repetitions. Subjects were required to refrain from any upper body resistance training for the 48 h preceding testing or making changes to their diets.

Normalization of EMG

Each testing session began with a general warm-up consisting of 5 min of dynamic stretching and two sets of six bench presses at loads equivalent to 50 and 60% of the estimated 1RM. The isometric contractions were then performed from a supine position, identical to that of a bench press, by pulling or pushing against an immovable load at an approximate elbow angle of 90°. The pull was executed by placing a block, adjustable to the nearest 0.025 m, on the subject's chest to limit the range of motion they could achieve when pulling themselves up towards the immovable barbell. Two, 3 s maximum voluntary efforts were performed for each condition, separated by 90 s of rest. EMG data was acquired and stored for future analysis.

RM testing

The 1RM for each subject was determined using procedures similar to those described in Doan et al. (2002). Subjects were instructed to complete one set of four repetitions at 60% of their estimated 1RM, one set of three repetitions at 70% 1RM, one set of two repetitions at 80% 1RM and one repetition at 90% 1RM, followed by a maximum of five attempts to identify their actual 1RM. Three minutes rest was given between each set. All 1RM testing was conducted using a stretch shortening cycle (SSC) movement with no pause between the eccentric and concentric phases; however, contacting the chest with the barbell was not permitted. If the barbell contacted the chest or failed to come within 0.05 m of the chest, it was disregarded and repeated following an additional 3 min of rest. Subjects were encouraged to move the barbell as quickly as possible, but required to maintain contact between their hips and back with the bench and feet with the force plate for the duration of the repetition. If the shoulders failed to remain in contact with the bench, but it was deemed to be the result of momentum from the barbell, the repetition was kept; otherwise it was repeated after an additional one minute of rest.

The 1RM achieved during the FW testing session was used to assign sub-maximal loads for both free weight conditions (FW and BALL). Subjects were asked to replicate the 1RM attempt made during the FW session when they returned to complete the BALL testing; all subjects were successful. The P 1RM was determined using the same protocol. Position, force and EMG data were acquired for each 1RM attempt.

Sub-maximal load testing

Four, single repetitions, separated by 1 min, were performed as explosively as possible at loads of 15, 30, 45, 60, 75 and 90% of the measured 1RM, with 3 min rest enforced between each percentage. Loads were assigned in an ascending order so as to make a systematic comparison across all subjects. Participants were instructed to lower the barbell as fast as they thought manageable, without touching the chest when transitioning from the eccentric to concentric phase. Any repetition that contacted the chest or failed to come within 0.05 m of the chest was disregarded and repeated after an additional one minute of rest. As with the 1RM testing, subjects were required to maintain contact between their hips and back with the bench and feet with the force plate for the duration of each repetition.

The sub-maximal loads assigned during the FW and BALL testing sessions were identical; however, to compensate for the recoil of the magnetic brake and equate the resistive forces, additional mass was added to the barbell during the BALL session. The recoil of the brake was estimated at 19 kg by identifying the mass that could be held by the brake at 0.40 m above the bench (~start of eccentric phase) without exhibiting any upward movement. Similarly, the appropriate P load, as displayed on the digital indicator, was adjusted so that the percentages assigned included the mass of the lightweight barbell and collars (3 kg). Furthermore, all pneumatic loads were set at a height of 0.64 or 0.74 m (distance from the pulley to the bottom of the cable attachment) by increasing the resistance, as it has been previously shown to exhibit a higher degree of linearity for progressively heavier loads (Frost et al. unpublished). All four repetitions were analysed, although only the two fastest (mean velocity) were used for all subsequent calculations of the means.

Prior to the commencement of any sub-maximal P testing, subjects completed two single repetitions with the 2.5 kg barbell, separated by 1 min of rest. Data from these two trials was stored and later used to estimate the peak contraction velocity.

Data analysis

Kinematics and kinetics

The raw displacement, force and switch data were filtered using fourth order, zero phase shift, low-pass Butterworth filters with cut-off frequencies of 100 Hz. Velocity and acceleration of the barbell were calculated by differentiating (single and double, respectively) the displacement and subsequently smoothed using fourth order, zero phase shift, low-pass Butterworth filters with cut-off frequencies of 10 and 4 Hz, respectively. Initiation of the eccentric phase was defined as the first instance of negative displacement, determined by searching the position array backwards from the point minimum displacement, which corresponded to the end of eccentric phase. The end of the concentric phase for the non ballistic conditions (FW and P) was defined as the point of maximum displacement to maintain consistency with previous literature (Alamasbakk and Hoff 1996; Asci and Acikada 2007; Cronin et al. 2000, 2003; Elliott et al. 1989; Jidovtseff et al. 2006). For the ballistic analysis, the concentric phase was either terminated at the point at which the switch voltage rose above 1 V or maximum displacement, whichever occurred first. For the purpose of this investigation, only the concentric phase was analysed in further detail.

Data for the concentric phase was subsequently analysed in two ways: as a function of time and as a percentage of the total concentric displacement. Mean, peak, time to peak as a percentage of the total concentric duration and the position of the peak as a percentage of the total concentric displacement were calculated for displacement, velocity, acceleration, force and power (force × velocity). The force and velocity contributions to peak power were expressed as percentages of the peak contraction velocity and maximum dynamic force, defined as the peak velocity from the faster of the two 2.5 kg explosive repetitions and peak force from the FW 1RM, respectively. The concentric data was then separated into 51, 2% bins by creating a 50 point array comprised of the position indexes (i), or locations, that corresponded to the appropriate percentile (n) (first sample greater than peak displacement × $2n/100$, for n 0–50). The first and last index of the array was defined as the start and end of the concentric phase, respectively. Lastly, the mean of all samples between each two successive indexes was calculated and used to express that percentage of the concentric displacement (an approximate sampling rate of 20–200 Hz depending on the load).

Electromyographic signals were analysed three ways: (1) rectified and integrated; (2) rectified, normalized and expressed as a percentage of the amplitude probability distribution function (APDF); and, (3) rectified, normalized, low pass filtered using a fourth order, zero phase shift, low-pass Butterworth digital filter with a cut-off frequency of

3 Hz (Freeman et al. 2006) and expressed as a percentage of the APDF and the total concentric displacement. Agonists (pectoralis major, anterior deltoid and triceps brachii) and antagonists (biceps brachii and latissimus dorsi) were normalized to the highest activity recorded in the isometric pushes and pulls, respectively. The raw isometric signals were rectified for analysis method 2 and rectified and low-pass filtered for analysis method 3 prior to calculating the maximum muscle activity. Data were analysed using customized software written with Labview™ (Version 8.1, National Instruments, Austin, TX, USA).

Statistical analysis

Dependent variables were expressed as mean and standard deviations and evaluated for reliability with coefficients of variation. Two way repeated measures analyses of variance were used to examine the effects that each independent variable (load and condition or percentage displacement and condition) had on the dependent variables. Holm–Sidak's multiple comparison tests were used to identify which variables were associated with significant effects and to adjust the level accepted as statistically different. The minimum level of significance was set at an alpha level of $P < 0.05$. All statistical analyses were performed using SigmaStat 3.1 (Systat Software Inc., Richmond, CA, USA).

Results

Average (SD) mean force for the free weight and pneumatic 1RM was 1035.6 (166.7) N and 937.7 (126.9), respectively, ($P < 0.001$). Assuming that the mean force is equal to the magnitude of the resistance, the forces can be divided by the acceleration due to gravity and expressed as mass equivalents of 105.5 (17.0) kg and 95.6 (12.9) kg. The coefficients of variation, describing within-subject inter-trial reliability, were below 10% for all reported variables.

Kinematics and kinetics

Velocity

Mean and peak velocity were significantly different between all three conditions at loads of 15–60% 1RM (Table 1), with the highest velocity being produced with a P load of 15% 1RM (2.23 and 3.53 m/s for the mean and peak, respectively). On average, the mean and peak P

Table 1 A comparison of the kinematic variables

1RM (%)	Condition	MV (m/s)	PV (m/s)	% TPV/DOC	% PPV/TD	MA (m/s^2)	PA (m/s^2)	DOC (s)	TD (m)
15	FW	1.73 (0.19)	2.91 (0.32)	53.3 (6.1)	56.4 (5.4)	0.47 (0.53)	24.92 (4.91)	0.339 (0.040)	0.582 (0.057)
	BALL	1.87[a] (0.17)	3.05[a] (0.23)	93.4[a] (3.5)	89.8[a] (5.2)	10.48[a] (1.46)	16.01[a] (2.42)	0.278 (0.029)	0.520[a] (0.056)
	P	2.23[c] (0.30)	3.53[c] (0.35)	55.7[b] (5.2)	56.4[b] (4.3)	2.43[c] (1.46)	37.69[c] (9.85)	0.251 (0.031)	0.556[c] (0.059)
30	FW	1.33 (0.14)	2.13 (0.21)	59.2 (5.1)	62.0 (4.5)	0.04 (0.21)	15.00 (3.28)	0.422 (0.035)	0.562 (0.057)
	BALL	1.51[a] (0.11)	2.29[a] (0.15)	85.1[a] (3.3)	78.3[a] (4.2)	5.39[a] (0.75)	10.96[a] (2.18)	0.384 (0.029)	0.580[a] (0.048)
	P	1.85[c] (0.17)	2.75[c] (0.20)	55.9[b] (8.5)	57.3[b] (8.3)	2.01[c] (0.75)	32.77[c] (8.40)	0.281 (0.026)	0.522[c] (0.050)
45	FW	1.02 (0.12)	1.60 (0.16)	64.6 (6.2)	65.6 (5.8)	0.07 (0.12)	9.57 (2.34)	0.525 (0.044)	0.535 (0.054)
	BALL	1.16[a] (0.09)	1.73[a] (0.16)	82.3[a] (3.6)	75.8[a] (4.1)	2.74[a] (0.67)	7.50[a] (1.46)	0.502 (0.044)	0.581[a] (0.044)
	P	1.46[c] (0.14)	2.09[c] (0.15)	60.8[b] (11.4)	62.1[b] (11.5)	1.39[c] (0.72)	23.75[c] (8.18)	0.337 (0.038)	0.492[c] (0.047)
60	FW	0.76 (0.11)	1.15 (0.17)	70.9 (5.4)	71.7 (5.3)	0.01 (0.08)	6.21 (1.81)	0.667 (0.069)	0.505 (0.056)
	BALL	0.84[a] (0.09)	1.27[a] (0.15)	82.4[a] (3.2)	77.3 (3.5)	1.16[a] (0.42)	4.99 (1.13)	0.674 (0.080)	0.564[a] (0.046)
	P	1.04[c] (0.12)	1.52[c] (0.18)	69.5[b] (11.0)	69.4[b] (10.9)	0.88[c] (0.37)	14.57[c] (5.05)	0.452[b] (0.060)	0.469[c] (0.042)
75	FW	0.50 (0.09)	0.77 (0.15)	77.6 (11.7)	77.9 (11.5)	0.01 (0.05)	3.73 (1.30)	0.950 (0.181)	0.465 (0.048)
	BALL	0.54 (0.12)	0.87 (0.18)	81.6 (11.4)	78.8 (11.2)	0.22 (0.23)	3.36 (1.20)	1.012 (0.234)	0.528[a] (0.058)
	P	1.04[c] (0.12)	1.06[c] (0.19)	80.0 (4.4)	78.4 (4.1)	0.54[a] (0.22)	8.87[c] (3.00)	0.656[c] (0.122)	0.447[c] (0.038)
90	FW	0.24 (0.10)	0.48 (0.13)	78.1 (26.9)	76.4 (24.4)	0.00 (0.03)	2.40 (0.93)	2.183 (1.283)	0.430 (0.045)
	BALL	0.25 (0.11)	0.54 (0.18)	81.0 (25.6)	77.9 (22.8)	0.01 (0.06)	2.29 (1.39)	2.303 (1.317)	0.464[a] (0.058)
	P	0.36[c] (0.10)	0.67[c] (0.19)	84.9[a] (16.2)	81.2 (15.4)	0.26 (0.13)	5.86[c] (2.63)	1.273[c] (0.368)	0.424[b] (0.038)

Data is expressed as a mean (SD) for each load and condition

MV mean velocity, *PV* peak velocity, *MA* mean acceleration, *PA* peak acceleration, *DOC* duration of concentric phase, *TD* total concentric displacement, *TPV* time to peak velocity, *PPV* position of peak velocity

[a] Significantly different than FW ($P < 0.05$)

[b] Significantly different than BALL ($P < 0.05$)

[c] Significantly different than FW and BALL ($P < 0.05$)

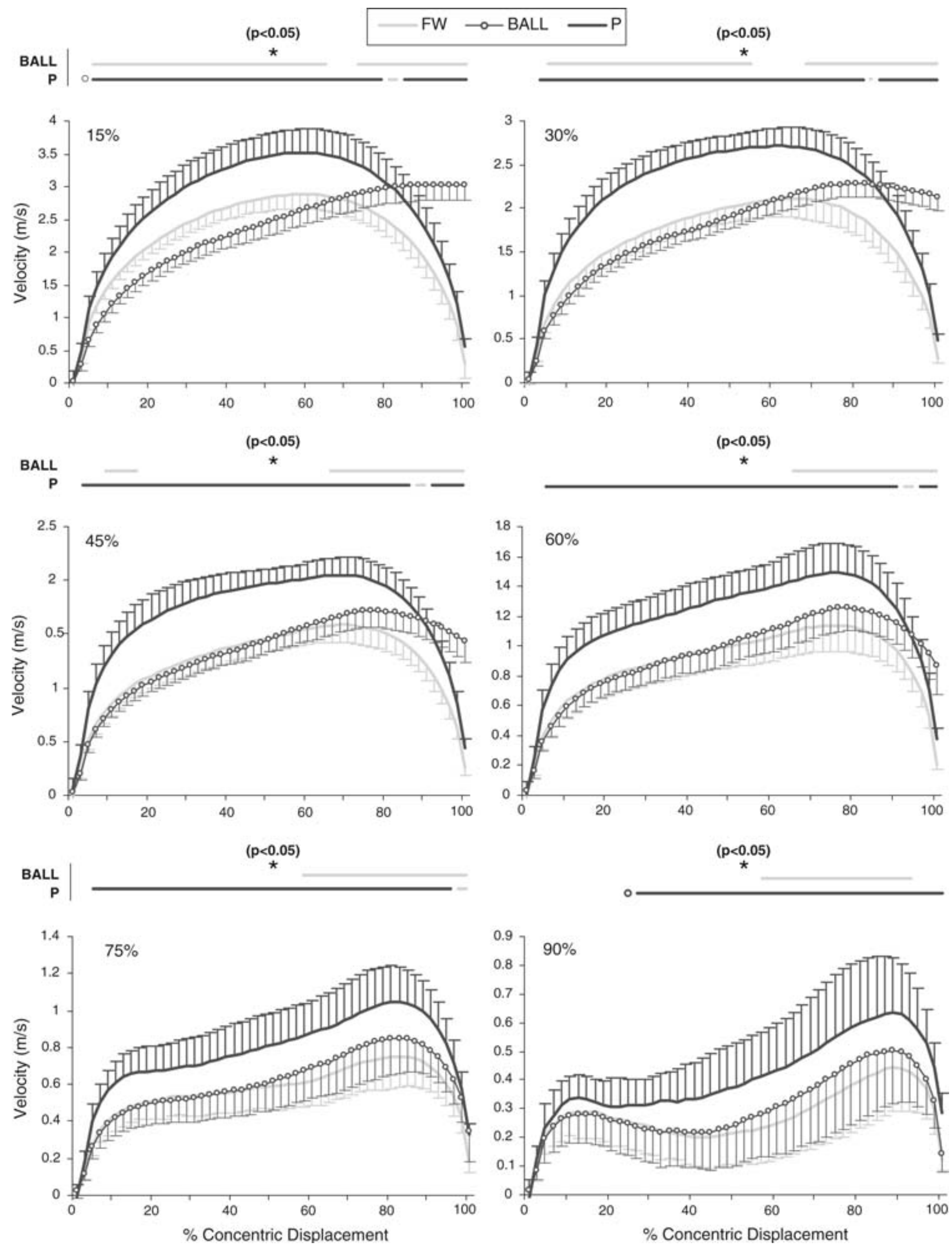


Fig. 2 Velocity expressed as a percentage of the concentric displacement. Any significant differences found ($P < 0.05$) from the ballistic (*BALL*) and pneumatic (*P*) conditions, are represented by the *two solid horizontal lines* above the corresponding graph. Differences are shown between BALL and free weight (*FW*) (*Gray*) and between P and FW/BALL (*Black*), FW (*Gray*) and BALL (*dashed circle*). *Error bars* signify standard deviation

velocity were 36.5 and 28.3% greater than the equivalent FW load, and 22.9 and 19.1% greater than the equivalent BALL condition throughout the spectrum of loads. The mean and peak velocity of the P load remained significantly higher than both the FW (75 and 39% for the mean and peak, respectively) and BALL conditions (68 and 25% for the mean and peak, respectively) at loads of 75 and 90% 1RM; however, there were no significant differences found between the two free weight conditions at these two heavier loads (Table 1). The data in Fig. 2 support these findings as the P velocity was significantly higher for the greater part of the concentric phase, independent of the load lifted. Projecting the barbell (BALL) was able to elicit greater velocity at the end range of movement, though it also prompted a significantly reduced velocity, as compared to both non ballistic conditions, during the first 60% of the concentric displacement, at loads of 15 and 30% 1RM (Fig. 2). An analysis of the time to and position of the peak velocity as a percentage of the total concentric duration and displacement revealed significant differences between the BALL and the other two conditions for loads of 60% 1RM and below; peak velocity occurred later in the concentric phase for the BALL condition.

Acceleration and force

Peak acceleration was significantly higher for the P condition across all loads, with a mean difference of 122.4 and

177.2% between the FW and BALL equivalents, respectively, while the FW condition was 40.1% higher than the BALL trials for loads of 15–45% 1RM (Table 1). As expected, the mean acceleration was significantly greater when the load was thrown (BALL) in comparison to the other two conditions between loads of 15–60% 1RM. No significant differences in peak force were found between the FW and BALL loads (Table 2), with the exception of the 45% 1RM (FW was 8.7% higher), though the pneumatic equivalent was significantly less at each load tested (on average 20.4 and 19.2% less than FW and BALL, respectively) (Table 2). The BALL mean force was significantly greater than the two non ballistic conditions for all loads, excluding 90% 1RM. With regards to displacement, the BALL mean force was significantly greater than both non ballistic conditions for the entire concentric phase, apart from the initial 15% of the displacement (Fig. 3). As the load was increased, differences between the two free weight conditions were shifted to the end range of motion, when an attempt was made to project the load. The P mean force was significantly lower than the FW and BALL equivalents during the first 50% of the concentric displacement across all loads; however the variation was not as significant towards the end of movement, as illustrated by higher force during the final 10% of the concentric phase for loads of 45–90% 1RM (Fig. 3).

Power

The FW mean power was significantly lower than the P (24.9–36.0%) and BALL (9.8–59.6%) equivalents for loads of 15–75% 1RM (Table 2). Significant differences were also found at each load tested, with the exception of 45%, between the BALL and P conditions. However, the most effective means of power development was load dependent, as projecting the barbell resulted in the highest mean powers produced at loads of 15 and 30% 1RM, while the P efforts were greatest between 60 and 90% 1RM. Analysing the mean power as a percentage of the concentric displacement showed that the significant differences between the BALL and P conditions were greatest during the second half of the concentric displacement at loads of 15 and 30% 1RM (Fig. 4). As the load increased, the P mean power became significantly greater, in comparison to both free weight conditions at either end of the concentric phase. The load that maximized mean power output for the FW, BALL and P conditions was 45% [503.5 (102.2) W], 15% [871.2 (179.5) W] and 45% of the 1RM, respectively.

Table 2 A comparison of the force and power variables

1RM (%)	Condition	MF (N)	PF (N)	% MF/PF	MP (W)	PP (W)	% MP/PP	% TPP/DOC	% PPP/TD
15	FW	173.5 (44.4)	799.9 (194.9)	22.5 (6.2)	351.7 (101.4)	1093.1 (260.4)	32.1 (5.0)	31.4 (10.3)	24.1 (11.6)
	BALL	523.6[a] (81.6)	805.3 (178.5)	66.2[a] (8.2)	871.2[a] (179.5)	1362.5[a] (402.1)	65.5[a] (7.7)	68.0[a] (11.7)	52.5[a] (14.9)
	P	226.4[c] (55.3)	732.7[c] (277.2)	32.8[c] (8.1)	549.9[c] (147.8)	1341.8[a] (362.2)	41.4[c] (7.2)	34.3[b] (10.0)	26.4[b] (11.2)
30	FW	320.9 (59.5)	942.5 (167.1)	34.4 (5.8)	468.8 (102.3)	1044.4 (250.6)	45.2 (3.6)	45.4 (7.4)	41.4 (8.6)
	BALL	577.6a (83.5)	891.2 (174.7)	65.9[a] (8.8)	784.3[a] (145.0)	1292.5[a] (295.1)	61.6[a] (6.8)	73.0[a] (7.3)	61.2[a] (9.3)
	P	341.9[c] (46.0)	773.5[c] (259.7)	47.1[c] (10.3)	651.2[c] (106.5)	1240.7[a] (355.9)	54.1[c] (7.8)	39.8[b] (12.7)	35.5[b] (15.3)
45	FW	475.7 (84.1)	1025.2 (163.2)	46.8 (7.2)	503.5 (102.2)	972.2 (216.7)	52.2 (4.1)	55.8 (10.1)	52.7 (11.4)
	BALL	635.0[a] (101.2)	943.0[a] (156.0)	67.8[a] (7.9)	678.4[a] (125.8)	1136.5[a] (243.0)	60.5[a] (7.0)	75.6[a] (5.7)	66.3[a] (6.4)
	P	470.4[b] (53.7)	768.7[c] (201.5)	63.5[c] (10.3)	697.6[a] (106.9)	1146.1[a] (252.7)	61.9[a] (6.8)	54.1[b] (14.8)	52.8[b] (16.7)
60	FW	623.5 (98.3)	1074.6 (169.9)	58.5 (7.3)	482.6 (89.3)	849.6 (204.4)	57.7 (5.1)	65.5 (9.3)	64.0 (10.2)
	BALL	718.9[a] (110.7)	1020.6 (185.6)	71.1[a] (6.8)	579.2[a] (107.0)	1064.3[a] (285.2)	55.8 (7.0)	78.6[a] (3.9)	71.8[a] (4.7)
	P	612.8[b] (81.0)	787.5[c] (115.3)	78.3[c] (7.0)	643.1[c] (99.8)	1012.9[a] (179.9)	64.0[c] (5.6)	65.7[b] (12.8)	64.3[b] (13.2)
75	FW	778.7 (121.3)	1109.1 (177.8)	70.6 (7.9)	390.2 (77.5)	668.1 (160.3)	59.3 (6.4)	74.6 (11.6)	73.5 (11.6)
	BALL	801.1[a] (120.5)	1109.6 (211.8)	73.1 (8.3)	432.6[a] (112.7)	844.5[a] (276.8)	52.7[a] (7.0)	78.8 (12.7)	74.5 (12.8)
	P	738.8[c] (95.4)	853.4[c] (121.4)	86.9[c] (5.8)	519.6[c] (114.7)	833.6[a] (197.0)	62.9[c] (7.4)	79.1 (5.1)	77.1 (5.3)
90	FW	924.3 (150.0)	1180.6 (226.8)	78.9 (6.9)	218.9 (81.3)	481.9 (149.4)	44.9 (9.3)	78.3 (25.7)	76.0 (23.2)
	BALL	928.0 (148.6)	1194.1 (248.9)	78.9 (9.7)	233.9 (108.8)	573.8 (234.3)	41.0[a] (11.1)	79.9 (25.8)	74.7 (23.7)
	P	859.1[c] (115.3)	930.6[c] (118.2)	92.3[c] (3.2)	307.6[c] (95.2)	595.0[a] (178.7)	52.8[c] (10.7)	87.2[c] (9.0)	83.2[c] (8.8)

Data is expressed as a mean (SD) for each load and condition

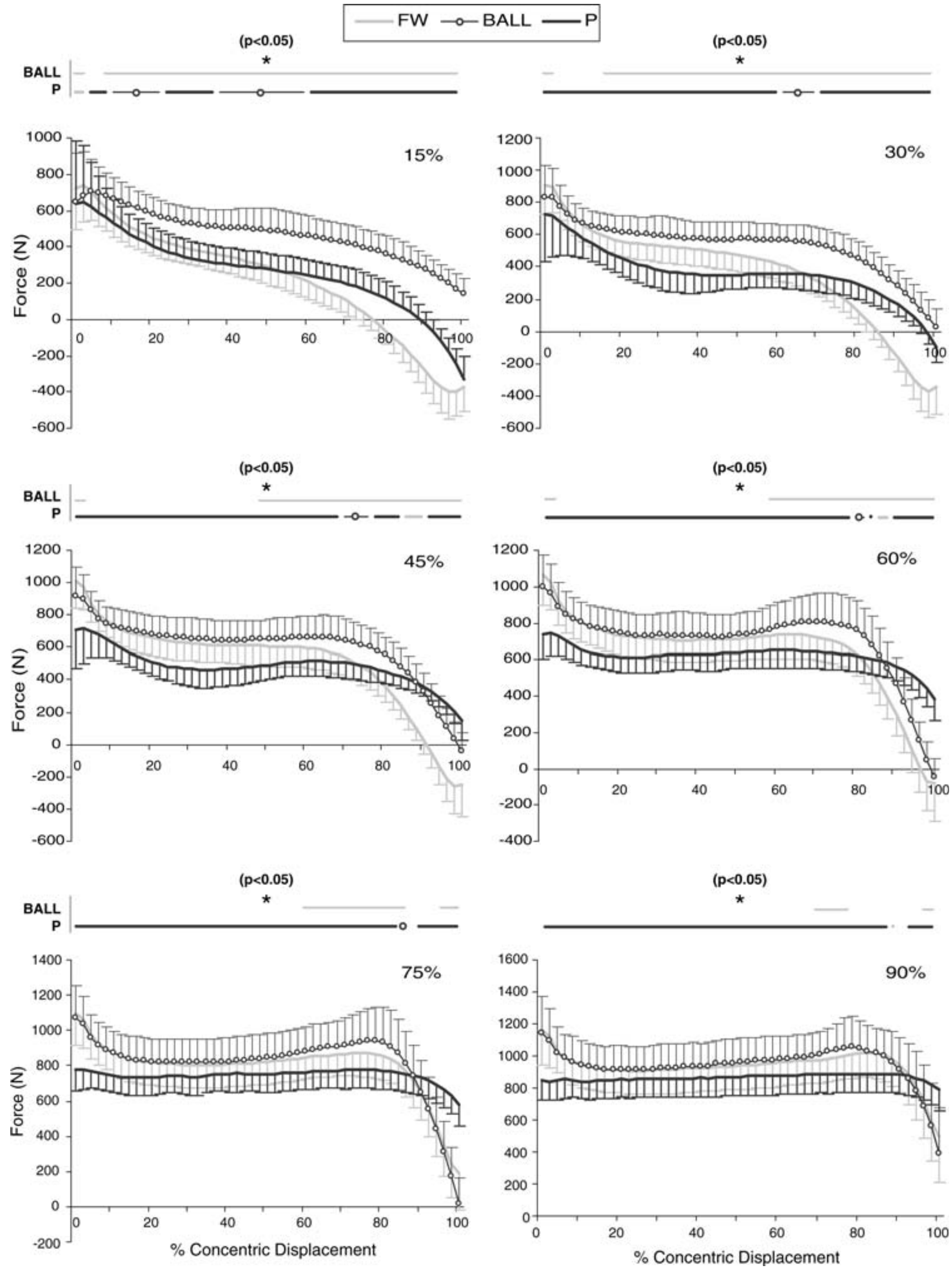
MF mean force, *PF* peak force, *MP* mean power, *PP* peak power, *DOC* duration of concentric phase, *TD* total concentric displacement, *TPP* time to peak power, *PPP* position of peak power

[a] Significantly different than FW ($P < 0.05$)

[b] Significantly different than BALL ($P < 0.05$)

[c] Significantly different than FW and BALL ($P < 0.05$)

Fig. 3 Force expressed as a percentage of the concentric displacement. Any significant differences ($P < 0.05$) from the ballistic (*BALL*) and pneumatic (*P*) conditions are represented by the *two solid horizontal lines* above the corresponding graph. Differences are shown between BALL and free weight (FW) (*Gray*) and between P and FW/BALL (*Black*), FW (*Gray*) and BALL (*dashed circle*). *Error bars* signify standard deviation



There were no significant differences in peak power between the P and BALL conditions at any load tested; however, both were statistically higher than the FW equivalent for loads below 75% 1RM (23.4 and 20.1% for P and BALL, respectively) (Table 2). Furthermore, the load that maximized peak power was produced with a 15% 1RM load for all three conditions [1093.1 (260.4) W, 1362.5 (402.1) W and 1341.8 (362.2) W for FW, BALL and P, respectively]. Expressed as a percentage of the peak contraction velocity [4.17 (0.71) m/s] and maximum dynamic force [1213.3 (203.4) N], the velocity and force contributions to peak power output were greatest during the P (67.3% V_{max}) and BALL (45.1% F_{max}) efforts respectively (Table 3). The P condition permitted a greater velocity contribution to peak power, as compared to both free weight equivalents across all loads, while the contribution from force was statistically higher when the barbell was thrown at each load tested, excluding 15 and 45% of the 1RM. With regards to the mean power, the velocity contribution was significantly higher for the P condition than both the FW and BALL at each load tested (Table 3). The BALL mean power was found to comprise a significantly higher force contribution than the FW and P conditions at loads between 15 and 75% 1RM. Allowing the load to be released at the end of the concentric phase also resulted in a significant increase in the time to and position of peak

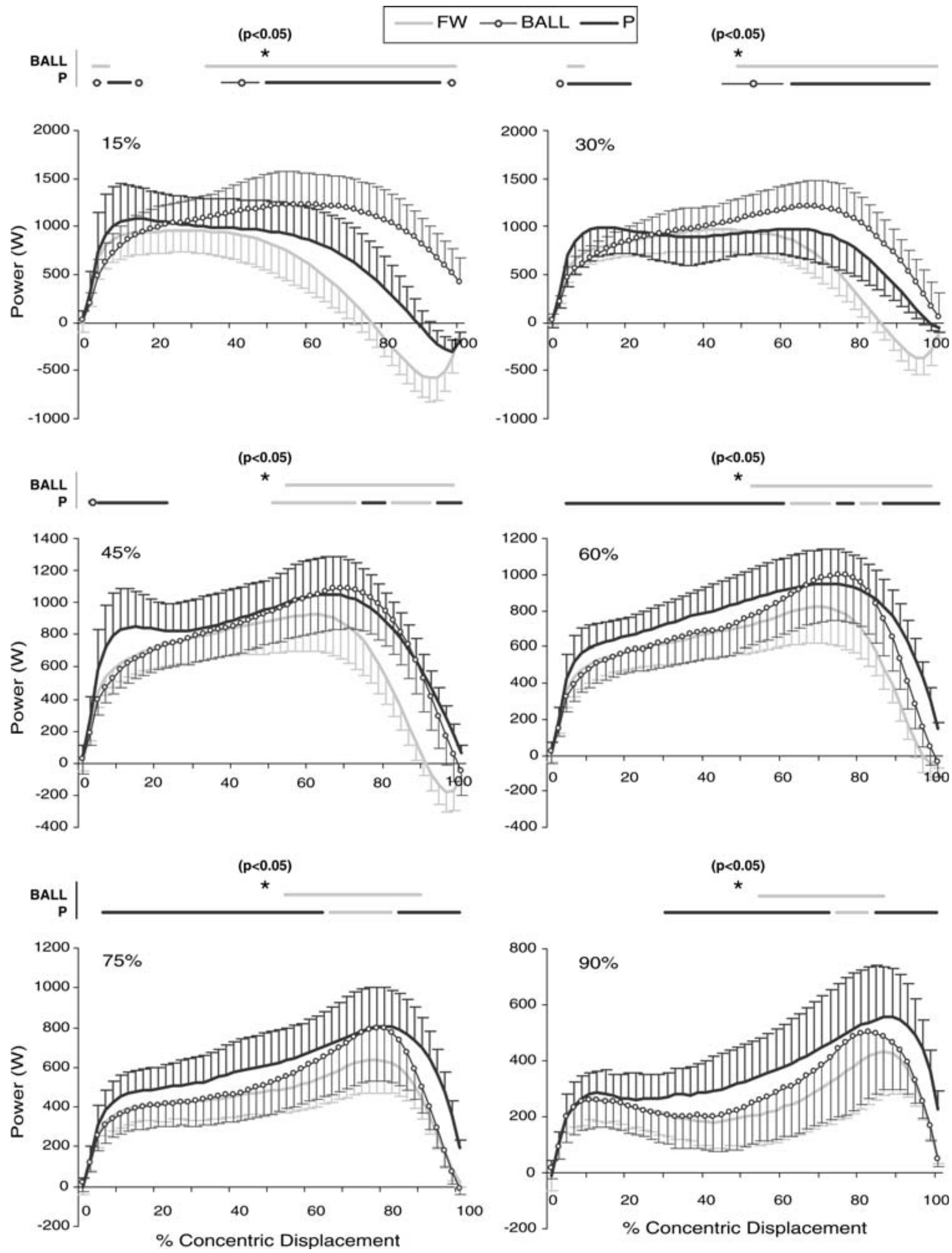


Fig. 4 Power expressed as a percentage of the concentric displacement. Any significant differences ($P < 0.05$) from the ballistic (*BALL*) and pneumatic (*P*) conditions are represented by the *two solid horizontal lines* above the corresponding graph. Differences are shown between BALL and free weight (*FW*) (*Gray*) and between P and FW/BALL (*Black*), FW (*Gray*) and BALL (*dashed circle*). *Error bars* signify standard deviation

power at 15–60% 1RM, as compared to the non ballistic equivalents (Table 2).

Muscle activity

Projecting a 15% 1RM load resulted in significantly higher pectoralis major activity, as compared to both non ballistic conditions, during the second half of the concentric phase (Fig. 5). Loads of 30–75% 1RM elicited similar differences between the two free weight conditions (FW and BALL), however, compared to the P efforts, both were statistically lower during the last 10–25% of the concentric displacement. Furthermore, no significant differences were found in the peak activity at any load tested, although the percentage of the concentric duration spent above 50% of the maximal activity was greater for the P condition at loads of 15–60% 1RM and 45–75% 1RM, as compared to the FW and BALL equivalents, respectively (Table 4).

Similar trends were seen for the anterior deltoid activity (Table 4); however, the BALL efforts produced significantly higher mean and peak triceps brachii activity than both non ballistic conditions at loads of 15–60% 1RM (Table 4). The P mean triceps brachii activity was significantly greater than the FW equivalent between 15 and 75% 1RM and significantly higher than both conditions during

Table 3 The force and velocity contribution to mean and peak power

1RM (%)	Condition	MP (W)	% MV/V_{Max}	% MF/F_{Max}	PP (W)	V_{PP} (m/s)	F_{PP} (N)	% V_{PP}/V_{Max}	% F_{PP}/F_{Max}
15	FW	351.7 (101.4)	42.1 (6.1)	14.3 (3.2)	1093.1 (260.4)	2.20 (0.44)	512.3 (115.1)	53.3 (11.3)	42.6 (8.7)
	BALL	871.2[a] (179.5)	46.0[a] (8.1)	43.5[a] (4.9)	1362.5[a] (402.1)	2.52[a] (0.38)	545.6 (137.8)	62.2[a] (13.5)	45.1 (9.0)
	P	549.9[c] (147.8)	54.1[c] (6.4)	18.7[c] (3.8)	1341.8[a] (362.2)	2.73[c] (0.38)	505.8 (153.8)	67.3[c] (12.4)	41.8 (10.3)
30	FW	468.8 (102.3)	32.5 (4.8)	26.6 (3.7)	1044.4 (250.6)	1.93 (0.20)	540.4 (101.0)	47.3 (7.5)	44.8 (6.5)
	BALL	784.3[a] (145.0)	37.0[a] (6.6)	47.9[a] (4.5)	1292.5[a] (295.1)	2.11[a] (0.22)	616.7[a] (137.2)	52.0[a] (10.0)	51.2[a] (10.2)
	P	651.2[c] (106.5)	45.4[c] (7.4)	28.5[c] (3.5)	1240.7[a] (355.9)	2.37[c] (0.31)	531.2[b] (147.1)	58.0[c] (11.5)	44.2[b] (11.0)
45	FW	503.5 (102.2)	24.9 (4.2)	39.3 (4.0)	972.2 (216.7)	1.51 (0.17)	642.6 (107.3)	37.1 (6.6)	53.3 (6.3)
	BALL	678.4[a] (125.8)	28.5[a] (5.9)	52.6[a] (4.6)	1136.5[a] (243.0)	1.66[a] (0.18)	686.1 (134.1)	41.0[a] (9.4)	56.8 (8.5)
	P	697.6[a] (106.9)	35.8[c] (6.5)	39.2[b] (4.2)	1146.1[a] (252.7)	1.98[c] (0.16)	579.4[c] (121.6)	49.1[c] (10.6)	48.1[c] (8.4)
60	FW	482.6 (89.3)	18.7 (4.0)	51.6 (4.4)	849.6 (204.4)	1.12 (0.17)	756.6 (121.4)	27.3 (5.8)	62.8 (7.0)
	BALL	579.2[a] (107.0)	20.7[a] (4.2)	59.5[a] (4.9)	1064.3[a] (285.2)	1.23[a] (0.15)	858.9[a] (182.1)	30.2[a] (6.0)	71.0[a] (10.8)
	P	643.1[c] (99.8)	25.6[c] (6.0)	50.9[b] (4.2)	1012.9[a] (179.9)	1.49[c] (0.18)	681.5[c] (100.7)	36.7[c] (9.0)	56.5[c] (5.3)
75	FW	390.2 (77.5)	12.3 (3.1)	64.5 (5.6)	668.1 (160.3)	0.75 (0.14)	892.5 (135.7)	18.4 (4.7)	74.2 (9.1)
	BALL	432.6[a] (112.7)	13.3 (3.7)	66.4[a] (5.1)	844.5[a] (276.8)	0.85[a] (0.18)	987.3[a] (208.5)	20.6 (5.8)	81.4[a] (10.4)
	P	519.6[c] (114.7)	16.9[c] (4.1)	61.4[c] (5.1)	833.6[a] (197.0)	1.05[c] (0.18)	791.7[c] (109.2)	25.7[c] (6.5)	65.8[c] (6.6)
90	FW	218.9 (81.3)	6.2 (3.0)	76.4 (6.4)	481.9 (149.4)	0.47 (0.13)	1027.7 (167.2)	11.7 (4.3)	85.3 (10.4)
	BALL	233.9 (108.8)	6.2 (2.9)	76.8 (6.6)	573.8 (234.3)	0.53 (0.17)	1075.2[a] (210.1)	12.8 (4.7)	89.6[a] (16.9)
	P	307.6[c] (95.2)	8.5[c] (2.7)	71.4[c] (6.5)	595.0[a] (178.7)	0.66[c] (0.19)	904.7[c] (118.9)	16.1[c] (5.3)	75.3[c] (7.6)

Data is expressed as a mean (SD) for each load and condition

MV mean velocity, *MF* mean force, *MP* mean power, *PP* peak power, V_{Max} maximum concentric velocity, F_{Max} maximum dynamic concentric force, V_{PP} velocity at peak power, F_{PP} force at peak power

[a] Significantly different than FW ($P < 0.05$)

[b] Significantly different than BALL ($P < 0.05$)

[c] Significantly different than FW and BALL ($P < 0.05$)

the last 10–15% of the contraction, when evaluated as a percentage of the concentric displacement.

The FW mean biceps brachii activity was statistically lower than both the BALL and P conditions between loads of 30–75% 1RM (Table 5), with the largest differences occurring during the last 30% of the concentric displacement. Significant differences were also found in the peak activity at loads of 60–90%, the FW condition was found to be lower. The highest mean latissimus dorsi activity was produced with a P effort at each load tested, although significant differences were only noted at every load between the FW equivalents. Differences were observed throughout the entire range of motion, but did not achieve a level of significance until the barbell reached 50% of the concentric displacement.

Discussion

The objectives of this investigation were to compare the kinematics, kinetics and muscle activity between three different mechanical stimuli, identify the load that maximized power production and subsequently assess such power in terms of the velocity and force contributions. Because the potential advantage of pneumatic resistance is a direct consequence of reducing the mass of the external load, the first objective will be addressed accordingly.

The effect of mass

Though often used synonymously to describe the magnitude of an external load (Asci and Acikada 2007; Zatsiorsky 1995), mass and weight are not representations of the same physical quantity; mass is a term used to describe the amount of matter in an object (kg) whereas weight is a measure of the Earth's gravitational force (N) acting on a body (Grimshaw et al. 2006). With regards to strength or power training, it is important to note that while weight (gravity) is just one of several forces that may be used to create resistance (air pressure, tension, friction), the magnitude of a load's mass will dictate the net forces required to elicit changes in its state of motion (position, velocity and acceleration; $F = ma$). Consequently, two equivalent loads with dissimilar masses will not exhibit the same kinematic, kinetic or electromyographic profiles, as was demonstrated by the findings from the current investigation.

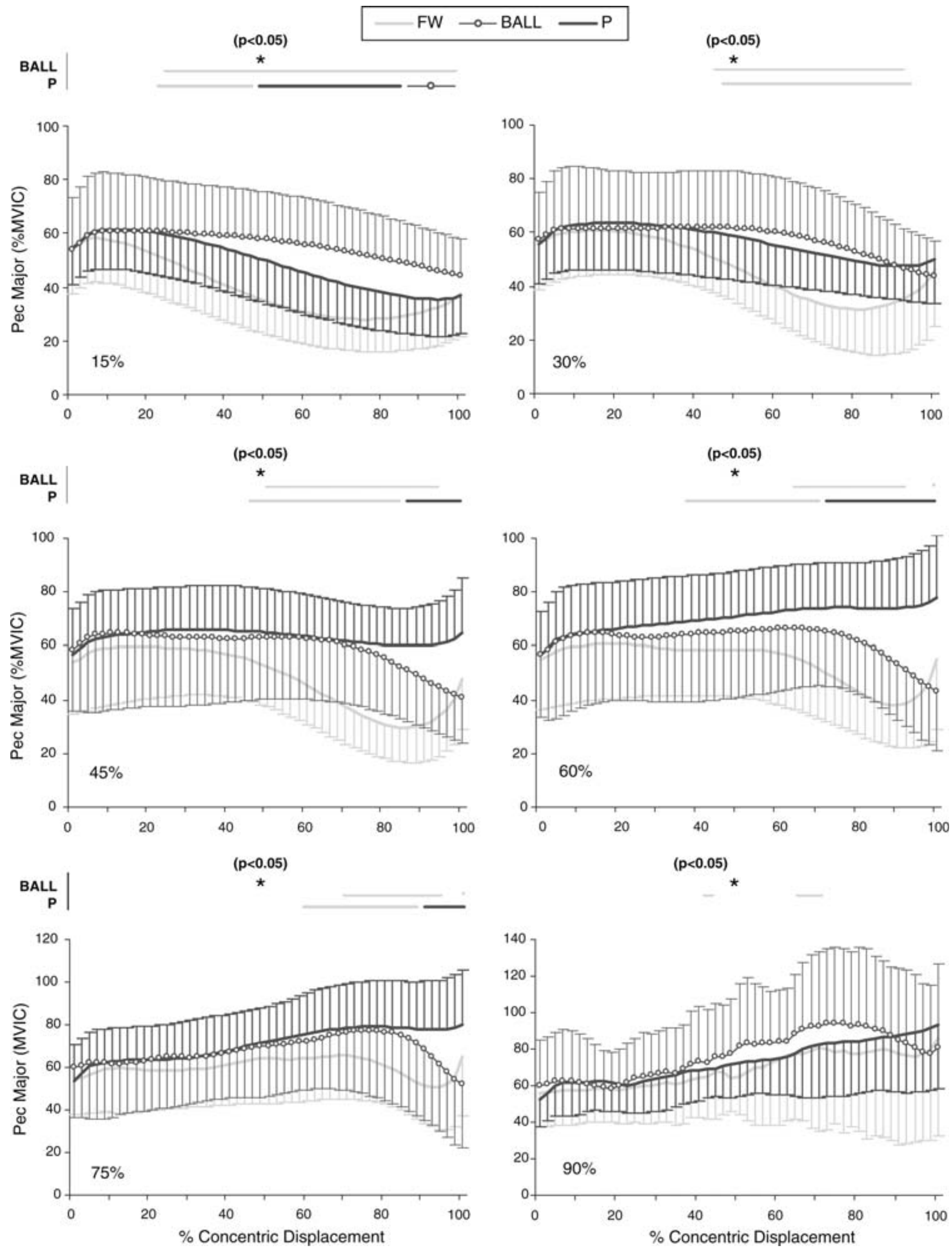


Fig. 5 Pectoralis major EMG normalized, low pass filtered and expressed as a percentage of the concentric displacement. Any significant differences ($P < 0.05$) from the ballistic (*BALL*) and pneumatic (*P*) conditions are represented by the *two solid horizontal lines* above the corresponding graph. Differences are shown between BALL and free weight (*FW*) (*Gray*) and between P and FW/BALL (*Black*), FW (*Gray*) and BALL (*dashed circle*). *Error bars* signify standard deviation

Kinematics

Ballistics have been regarded as a superior form of free weight resistance training as they allow for a greater percentage of the concentric duration to be spent accelerating (Newton et al. 1996), thereby increasing the mean and peak velocity in comparison to their non ballistic free weight equivalents (Cronin et al. 2003; Newton et al. 1996). However, the results from the current investigation suggest that by limiting the mass, inertia and thus the net force required to accelerate each successive pneumatic load, the velocities that can be achieved are significantly higher than those of an equivalent free weight resistance, independent of the contraction type (FW or BALL). Although the pneumatic velocity was reduced with each subsequent load, the mean and peak remained, on average, 36.5 and 28.3 and 22.9 and 19.1% higher than the FW and BALL conditions, respectively, between loads of 15–60% 1RM, while differences at 75 and 90% 1RM were even greater (Table 1). Furthermore, the peak velocity achieved with a 15% 1RM pneumatic load was equal to 86% of the absolute peak contraction velocity, in contrast to just 71 and 75% for the corresponding FW and BALL conditions. Investigating the advantages of contracting in a ballistic manner, Newton et al. (1996) found that projecting the load (45% 1RM) at the end of the concentric phase increased the mean and

Table 4 A comparison of the pectoralis major, anterior deltoid and triceps brachii EMG activity

Muscle group		Pectoralis major			Anterior deltoid			Triceps brachii		
1RM (%)	Condition	Mean (% MVIC)	Peak (% MVIC)	50% APDF	Mean (% MVIC)	Peak (% MVIC)	50% APDF	Mean (% MVIC)	Peak (% MVIC)	50% APDF
15	FW	41.7 (11.3)	64.0 (16.0)	29.6 (21.7)	42.5 (11.4)	76.3 (18.8)	35.9 (14.6)	51.4 (11.9)	66.3 (15.2)	52.1 (30.5)
	BALL	57.0[a] (16.4)	70.8 (21.5)	59.0[a] (30.3)	77.6[a] (30.4)	99.5[a] (38.5)	78.9[a] (18.3)	72.9[a] (17.5)	90.5[a] (23.8)	85.8[a] (14.4)
	P	48.8 (12.5)	65.8 (14.9)	47.2[c] (29.1)	55.1[c] (15.3)	82.0[b] (21.9)	54.1[c] (22.5)	57.5[c] (12.7)	69.4[b] (13.5)	68.6[c] (30.9)
30	FW	48.3 (11.8)	72.6 (19.3)	41.4 (23.4)	48.9 (12.6)	82.9 (22.2)	44.7 (13.5)	55.9 (11.8)	75.7 (17.1)	58.2 (25.7)
	BALL	58.7[a] (17.9)	74.9 (23.0)	57.6[a] (31.2)	77.2[a] (25.6)	102.0[a] (32.0)	77.4[a] (18.5)	77.7[a] (16.7)	99.2[a] (24.9)	86.9[a] (15.8)
	P	56.2 (12.5)	72.2 (17.0)	58.7[a] 32.2)	65.0[c] (15.1)	92.0 (24.1)	69.7[c] (20.0)	63.3[c] (11.3)	77.0[b] (11.8)	78.0[c] (23.7)
45	FW	49.4 (12.4)	74.1 (21.6)	47.1 (23.8)	55.1 (12.4)	90.4 (22.1)	54.9 (10.5)	57.5 (10.9)	78.3 (14.0)	66.4 (20.8)
	BALL	60.2[a] (20.9)	79.9 (28.0)	61.2[a] (32.7)	75.0[a] (25.1)	104.0[a] (34.7)	76.1[a] (16.2)	77.2[a] (16.6)	103.9[a] (27.4)	85.9[a] (11.1)
	P	63.1[a] (13.2)	81.3 (19.6)	74.5[c] (26.2)	70.5[a] (14.4)	98.0 (21.2)	75.6[a] (16.8)	69.2[c] (11.7)	85.6[b] (13.2)	86.6[a] (16.4)
60	FW	54.7 (13.9)	81.6 (26.9)	56.8 (24.8)	59.6 (12.7)	91.1 (20.3)	65.2 (10.6)	60.5 (11.6)	84.0 (16.9)	71.1 (21.1)
	BALL	61.7 (19.4)	85.7 (28.1)	63.2 (28.6)	72.5[a] (21.5)	98.9 (28.9)	78.0[a] (15.4)	78.6[a] (16.3)	107.6[a] (24.7)	85.3[a] (14.8)
	P	69.7[a] (14.1)	92.3 (20.4)	82.1[c] (21.6)	76.6[a] (17.8)	104.2 (28.8)	82.7[a] (12.6)	71.5[c] (11.6)	90.0[b] (16.0)	88.1[a] (15.2)
75	FW	60.2 (15.4)	90.4 (28.3)	68.8 (25.5)	63.5 (14.1)	91.0 (21.2)	72.7 (14.0)	63.7 (12.5)	85.6 (16.3)	79.1 (22.0)
	BALL	66.3 (20.2)	98.5 (34.4)	69.4 (26.0)	69.7 (17.6)	98.4 (23.9)	76.3 (17.0)	76.6[a] (18.9)	109.5[a] (33.4)	85.0 (13.3)
	P	69.5 (14.6)	96.3 (23.4)	82.2[b] (20.4)	78.3[a] (15.6)	101.9 (28.1)	90.6[c] (8.7)	72.2[a] (12.0)	92.0[b] (15.7)	89.0 (14.6)
90	FW	68.8 (24.9)	114.0 (53.0)	76.5 (22.9)	71.6 (18.5)	101.8 (28.4)	81.2 (21.1)	68.1 (15.3)	94.4 (25.0)	84.2 (23.1)
	BALL	75.3 (24.2)	127.8 (51.8)	79.4 (23.4)	71.4 (19.0)	101.8 (30.6)	83.6 (14.2)	77.4[a] (21.7)	109.5[a] (36.7)	88.8 (16.1)
	P	70.4 (15.0)	109.9 (35.0)	82.0 (20.7)	77.8 (16.3)	104.2 (27.4)	93.0 (6.9)	72.4 (14.3)	95.3[c] (21.0)	89.4 (17.6)

Data is expressed as a mean (SD) for each load and condition

MVIC maximum voluntary isometric contraction, *APDF* amplitude probability distribution function (percentage of the concentric phase spent above a % MVIC)

[a] Significantly different than FW ($P < 0.05$)

[b] Significantly different than BALL ($P < 0.05$)

[c] Significantly different than FW and BALL ($P < 0.05$)

peak velocity by 27.3 and 36.5%, respectively, in comparison to the non ballistic free weight equivalent. The findings from the present study however, suggest that the benefit to movement velocity is not as substantial at the same 45% 1RM load (13.7 and 8.1%) and even less when the differences were expressed as a cumulative mean across all loads (9.7 and 9.4% for the mean and peak, respectively), therefore emphasizing the dissimilarities in the velocity profiles between pneumatic and all free weight resistance efforts.

Though only a limited number of researchers have examined the kinematics of ballistic upper body movements (Cronin et al. 2003; Newton et al. 1996, 1997), it is worth noting that the mean and peak velocities reported have all been substantially lower than what was presently found, for the same relative loads. For example, contracting against a 30% 1RM load was shown to elicit a peak velocity of 1.52 and 1.65 m/s by Cronin et al. (2003) and Newton et al. (1997), respectively, but 2.29 m/s in the current investigation. The calculation of the means will be largely influenced by the acquisition and analysis strategy implemented (Frost et al. unpublished); however, the peak values should demonstrate a certain level of agreement, provided that the sampling rate used was sufficient to capture the corresponding section of the velocity curve (Grimshaw et al. 2006). As both previously mentioned studies used a Smith machine, perhaps additional research is required to evaluate whether or not the velocity differences can be attributed to inherent limitations of machine based research and training as well as the influence of friction, which was not quantified in these studies.

Assessing the means or peaks of a variable may provide insight into the gross differences that exist between conditions or resistance types, however to truly understand the magnitude of such differences it is important to evaluate the profile, or shape of each curve (Cormie et al. 2008). The time to peak velocity, which also signifies the end of the acceleration phase, was found to occur significantly later during the concentric contraction when the free weight load was thrown (Table 1), which is in agreement with previous findings (Cronin et al. 2003; Newton et al. 1996). However, of interest was the fact that at this same percentage of the concentric displacement, the absolute pneumatic velocity was consistently greater and to a significant degree at loads above 15% 1RM (Fig. 2). Furthermore, although ballistic contractions were shown to elicit significantly greater velocity during the last 10% of the concentric displacement

Table 5 A comparison biceps brachii and latissimus dorsi EMG activity

Muscle group		Biceps brachii			Latissimus dorsi		
% 1RM	Condition	Mean (% MVIC)	Peak (% MVIC)	10% APDF	Mean (% MVIC)	Peak (% MVIC)	10% APDF
15	FW	13.4 (9.4)	30.1 (20.1)	47.0 (36.6)	14.1 (6.9)	21.7 (11.8)	57.7 (35.0)
	BALL	20.1[a] (14.3)	39.6 (36.4)	74.3[a] (31.2)	14.5 (9.1)	23.4 (15.2)	63.4 (36.6)
	P	16.1 (11.4)	31.7 (23.3)	55.9[b] (32.8)	20.4[c] (10.9)	30.2[c] (18.0)	77.5[a] (24.4)
30	FW	12.2 (7.5)	27.3 (17.4)	46.0 (34.4)	12.6 (6.1)	19.9 (10.4)	51.7 (30.9)
	BALL	18.8[a] (13.6)	40.3 (41.5)	70.8[a] (32.6)	13.7 (8.9)	21.5 (13.7)	62.4 (37.0)
	P	17.2[a] (9.9)	35.4 (22.0)	65.5[a] (30.4)	16.6[a] (7.6)	23.3 (12.5)	74.4[a] (30.9)
45	FW	12.2 (7.1)	32.1 (19.6)	43.0 (33.3)	11.5 (6.1)	18.2 (10.4)	46.6 (37.1)
	BALL	18.0[a] (11.0)	42.7 (35.9)	68.6[a] (33.1)	13.4 (7.8)	22.5 (11.2)	63.3 (35.8)
	P	16.9[a] (9.9)	35.3 (24.0)	60.2[a] (30.1)	17.5[c] (8.5)	24.4 (14.0)	72.3[a] (35.5)
60	FW	11.5 (6.6)	28.7 (17.4)	42.1 (34.7)	10.8 (6.8)	17.6 (11.9)	39.0 (36.4)
	BALL	18.0[a] (11.4)	48.5[a] (42.0)	68.9[a] (32.1)	14.3[a] (7.8)	22.0 (10.9)	67.7[a] (37.5)
	P	17.5[a] (9.6)	40.1 (25.4)	62.1[a] (30.3)	16.3[a] (6.8)	25.7[a] (13.4)	72.9[a] (33.0)
75	FW	11.2 (6.5)	28.1 (17.6)	38.1 (36.5)	10.6 (6.7)	16.1 (11.7)	38.8 (39.0)
	BALL	17.8[a] (10.5)	52.7[a] (43.0)	66.3[a] (30.0)	14.0[a] (6.2)	21.9 (10.5)	66.0[a] (39.5)
	P	16.2[a] (8.1)	41.2[c] (24.7)	56.9[a] (31.6)	15.0[a] (6.0)	22.0 (11.5)	75.6[a] (31.9)
90	FW	12.1 (8.3)	34.4 (25.3)	40.5 (38.4)	11.3 (7.0)	17.2 (12.5)	45.8 (40.4)
	BALL	14.8 (6.6)	54.8[a] (53.5)	61.5[a] (37.6)	14.9[a] (7.7)	23.4[a] (15.3)	66.0[a] (41.5)
	P	15.9 (7.0)	46.5 (28.2)	55.2[a] (28.1)	15.1[a] (6.1)	24.2[a] (12.3)	74.7[a] (31.5)

Data is expressed as a mean (SD) for each load and condition

MVIC maximum voluntary isometric contraction, *APDF* amplitude probability distribution function (percentage of the concentric phase spent above a % MVIC)

[a] Significantly different than FW ($P < 0.05$)

[b] Significantly different than BALL ($P < 0.05$)

[c] Significantly different than FW and BALL ($P < 0.05$)

for loads of 15–45% 1RM (Fig. 2), such a conclusion may be misleading as the last 10–20% of the displacement for non ballistic movements may be attributable to the momentum of the body and not the force capabilities of the muscle (Frost et al. unpublished), which is more likely for the FW condition.

An athlete's acceleration will be limited by the force that they are able to generate so as to overcome the inertia, or mass of the external load being lifted. However, given the present situation in which each pneumatic load tested included minimal mass, there was little resistance to change in motion, thereby permitting the production of significantly greater peak accelerations (Table 1). Maximum differences were recorded at a load of 45% 1RM, at which the peak pneumatic acceleration was 148 and 217% greater than the corresponding FW and BALL load. Interesting to note was the fact that there were also significant differences between the peak accelerations attained with either free weight condition at loads of 15–45% 1RM, the non ballistic condition higher. Initially, it was hypothesized that these differences were the product of additional mass (more inertia) being added to the barbell to equate the free weight loads and offset the recoil forces of the magnetic brake. However, a second contention is that the magnetic brake did not allow for the barbell to fall freely, thus reducing the eccentric velocity and acceleration, in comparison to the FW condition. If at lighter loads, the subjects increased the eccentric acceleration by pulling the barbell towards their chests to facilitate a greater stretch shortening cycle contribution, but receiving opposition from the brake, the first 5% of the concentric acceleration may have been compromised. This anomaly is also reflected in the velocity–displacement profiles as the FW velocity was significantly higher for the first 60% of the concentric phase at loads of 15 and 30% 1RM.

Kinetics

For non ballistic movements, with which the end of the concentric phase is defined as the point of peak displacement, the mean concentric force should theoretically, equal the magnitude of the resistance being lifted. While this was found to be true of free weight, within an acceptable range of error, the mean concentric force for each pneumatic load tested was higher than expected; interestingly enough, by a difference of approximately 60–70 N across all loads. Upon further examination, a discrepancy was found between the resistive forces experienced when the load was held isometrically at arms length versus when contracting concentrically. Several measures were taken to ensure that there was a high degree of linearity across loads; however, the authors did not anticipate having to factor in an additional 60 N when each percentage of the pneumatic 1RM was assigned, which has consequently resulted in a slight increase in the actual percentage that was lifted (1–5%). It should be noted that had the appropriate lighter pneumatic load been used, movement velocities, accelerations and peak power outputs would likely be even greater. Thus, the authors have assumed that all comparisons made prior to and subsequent to this point are valid and an acceptable representation of the kinematic, kinetic and electromyographic differences between pneumatic and free weight resistance.

Reducing a load's mass necessitates the production of less force in order to accelerate, but also limits the degree to which momentum can be used as an advantage. Because none of the participants had previously trained with pneumatic resistance, the significant differences in the 1RM capabilities between the two resistance types may have been the result of an inability to employ momentum through the "sticking region", defined by Lander et al. (1985) as the point at which the applied force drops below the magnitude of the resistance. Conversely, less mass also implies a reduction in the resistance to change in motion in all directions, not just the vertical, thereby placing a greater emphasis on controlling the load while contracting concentrically. Had the participants trained with pneumatic resistance for an extended period of time prior to testing, the results might be more comparable (Behm et al. 2002). Therefore, further research is warranted to investigate whether or not maximal pneumatic strength is a product of training adaptations or simply, the inertial properties of the resistance.

Contracting against a pneumatic resistance was unable to elicit a peak force of similar magnitude to either free weight equivalent at any load tested (Table 2). Though expected, due to the lower absolute load and reduced mass, what was interesting was the fact that there were no significant differences between the peak pneumatic forces produced at any load within the range of 15–60% 1RM, contrary to the findings for both free weight conditions. If the peak force produced during the two 1RM trials (FW and P) was a valid representation of the maximum force capability for the respective resistance type, these results then suggest that the pneumatic load was able to facilitate the production of substantially more force, expressed as a percentage of the maximum, at lighter loads; particularly 15% of the 1RM (76 vs. 66% for both FW and BALL). Although not presented, the pneumatic technology used permitted a substantially higher eccentric acceleration than that due to gravity, thereby not requiring the subjects to pull the barbell towards their chest to enhance the SSC action at lighter loads. Given that peak force for a SSC contraction is produced at the point when the muscle action changes from eccentric to concentric (Newton et al. 1997), the greater force contribution may be the result of a higher active muscle state preceding the initiation of concentric phase (Walshe et al. 1998), however, these speculations deserve further attention.

In agreement with Newton et al. (1996), permitting the release of the barbell was able to facilitate greater peak power production in comparison to the non ballistic free weight equivalents; however, what was interesting was the finding that the ballistic contractions were unable to elicit any statistical difference from the pneumatics at each load tested (Table 2). Minimizing the mass of the external resistance and thereby allowing greater movement velocities to be achieved appears to offset any limitations in peak power production that may arise as a result of reductions to force. Conversely, significant differences were found in the mean power produced between the pneumatic and ballistic trials, though the results may be influenced in part by the degree to which the body mass involved affected the kinetic profiles of the movement. An increase in the pneumatic load corresponds to a decrease in the relative contribution from mass to the total resistive force and therefore the percentage of the load subject to momentum. Consequently, at lighter loads less force will be required during the second half of the concentric phase, thereby leading to a reduced power output. The results reflect this notion as the ballistic contractions were found to produce the highest mean power at loads of 15 and 30% 1RM, the two resistances were comparable at 45% 1RM and the pneumatic loads were greatest between 60 and 90% 1RM. The FW condition was unable to produce comparable mean forces at any load.

Although the time to and position of peak power were both significantly higher when the barbell was thrown for loads of 15–60% 1RM, such findings appear to be less relevant when assessing the change in power over the entire concentric phase. At loads greater than 30% of the 1RM load, the pneumatic resistance was able to elicit a similar profile and significantly greater power output during the last 5–10% of the concentric displacement.

Cited as one of the primary limitations to resistance training with mass, momentum reduces the magnitude of muscular work required during the second half of the concentric phase (Keiser 1981). This notion has been substantiated by previous work with non ballistic free weight movements (Elliott et al. 1989; Lander et al. 1985), however the results from the present investigation suggest that momentum may also influence ballistic contractions and movements performed with pneumatic resistance when the relative mass (body segments or barbell) contribution to the total resistive force is high.

Irrespective of the contraction or resistance type, the instance sufficient forces are generated to initiate movement, momentum will be transferred to the external load; the magnitude of the momentum, however, will depend on the movement velocity and the load mass and is reflected in the shape of the force curve. Although the ballistic efforts were performed with the intent to maximally contract and accelerate through the entire movement range, significant reductions in force were observed at every load between 70 and 100% of the concentric displacement (Fig. 3). Similar findings were reported by Newton et al. (1997), though Newton et al. (1996), using a 45% 1RM load, suggested that forces could be maintained until the point of release. However, upon further investigation is was noted that the end of the concentric phase had been prematurely defined as the point at which the barbell reached the position it was held, at arms length, prior to initiating movement (Frost et al. unpublished), thereby not including the entire range of the concentric phase prior to the point of release and thus, the section of the force curve affected by momentum.

A resistive force manufactured by air pressure is not influenced by momentum, thus theoretically, it is impossible for a pneumatic force curve to be negative at any point of the concentric displacement; however, the barbell (or cable attachment) and body segments involved in the movement being performed are, and as such, will influence the kinetic profiles accordingly. The end of the concentric phase was defined as the point of peak displacement to maintain consistency with previous literature (Alamasbakk and Hoff 1996; Asci and Acikada 2007; Cronin et al. 2000, 2003; Elliott et al. 1989; Jidovtseff et al. 2006), but also to provide a comparison of the associated momentum between pneumatic and free weight resistance. As highlighted in Fig. 3, the percentage of the concentric displacement spent below 0N, at loads of 15–45% 1RM, is substantially greater for the free weight condition. This point is of importance as it has been described as the instance when force can no longer be applied to the load (Newton et al. 1997), making any subsequent displacement the result of momentum from either the load or body segments involved. The degree to which momentum impacted the movement can be estimated by examining the variation in the force curve, particularly at the end range of motion when the load was thrown or decelerated. Though the intent was to move all loads as explosively as possible, the variation in the pneumatic force curve became substantially less, in comparison to both free weight conditions, as the percentage of the load comprising mass was decreased. Therefore, although not completely unavoidable, pneumatic resistance was much better suited to limit the effects of momentum than a ballistic contraction, as force and power output were significantly higher than both free weight conditions at the end of the concentric displacement, for loads above 30% 1RM.

Muscle activity

In agreement with Newton et al. (1996), the EMG profiles of the agonist musculature were found to reflect the kinematic and kinetic data. At a load of 15% 1RM, when the pneumatic load comprised a greater percentage of mass, ballistic contractions elicited the highest pectoralis major, anterior deltoid and triceps brachii activity throughout the entire concentric range of movement. However, as the pneumatic load increased and the influence of inertia and momentum subsided, the electromyographic dissimilarities between the two conditions were reduced, although EMG activity remained significantly higher than the non ballistic free weight equivalent. Throwing, or attempting to throw the load proved to be the stimulus most conducive to increasing triceps brachii activation during the initial 60% of the concentric phase, irrespective of the load; though the same level of EMG activity could not be maintained through to the point of barbell release. Similar reductions in activity were seen in pectoralis major and anterior deltoid activity for both free weight conditions, highlighting the effect of momentum on all mass—comprised loads. Consequently, the agonist activity produced with a pneumatic resistance during the final 10–20% of the concentric displacement was significantly higher for all loads above 15% of the 1RM.

Resistance training with free weight permits greater mean and peak forces to be produced than does the same relative pneumatic load; however, the present findings suggest that this is not a direct consequence of a reduction in the agonist contribution. Compared to the non ballistic free weight condition, mean and peak activity was consistently higher for all three muscle groups when contracting against a resistance comprising minimal mass. Whether these findings are the result of an increased stability demand (Anderson and Behm 2004) or the product of a neuromuscular response specific to pneumatic resistance, is unknown but warrants further research.

Biceps brachii and latissimus dorsi activity were assessed as both muscle groups play an antagonistic role in the bench press and may assist with joint stabilization and the deceleration of the load and/or limbs at the end of the concentric phase (Hancock and Hawkins 1996; Newton et al. 1996). Though originally hypothesized that the greatest biceps brachii activity would be produced with a non ballistic free weight effort, as a result of having to oppose momentum and generate a muscular force sufficient to decelerate the load, the results suggest the contrary. Both the pneumatic and ballistic conditions elicited substantially higher mean and peak activity across loads. A possible explanation for this finding is that the biceps are acting to stiffen the elbow and prevent injury during the high velocity contractions (Newton et al. 1996). Ballistic contractions permit the load to be thrown at the end of the concentric phase while pneumatic resistance offers a load comprising minimal mass. In both instances the deceleration phase is reduced, which results in less time to decelerate the upper body limbs, thereby demanding greater activation levels. Newton et al. (1996) proposed that the biceps brachii activity demonstrates a similar activation pattern to that of pectoralis major when performing explosive upper body movements. However, the present findings provide support for the notion that the muscle group is assisting to prevent injury as the activity conforms to a "U" shaped curve in which the greatest activation is seen at the onset and end of the concentric phase.

A weak antagonist may limit the movement velocity and thus lead to inferior performance (Jaric et al. 1995; Wierzbicka and Wiegner 1992), yet few researchers have investigated the latissimus dorsi's involvement in the bench press (Barnett et al. 1995). In the present study the highest mean and peak EMG activity of the latissimus dorsi was noted at the lightest load tested, irrespective of the condition, though significantly higher for the pneumatic. The significantly greater movement velocities, and thus shorter deceleration phase associated with a reduction in mass may substantiate the increased activity, which was shown to peak at the end of the concentric contraction. Though ballistic efforts also seek to extend the acceleration phase, the small difference seen between the EMG profiles at each load, may be attributable to the instability of the pneumatic load. As stated previously, less mass also implies that less force is required to move the barbell in any direction; therefore the latissimus dorsi may assist to control any extraneous movement of the load.

Optimal load for power development

Loads ranging from 30 to 70% of a 1RM have been described previously as optimal for mean power production with non ballistic (Asci and Acikada 2007; Cronin et al. 2000, 2001, 2003; Izquierdo et al. 2002) and ballistic (Baker 2001; Baker et al. 2001; Cronin et al. 2001, 2003; Newton et al. 1997; Siegal et al. 2002; Thomas et al. 2007) bench press movements. Though the present findings provide support for the use of an intermediate load (45% 1RM) to maximize mean power output with non ballistic efforts (503.5 and 697.6 W for the FW and P conditions, respectively), permitting the release of the barbell facilitated the highest mean power production at the lightest load (15% 1RM) lifted (871.2 W; Table 2). This is an interesting result given that, in comparison, the mean power reported by Baker (2002), using an absolute load of 20 kg (14% 1RM) with professional rugby players, was only 341 W. Upon closer examination of the methodology used by Baker (2001, 2002), and Baker et al. (2001) it was noted that, in each study, the point of barbell release was not identified, thus leading to an underestimation of all subsequent calculations of the means (Frost et al. unpublished). Power was calculated by dividing the total work (barbell displacement × mass × gravity) by the time taken for the barbell to reach its peak displacement and not the duration of the concentric phase spent in contact with the hands. This is analogous to multiplying the mean force of the entire barbell displacement by the mean velocity, including the duration of the repetition when force is no longer being applied; which was, interestingly enough, the methodology used by Cronin et al. (2003). Furthermore, at lighter loads when the barbell can be thrown a greater distance, the underestimation is more substantial as a smaller percentage of the total barbell displacement is spent in contact with the hands; hence the inverted 'U' shaped power-load curves reported by Baker (2001) and Cronin et al. (2003) and the possible reason for differences between these and the present study.

To the authors' knowledge, Newton et al. (1997) has been the only other investigation to examine the mean power output at a range of loads extending below 30% of a 1RM for ballistic movements. Although the group's findings suggested that loads of either 30% or 45% 1RM should be used to optimize mean power production, possible differences may be the result of using a Smith machine for all testing purposes. For example, despite similar absolute loads being used for sub-maximal testing (1RMs of 104 and 106 kg, respectively), the mean velocities at loads of 15 and 30% were substantially lower for the Newton et al. (1997) study, as compared to the present research (1.87 vs. ~1.3 m/s and 1.51 vs. ~1.1 m/s for loads of 15 and 30%, respectively); possibly the result of friction between the linear bearings and steel shafts that control the vertical motion of the barbell. If the movement velocity is compromised at lighter loads it will also be reflected in the calculation of power; thus the optimal load for mean power development may differ between ballistic modalities.

Cronin et al. (2001) and Asci and Acikada (2007) found loads of 50–60% of a 1RM to produce the highest peak power outputs for both non ballistic and ballistic movements, however, the findings from the present study are in agreement with those who have cited the lightest load tested as optimal for peak power development (Newton et al. 1997; Thomas et al. 2007). Peak power is the instantaneous product of force and velocity and therefore may be influenced by the absolute or relative strength of the population tested (Cronin et al. 2000), the calculation method used (Dugan et al. 2004) or the sampling frequency applied to acquire the data (Grimshaw et al. 2006). While the combination of a force plate and position transducer has been shown to be the most appropriate means of calculating power (Dugan et al. 2004), higher sampling rates are recommended so as to provide the most accurate representation of the kinetic and kinematic profiles for high velocity movements (Grimshaw et al. 2006). Worth noting is the fact that, converse to the methodology used by Newton et al. (1997) and the present study, both investigations mentioned previously as recommending an intermediate load (Asci and Acikada 2007; Cronin et al. 2001), employed subjects with poor relative strength in relation to their bodyweight (1RM < BW), a linear position transducer to estimate the power output and sampling rates of 200 and 100 Hz, respectively.

Although the results from the present investigation suggest that loads of 45 and 15% of the 1RM be used to maximize mean power output for non ballistic and ballistic movements respectively, these findings are likely specific to the methodology used to acquire and analyse the data. Subtle alterations such as using a Smith machine or redefining the position of the end of the concentric displacement for non ballistic movements (Frost et al. unpublished) may result in a different optimal load and thus dissimilar interpretations. Or conversely, perhaps the "optimal load" for power development is not the load at which the highest mean or peak power was produced during a test, but a load conducive to improving athletic performance within an individual's sport; determined by placing greater consideration in the force and velocity contributions to such power development.

Force and velocity contribution to power

Despite a considerable volume of research completed by various groups, there remains to be ongoing debate over the "optimal load" that should be used for power development; however, on account of the complex nature of sport, different training histories and a myriad of methodological strategies used to acquire and analyse data, researchers should not be surprised by the diversity in the results. Maximum power is the product of a compromised level of force and velocity (Siegal et al. 2002) and as such, should be investigated accordingly in order to facilitate the most appropriate interpretation of the results. Producing similar mean or peak power outputs at multiple loads does not imply that each will also provide a stimulus conducive to improving athletic performance. Success may be limited by an individual's ability to develop power at a specific load (Moss et al. 1997), thereby placing greater dependence on the velocity contribution to power production. However, to the authors' knowledge, only one previous investigation has reported the force and velocity contributions to peak power (Cormie et al. 2008) and the researchers failed to discuss the relevance of such measures or their possible implications for training. Therefore, assuming that the methodology used to obtain the peak contraction velocity and maximum dynamic force is valid, the subsequent section of this discussion will describe the mean and peak power outputs as a function of their constituents.

Siff (2003) has stated that maximum power is produced at one-third of the peak velocity and one quarter of the peak force, however, results from the current investigation suggest that the degree to which each variable contributes may be dependent on the type of load being used. Both ballistic and pneumatic contractions provide a mechanical stimulus more conducive to power development, in comparison to their non ballistic free weight equivalents, albeit attributable to dissimilar means. Pneumatics offer a load comprising minimal mass, with which greater movement velocities can be achieved and was found to facilitate a significantly greater velocity contribution to mean and peak power production across all loads (Table 3). Whereas ballistics, extend the duration of the acceleration phase providing a comparable increase in peak power, though primarily the result of an increase in force. Worth noting was that the highest mean and peak power outputs, irrespective of the load type or the magnitude of power, were produced with a force contribution in the range of 39–45% of the maximum dynamic force. Though this finding is likely specific to the subjects used in the current study, the fact that the same absolute force maximized mean and peak power for each type of load is interesting and warrants additional research.

Given that there is empirical evidence to support the notion that training should be adapted to meet the specific demands of the sport (McBride et al. 1999), the load, or resistance type, able to elicit the highest power output may not be the most appropriate stimulus. In the present study, maximum mean power was produced with a ballistic contraction at a load of 15% of the 1RM; however, the velocity contribution was significantly less than the pneumatic equivalent (15%) and the force contribution only 43% of the peak. Similarly, using pneumatic resistance may not be advantageous for an athlete participating in a sport dependent on force production, as power was found to be produced with only 39% of the maximum force using a 45% 1RM load, in contrast to 53% for the same relative ballistic effort.

Rather than prescribing one load, researchers often advocate the use of the range of loads found to produce the highest mean and peak power outputs (Baker et al. 2001; Cronin et al. 2003; Siegal et al. 2002); however, the present findings suggest that a 15% load adjustment may increase or decrease the contribution of the constituents by as much as 20%. The mean power outputs produced for the non ballistic free weight condition were not significantly different between loads of 30–60% 1RM (469–504 W); consequently, it may be assumed that each is equally appropriate to facilitate improvements in power production. However, within this range the contributions from velocity and force were shifted from 33 to 19 and 27 to 52%, respectively. Therefore, if there is a load specific response to power development, as some research would suggest (Kaneko et al. 1983; Mayhew et al. 1997; Moss et al. 1997), it may be prudent to identify the force and velocity demands of the athlete's sport prior to assigning specific training loads.

Although presenting power output as a function of its constituents will assist the researcher and practitioner to assess the appropriateness of the load, resistance and contraction type being used, it may also provide a means of monitoring training progress or assigning loads based on maximum velocity. The results from the present investigation suggest that the velocity contribution to mean and peak power does not increase proportionally with a decrease in the load, or force. Whether or not this will influence the adaptations to power training is unknown and requires further investigation.

Practical application

Limiting the mass of the external load, as pneumatic resistance does, reduces the forces that are required to initiate the concentric phase of a stretch shortening cycle movement. While this may have negative implications for improving a free weight bench press, though yet to be observed, the transference to sporting applications deserves further investigation. Sprinting, jumping and changing direction are specific skills that require the movement velocity to be high and as such may see greater benefit from a training program designed to elicit velocity specific power production. Resistance training with an external load comprising free weight, or mass, necessitates sufficient forces to overcome the inertia of the external load in addition to the body, which may subsequently limit the maximum movement velocity that can be achieved. Although an excellent means of increasing strength and the rate of force development, free weight may not be the most appropriate method to facilitate velocity specific adaptations. Pneumatic resistance offers an alternative whereby the athlete's body mass represents the only inertia (other than the cable attachment or barbell) that must be overcome to initiate movement. Elevated peak forces are still be required to accelerate the mass of the body; however, the inertia of the external load will no longer be a limiting factor. Consequently, an athlete should be able to achieve greater movement velocities while maintaining a sufficient level of force production, thereby possibly leading to a greater degree of transference to performance in high velocity sports. However, this contention is highly speculative and requires further investigation.

Conclusions

As a sports science community it may be advantageous to place greater merit in understanding the mechanical advantages or disadvantages inherent to the resistances or contraction types we are using to facilitate improvements in athletic performance. There is not one training stimulus likely to be most suited for all training purposes, however, realizing when and/or why each is appropriate will assist with program design and improve future research. The nature of ballistic movements guarantee that the kinematic and kinetic means will be higher in comparison to their non ballistic free weight equivalents; however, because they are performed with an external load comprising mass and are therefore subject to momentum, limitations may exist. Pneumatic resistance offers a load developed from air pressure, whereby the effects of mass, inertia and momentum are reduced so as to permit greater movement velocities; however, there may also be a concomitant reduction in force. Those researchers who have advocated the use of ballistic contractions suggest that they may facilitate improvements in athletic performance by permitting force and muscle activity to be maintained throughout the concentric displacement; however findings from the current investigation suggest that such a claim is more indicative of the kinetic and electromyographic profiles of training with pneumatic resistance.

In summary, it is the authors' opinion that pneumatic technology may offer specific advantages over resistance training with free weight. Given the greater movement velocities and higher muscle activity at the end range of motion, in comparison to a ballistic contraction, further research is needed to investigate the effects of long term pneumatic resistance exposure and the possible training induced neuromuscular adaptations.

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