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The Acute Effects of Heavy Loads on Jump Squat Performance: An Evaluation of the Complex and Contrast Methods of Power Development

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ABSTRACT

The purpose of this investigation was to examine power performance in jump squats when using the complex and contrast training methods. Eleven ($n = 11$) women participated in a familiarization session and in three randomly ordered testing sessions. One session involved completing sets of power exercises (jump squats) before sets of half squats (traditional method). The second session involved sets of half squats before sets of jump squats (complex method). A third session involved the alternation of sets of half squats and jump squats (contrast method). No significant difference in jump squat performance between each of the training methods was found. There was a significant difference ($p < 0.05$) in the first set of each session, with the complex method having a significantly lower peak power. Further, there was a significant difference ($p < 0.05$) in performance changes between the higher and lower strength groups, with the higher strength group having a greater improvement in performance using the contrast training method compared with the traditional method. It was concluded that contrast training is advantageous for increasing power output but only for athletes with relatively high strength levels.

Key Words: neuromuscular activation, jump squat, strength

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Introduction

The order of exercises within a resistance training session is an important factor when establishing a resistance training program (11). Power training is commonly conducted using lighter resistances that are performed explosively because it was previously shown that performance gains will be optimized through the use of a training load that maximizes the mechanical power output of an exercise (26). To achieve the greatest benefits from power training it should be performed in a fatigue-free state and therefore should be performed at the beginning of an exercise session or on a separate training day (18). The best results are attained when a combination of heavy and light loads are implemented within the 1 workout (24). By performing heavy loads before light power exercises there is greater activation and preparation for maximal effort in the lighter load (24). The heavy resistances are an attempt to bring about adaptation in tension-dependant neural mechanisms that inhibit the excitation of motor neurons in voluntary maximal contractions (10).

The use of heavy resistance exercises and lighter resistance exercises within a session has repeatedly been referred to as ''complex training'' (5–7, 9). Chu (6) claimed, ''the power increases achieved through complex training are up to three times more effective than conventional training programs!'' Fleck and Kontor (10) described complex training as a series of several exercises performed in succession, designed to increase the ability to produce power quickly. To add confusion, the terms ''complex training'' and ''contrast training'' have been used interchangeably to define the use of heavy and light resistance loads within the same workout. For the purpose of this investigation ''complex training'' defines various sets of groups/complexes of exercises performed in a manner in which several sets of a heavy resistance exercise are followed by sets of a lighter resistance exercise. The term ''contrast training'' refers to a workout that involves the use of exercises of contrasting loads, that is, alternating heavy and light exercises set for set. Performing lighter resistances before the heavy resistances will be termed the ''traditional training'' method.

It has been repeatedly demonstrated that there is an increase in twitch tension after high-intensity voluntary contractions (12–14, 23), and it has been stated that the use of maximal voluntary contractions (MVCs) results in short-term increases in explosive force in the upper and lower body that can be attributed to ''an improved neuromuscular activation due to neuronal Post Tetanic Potentiation (PTP) effects'' (14). This potentiation effect predominates in FT fibers (3, 4, 12, 13, 17) implying that strength- and speed-orientated athletes would demonstrate greater potentiation due to these sports using predominantly fast twitch (FT) muscle traits.

Radcliffe and Radcliffe (20) integrated power- and strength-orientated exercises into a standard warm-up routine to establish any improvement in peak power output in a single response jump task. Men improved standing long jump (3.9 cm), when the warm-up included 4 sets of 4 power snatches at 75–85% of 4RM (4 repetition maximum) compared with a warm-up without high-intensity exercises.

Young, Jenner, and Griffiths (27) examined the acute enhancement of power performance using heavy load squats. Power performance was measured from jump squat height, and heavy load 5RM squats were used to stimulate the neuromuscular system. Men were required to conduct a familiarization session to establish a 5RM load for the squats and also to familiarize subjects with the jump squat exercise. On a separate day, subjects performed 2 sets of 5 jump squats (19 kg), then a set of 5 half squats (5RM), and then another set of 5 jump squats (19 kg). Four minutes of rest was observed in between all sets, and there was a statistically significant 2.8% increase in jump squat height after the set of half squats. Young et al. (27) suggested that this difference occurred because of the squats producing an acute potentiation.

Gullich and Schmidtbleicher (14) reported that 3 MVCs of the leg extensor muscles produced a 3.3% ($p < 0.05$) increase in counter movement jump (CMJ) height for men and women athletes. Drop jump (DJ) height also increased, even though contact time remained the same. Also, after 1–3 upper-body MVCs, a purely concentric bench throw had a reduction in the maximal force achieved; however, there was a trend for the rate of force development to increase. Consequently, explosive force and movement velocity were greater. One important factor noted by Gullich and Schmidtbleicher (14) was that speed-strength potentiation has high general validity within populations of trained speed-strength athletes. It was suggested that ''if during specific speed-strength training, maximum performances are achieved under conditions of improved neuromuscular activation (after MVCs), particularly high adaptations are to be expected as more FT-units are recruited by the training stimulus'' (14).

Ebben, Jensen, and Blackard (8) examined motor unit recruitment, using electromyography (EMG), in the upper body of men during the medicine ball power drop exercise after 1 set of heavy bench press (3–5RM). During the medicine ball power drop there were neither changes in EMG activity nor in the peak ground reaction forces after the heavy bench press. However, no direct measurement of the medicine ball power drop performance was measured. Further, it was not stated whether the maximal force achieved was a result of catching the ball or the force generated in the pushing movement of the exercise. Because of no significant differences in the results, complex training does not result in a decrease in performance and therefore may provide an organizational advantage to the performance of heavy resistance training and plyometric exercises.

Verkhoshansky and Tatyan (25) examined if there was any significant difference in power development when manipulating the order in which exercises are conducted within a single training session. Novice track and field athletes were subjected to a 12-week program that included 36 sessions. One group performed speed-strength exercises after strength exercises. A second group used the opposite order of exercises. A third group used only 1 method of training, DJs, and this was referred to as the control group. Compared with the second and control group the complex method had the least improvement in speed-strength. Therefore, an increase in the training effect of speed-strength exercises performed after heavy loaded exercises was not supported. This investigation used novice track and field athletes, and the authors highlighted that such training methods may be beneficial to highly strength-trained athletes.

Although intense exercise results in a potentiation of power performance (27), and this was because of increased neuromuscular activity (14), the effect of several sets of a heavy loaded exercise on power performance, as in a typical weight-training session, has not been examined. If such an effect could be maintained during an entire weight-training session, then a greater training stimulus could occur (14, 27). This, over time may lead to greater adaptation and therefore greater improvements in performance. The purpose of this investigation was to establish if the use of complex or contrast training methods could improve power performance throughout an entire weight-training session.

Methods

Experimental Approach to the Problem

To examine the effects of combining heavy resistance exercises with a lighter exercise, 3 different weight-training sessions were conducted. The half squat was used as a heavy loaded exercise, whereas jump squats were performed as the lighter load exercise. Both exercises are commonly used by athletes for the development of strength and power. Three sets of both the half squats and the jump squats were performed during each session because the subjects were currently using this protocol in their resistance training programs. This number of sets is also recommended for the development of both strength and power (11). Subjects were required to attend 4 sessions. A familiarization session in which the subjects fully practiced the procedures of the study was first conducted. Each of the other sessions examined the traditional, complex, and contrast training methods for power development. The training sessions were performed in a balanced randomized order with each session being approximately 1 hour, with a minimum of 3 days and a maximum of 5 days separating each testing session for each subject. The testing sessions were designed to be part of the athletes current training program, and the subjects were given verbal encouragement throughout each session. Within each session, power performance in the jump squat was determined by jump height, peak power output, and maximal force achieved during a jump squat movement.

Subjects

Eleven women ($n = 11$), aged between 19 and 31 years participated in the investigation. The participants regularly undertook resistance training of approximately 5 hours per week, along with training for their selected sports (hockey and softball) for a total of approximately 20 hours per week. All had been involved in high-intensity resistance training, aimed at increasing strength and power, for more than 2 years. During the 6 months before testing, the resistance training programs of the participants had involved both the half squat and jump squat exercises. The participants were accustomed to performing explosive exercises, and such training forms a large part of their physical preparation. Previous experience was a perquisite for participation because of the testing involving a 3RM loading for the squat exercise. The subject's mean (standard deviation, *SD*) age, weight, and height were 23.7 (3.2) years, 64.5 (5.5) kg, and 168.2 (4.9) cm, respectively. After thorough explanation of the procedures and risks of the study, subjects read and signed a consent form that fulfilled the University of Ballarat's ethics requirements.

Testing Sessions

All subjects first undertook a familiarization session that allowed subjects to practice the testing procedures, establish the positioning in the Smith machine that set the knee angle at 90°, and established a 3RM load for the half squat exercise. A 3RM load was used because this load aims to develop maximal strength (11), and it was also a load that was commonly used in the training of the subjects. The half squat exercise required subjects to descend to a 90° knee angle in the squat position. To establish the 3RM load, subjects attempted 3 repetitions of a load and if successful, increased the weight in increments of 5 kg. All subjects had previously been exposed to 3RM testing for the half squat exercise. A 5-minute rest was imposed between all trials to allow subjects adequate time to replenish energy stores and also allow recovery of the nervous system (21).

All subjects were required to refrain from any high-intensity exercise on the day before testing to reduce the possible effects of decreased performance because it had been reported that fatigue negatively affects neural activation responses (14). A standardized warm-up that preceeded every testing session required subjects to cycle on a stationary ergometer for 4 minutes, followed by 5 minutes of light static stretching of the lower extremities. Subjects then performed several sets of submaximal half squats (60 and 80%). A 1-minute rest period was used between all warm-up sets. Although submaximal sets of half squats were performed in the warm-up, it has been shown that submaximal contractions of less than 85% do not induce potentiation of the nervous system (14). Submaximal and maximal sets of jump squats were performed to prepare the subjects for the explosive nature of maximal effort jump squats. Because all sessions involved the same warm-up, the final set of maximal jump squats in the warm-up was performed under the same conditions; therefore the interday reliability of the testing procedures was established.

The traditional training session involved the order of exercises in which the light loads (jump squats) are performed before heavy loads (half squats). This session also acted as a control because no 3RM half squats were performed before the jump squats; however, the half squats were performed after the jump squats to simulate a conventional training session. The complex testing session involved the completion of all sets of heavy resistance exercises followed by sets of the lighter exercises. The contrast training method involved contrasting heavy half squats with the lighter jump squats in an alternating fashion.

Testing Procedures

The jump squats were performed in a modified Smith machine (Plyopower Technologies, Lismore, Australia) positioned over a force plate (ONSPOT 2000-1). The Smith machine is 3 m high and allows for safe completion of the jumps. The bar is fixed using low-friction linear bearings so that it can only slide vertically. The 1RM was calculated by multiplying the 3RM value by 1.06 (2). Thirty percent of the 1RM half squat was used as the loading for the jump squats because it has been previously found to produce maximal mechanical power outputs (26). Subjects were instructed to keep the bar in contact with the shoulders, with any loss of contact being deemed a false trial.

The Smith machine used in this investigation has adjustable brackets that do not allow the bar to travel past a set point. During the familiarization session, the brackets were positioned to allow each subject to attain a knee angle of 90° for the jump squat position. Subjects were required to position themselves under the bar, firmly grasping the bar and supporting it upon their shoulders. Subjects were then instructed to lower themselves, flexing the hip, knee and ankle joints, while maintaining a neutral position of the spine. Both heels were required to maintain contact with the ground throughout the squat movement. Knee angle was then evaluated by a manual goniometer, with the brackets then positioned below the bar to prevent any further descent below the specified 90°. The position of the brackets was recorded for subsequent testing sessions.

The jump squat was chosen as a procedure for measuring the explosive strength of the leg extensors. The jump squat was undertaken from a stationary position with the knees flexed at an angle of 90°. Thus, the jump squat involved a purely concentric action and eliminated the influence of muscle prestretch, which exists in other jumping tests such as a countermovement jump. Also the stationary position eliminated the influence of different knee angles and different speeds of dip that can occur with a countermovement jump, which can significantly influence jump performance (1, 16). The 90° knee angle had been previously used in the testing of the strength-power qualities of elite athletes (28). The bar rested on the shoulders and the jump was performed with the hands on the bar, therefore eliminating any influence of impulse produced by an arm swing.

After lowering the bar under control until it stopped on the preset brackets, subjects were instructed to lightly hold the bar on the brackets while maintaining the weight of the bar on their shoulders. After a pause of 2 seconds they were instructed to jump explosively for height. After completion of the jump, subjects regained their balance and repeated the above process for 4 repetitions. All subjects were given verbal encouragement to attain the highest possible jump height for each repetition.

The half squat exercise was selected because of the mechanical relationship to the jump squat and also because it is a common exercise used for training strength and power. Because both exercises are performed in the Smith machine, the travel of the bar was similar and therefore it is assumed that any muscle activation that occurred in the half squat could have potentially affected performance in the jump squat. During all sets of half squats, including warm-up sets, subjects were encouraged to attain a knee angle of 90°. Subjects were also instructed to raise the weight as fast and as explosively as possible.

Jump Squat Analysis

The ballistic measurement system (BMS, Optimal Kinetics, Muncie, IN) was used to collect bar displacement data during the jump squats. The BMS comprises a cable-extension potentiometer (distance transducer) that produces a variable voltage output in relation to the extension of a cable. An analog to digital card (National Instruments, AT-M10-16EZ, Austin, TX) then captured the voltage data, with customized software, sampling at 500 Hz, converting the voltage data into displacement data. The position transducer accurately tracked the movement of the bar during the jump squats with 4 repetitions being recorded as 1 set of data. The BMS system was calibrated against known distances for the range in which the jump squats were performed; this calibration was performed before all testing sessions.

A force plate was used for the kinetic analysis of the jump squat. The kinetic system comprised a force plate, instrument amplifier, and a personal computer (INTEL Pentium 166) using customized software sampling at 500 Hz. The software synchronized both the BMS and force plate data for comparable analysis. The force plate and the BMS data were filtered using a fourth-order dual Butterworth filter, with the cut off frequency set at 50 and 10 Hz, respectively. The force plate was calibrated with known masses before each testing session. Customized software then allowed the resulting force-time curve to be cropped for analysis of individual jumps. Individual jumps could then be displayed, with the force analysis commencing at force application during the jumping movement.

The maximal force applied for each jump was established from the force plate data. Acceleration was derived by subtracting the mass of the subjects and the 30% loading (system mass) and then dividing by the system mass. This acceleration data was then integrated with respect to time to determine the velocity of the jump squat movement. Power was determined by the product of instantaneous force and velocity with peak power being the maximal value before toe off in the jump squat movement. To determine the jump height achieved in each jump squat, the point at which the subject leaves the ground in the upward movement of the jump was ascertained from the force data. Because the BMS and force data were synchronized, the same point was then extrapolated to the displacement data provided by the BMS. The peak displacement was calculated from the BMS, and the difference between the points was the displacement between leaving the force plate and the peak height achieved, this being the jump height.

Statistical Analyses

To establish the reliability of the testing procedures a 1-way analysis of variance (ANOVA) was conducted on the jump results from the final set of the warm-up. This data was termed the reliability set and was used to establish that there was no significant difference between methods at the beginning of each session. Also, the reliability established the ability of the testing procedures to discriminate small changes in performance across different testing days. The mean values for the set were calculated and both the intraclass correlation (ICC) and the technical error of measurement (TEM) were established using the procedures from Pederson and Gore (19).

The mean of the jump height, peak power, and maximal force for each set within a testing session were calculated. These variables have also previously been used to measure the explosive capabilities of the leg extensor muscles (28). Statistical analyses consisted of a repeated measures multiple analysis of variance (MANOVA) to determine

- (a) If there was a significant difference in the dependent variables *between* the training methods examined for the entire session, that is, the mean of all repetitions of the jump squat within a session.
- (b) If there was a significant difference in the dependent variables *between* the training methods examined for the first, second, or third set between sessions. This analysis was aimed at determining the influence of the heavy load squats on jump squat performance for individual sets between sessions. For example, the first set of 1 session may differ significantly from another session; however, this difference may not persist in further sets.
- (c) If there was a significant difference in the dependent variables between each set *within* a training session. By examining the performance for each set within a method any changes in the power performance were monitored. Factors such as fatigue were monitored for any change during the entire session.

In the presence of a significant *F* value for the independent variable *Pairwise LSD Comparisons* were conducted to compare each level of the independent variable with each of the other levels. Because previous research indicates that stronger individuals benefited more than weaker subjects (27), the sample groups were median split into higher strength (n = 5) and lower strength (n = 5) groups on the basis of their predicted 1RM squat. The 2 groups were then compared using a repeated measures MANOVA with between subjects contrasts to determine if differences between training methods existed as a function of leg strength. For all statistical analysis the level of significance was $p \leq 0.05$.

Results

The strength results of the subjects are presented in Table 1, and all jump squat results are presented in Table 2. For each variable tested there was no significant difference in the reliability sets between each of the testing sessions. The TEM and ICC for each variable tested are presented in Table 3. Statistical analyses revealed no significant difference between the mean

Table 1. Mean squat strength.*

	Mean	*SD*
Half squat 3RM (kg)	120.5	12.8
Predicted 1RM† (kg)	127.7	13.6
Relative strength (1RM/body weight)	1.98	0.18
Jump squat load (30% of 1RM, kg)	38.3	4.0

* *SD* = standard deviation; 1RM 1 repetition maximum.
† 1RM = 3RM × 1.06 (2).

jump height, peak power, or maximal force for each of the sessions. There were also no significant differences in the mean jump height and maximal force *between* each method when examined by individual sets. However, there was a significant difference in the mean peak power of sets, with the mean peak power for the complex method being 74 W lower than the traditional method.

When comparing the changes in jump height within a single session, there was no significant difference in the mean jump height between sets *within* the traditional, complex or contrast training sessions. When comparing the changes in peak power within a single session there was a significant difference in the mean peak power between sets within the traditional training session. The second set of the traditional training method had a significantly lower peak power (−47 W) than the first set of the traditional training session. There was no significant difference in the mean peak power between sets within the complex and contrast training sessions.

Comparisons in maximal force within a single session revealed that there was no significant difference in the mean maximal force between sets within the traditional and complex training sessions. Within the contrast training session there was a significant difference in the mean maximal force between set 1 and set 2, and set 1 and set 3 (Table 2). For individual subjects, the difference between the session mean of each variable in the traditional and the session mean in the complex and contrast training methods was established. The resulting values were then correlated to the predicted 1RM strength in the half squat exercise. There was a significant correlation between an individual's absolute strength level and changes in peak power (r = 0.66), and maximal force (r = 0.76), in the contrast training session. A positive correlation meant that stronger individuals had an improvement in jump squat performance in relation to the traditional training session.

Because of the difference in power performance in the traditional and contrast training methods being significantly correlated with strength levels, the 11 subjects were median split (median value removed)

Table 2. Jump squat results.

	Jump height (cm)			Peak power (W)			Maximal force (N)		
	Traditional	Complex	Contrast	Traditional	Complex	Contrast	Traditional	Complex	Contrast
Reliability	13.1 ± 1.7	13.2 ± 1.9	13.2 ± 2.0	2,880 ± 339	2,864 ± 372	2,918 ± 385	1,851 ± 130	1,849 ± 140	1,869 ± 141
Set 1	12.5 ± 1.9	12.6 ± 2.0	12.8 ± 1.9	2,842 ± 331	2,768 ± 350*	2,867 ± 352	1,836 ± 128	1,828 ± 127	1,856 ± 137
Set 2	12.5 ± 1.7	12.5 ± 1.8	12.8 ± 2.1	2,795 ± 330*	2,781 ± 331	2,851 ± 358	1,829 ± 132	1,841 ± 125	1,840 ± 140†
Set 3	12.5 ± 1.8	12.4 ± 1.9	12.7 ± 2.0	2,790 ± 303	2,748 ± 332	2,826 ± 360	1,825 ± 131	1,830 ± 136	1,839 ± 140†
3 set mean	12.5 ± 1.8	12.5 ± 1.9	12.7 ± 2.0	2,809 ± 320	2,766 ± 335	2,848 ± 355	1,830 ± 129	1,833 ± 128	1,845 ± 138

† Significantly different ($p < 0.05$) to contrast set 1 maximal force.
* Significantly different ($P < 0.05$) to traditional set 1 peak power.

Table 3. Interday reliability.*

	TEM	%TEM	ICC
Jump squat (cm)	0.4	3.29	0.94
Peak power (W)	84.7	2.93	0.95
Maximal force (N)	28.5	1.53	0.96

* TEM = technical error of measurement; ICC = interclass correction.

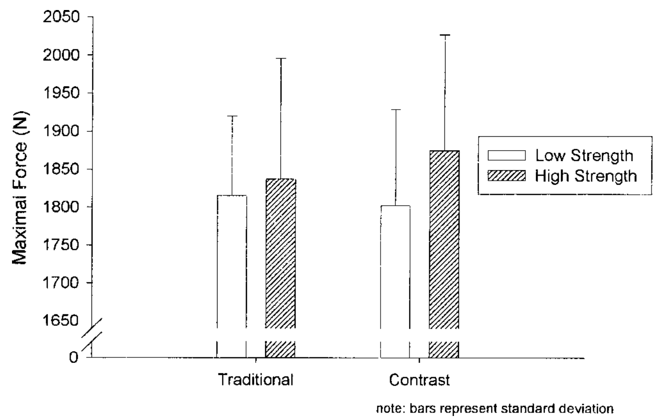

Figure 1. Maximal force for lower and higher strength subjects.

relative to predicted 1RM strength levels. This resulted in 2 equal groups of 5 that were termed the higher and lower strength groups. An independent samples T-test revealed a significant difference in the mean predicted 1RM strength of these 2 separate groups with the lower and higher strength groups having a mean ± *SD* predicted 1RM of 116 kg ± 10.0 and 139 kg ± 5.8, respectively.

A Repeated Measures MANOVA with Between Subject Comparisons was then conducted to examine the interaction between changes in power performance between the traditional and contrast training methods and strength levels. Maximal force demonstrated a significant interaction between strength levels and the difference in maximal force for the traditional and contrast training methods. For the lower strength group the mean ± *SD* maximal force achieved in the traditional training and contrast training methods was 1815 N ± 105 and 1802 N ± 126, respectively. For the higher strength group the mean ± *SD* maximal force achieved in the traditional training and contrast training methods was 1837 N ± 158 and 1874 N ± 152, respectively. Figure 1 illustrates that the lower strength group had a decrease (−1%) in maximal force between the traditional and contrast training methods. Conversely, the higher strength group had an increase (+2%) in maximal force between the traditional and contrast training methods.

Discussion

The reliability results indicate that all the measured variables were reliable as established by the ICC and the TEM. This indicates that the measurement procedures had the ability to detect small changes in performance. Also, there was no significant difference between methods for any of the measured variables in the reliability set, indicating that individual subjects attended each session in a similar physical state.

When all subjects' data were pooled, no training mode was significantly different from the traditional training method for all the variables tested. It can therefore be concluded that no method was superior to another. There was a trend, although not significant, for the contrast training method to have superior results on all variables tested.

During the first set the complex training method subjects had a significantly lower peak power than the traditional training method, demonstrating that the complex training method had a decrease in performance for the first set. One possible explanation is a fatigue effect from the 3 sets of 3RM squats. Although this did not result in the entire method being significantly different from the traditional training method, there was also a trend for the complex training method to have the poorest results for the training session. Verkhoshansky and Tatyan (25) found that performing heavy loads before speed-strength exercises resulted in the poorest improvement in ''explosive strength'' during a 12-week training program. A 3RM loading was also used; however, only 2 sets were performed before the speed-strength exercises (25).

The comparison of sets within each method revealed some significant differences. There was a clear trend for the values to decrease during the training session (Table 2), regardless of the nature of the ordering of exercises, indicating a fatigue effect during each of the training sessions. Although there was a trend for performance to decrease during the training session, it should be noted that the subjects regularly performed this volume of sets, or greater, in their resistance training programs and were therefore accustomed to the demands of this investigation. When comparing each of the sessions, the contrast training method had a smaller decrement in performance and this may be due to a potentiation effect occurring to counterbalance with the fatigue. It has been suggested that muscle twitch responses after MVCs are the net result of force-potentiating and force-diminishing effects (15). It is therefore possible that during the contrast training session there was a potentiating effect from the 3RM squats that decreased the influence of the fatigue in the jump squats.

Although Young et al. (27) and Gullich and Schmidtbleicher (14) demonstrated a potentiation in power performance for a single set after a high-resistance exercise, this finding was not investigated for an entire weight-training session. But it is important to note that although maximal effort was required for all jumps, this investigation required subjects to complete further sets of jump squats to examine the effect for an entire weight-training session. Also, although potentiating effects have been demonstrated in women after MVCs (14), improved performance after heavy loaded resistance exercises in women has not been shown and requires further investigation. But muscle hypertrophy and fast fiber type conversions in heavy resistance-trained women have been shown to have similar characteristics to those of men (22), which may suggest that potentiating effects within muscle would also be similar. One possible explanation for the failure to increase performance may have been the strength levels of the athletes. Young et al. (27) found that the 5RM half squat of 10 men with at least 1 year of experience in the half squat exercise was 152.2 kg $\pm$ 30.1. When comparing this with the current investigation, 120.5 kg $\pm$ 12.8 for a 3RM half squat, it can be concluded that subjects in the current investigation had a lower absolute strength than the subjects in the study of Young et al. (27). But because the mass of the subjects was not reported, no comparisons of relative strength can be made.

Subjects in the current investigation were national and international women hockey and softball players. The training program of the athletes in the current investigation does not solely focus on the development of strength and power; rather aerobic conditioning, speed and agility training, and rehabilitative resistance training are also conducted. The results of this investigation are therefore specific to the subject population and cannot be generalized for athletes from different populations.

A significant correlation was established between predicted 1RM strength levels and the difference between the traditional and contrast training methods for peak power and maximal force. The correlation indicated that subjects with greater strength levels were able to benefit from the contrast training method compared with subjects of a lower strength level. This finding is in agreement with that of Young et al. (27), who showed that stronger subjects had greater gains in jump squat performance after 1 set of heavy 5RM half squats. Similarly, Gullich and Schmidtbleicher (14) displayed a significant potentiation response in the H-reflex for highly trained strength athletes but not in physical education students.

When subjects were split into higher and lower strength groups based on predicted 1RM strength levels, for maximal force, stronger subjects had a greater performance in the contrast training method compared with the traditional training method. Conversely, the lower strength subjects had a declined performance in the contrast method compared with the traditional method. This may suggest that stronger athletes were able to benefit from manipulating the order of exercises in the contrast training method. Because of the coexistence of fatigue and potentiation after voluntary contractions (15), it is possible that the stronger athletes had a greater potentiation than fatigue, whereas the opposite occurred in the lower strength subjects. Therefore it could be recommended that athletes develop a sound strength base before undertaking the contrast method of power development. For example, the results indicate that women hockey and softball players with a mean predicted 1RM half squat of 116 kg were unable to benefit from contrast training and had a decrease in both peak power (−1%) and maximal force (−1%) in the contrast training session compared with the traditional session. Subjects with a mean predicted 1RM half squat of 139 kg were able to benefit from contrast training with an increase in peak power (+4%) and maximal force (+2%) when compared with the traditional training session. Possible mechanisms behind this difference may be that lower strength athletes were not able to lift a load that represented their maximal capabilities and therefore did not achieve the stimulation required to induce a potentiating response (14).

It therefore appears that higher level strength athletes may benefit from the contrast training method and that to benefit from contrast training, athletes would be required to have high maximal strength levels. To trigger a potentiation response, a high proportion of FT units, maximal stimulus intensity (100%), and considerable stimulus duration (several seconds) are necessary (14). It is theoretically possible that only highly trained strength athletes are capable of producing such an intense stimulus during a resistance training exercise.

It should be noted that there were limited subject numbers, and therefore these suggestions should be treated with caution. Also, previous research into potentiating effects in women is limited. The results demonstrated that stronger athletes benefited from the contrast training method using a 3RM load for the half squats. A 3RM loading was used in this investigation because a load of 3RM may cause a potentiating response. Young et al. (27) found that a 5RM load caused a potentiation of power performance, as measured by countermovement jump height. Although MVCs would be expected to provide a higher force output, and therefore a greater potentiating response, half squats are commonly used in the strength conditioning of athletic populations and are more realistic in the training of athletes.

The results of the current investigation demonstrate that the benefits of the so-called ''complex training methods'' cannot be assumed to be general to all athletic populations. But individual experimentation is recommended because stronger subjects had a significant improvement in performance in the contrast training method. Although mean values demonstrated a trend in favor of the contrast training session, all subjects did not demonstrate this. Given the designated rest period between all sets for all subjects in the current investigation, some subjects may have missed their ''window'' of potentiation and were therefore incapable of demonstrating an augmentation in power performance. Indeed, because of their high interindividual differences, Gullich and Schmidtbleicher (14) concluded that generalized instructions to athletes would be inappropriate. Therefore, in the development of training programs for athletes, the time period between performing heavy loads and lighter loads should be determined individually.

It can be concluded that the contrast training method for power development may lead to greater improvements in power performance than the traditional method of training. But significant strength levels are required before benefits will be seen from this training method because the contrast training method provides little advantage to athletes of lower strength levels. The complex method of power development resulted in a significant decrease in performance during the first set of the training session. It is therefore concluded that this method results in a reduced performance that over time may lead to the impairment of power development. Individual experimentation is necessary for athletes to develop their own training program consisting of the optimal weight-training practices that will lead to significant gains in power performance.

Practical Applications

Any practical application requires careful implementation and individual experimentation. The most important finding in this research is that significant strength levels are required for an athlete to use the contrast training method effectively. For example, within the current study, women hockey and softball players who had a predicted 1RM half squat in excess of 135 kg were able to benefit from the contrast training method. Therefore, it could be suggested that athletes that have undergone an intensive strength training background and have developed a high level of strength may have the capability to benefit from such training methods. The results of this investigation suggest not performing exercises in a complex training method as several sets of a heavy strength exercise resulted in a decrease in performance for the first set of the jump squats.

It could be suggested that over a period of time, training with the contrast might result in greater improvements in performance than the traditional or complex methods of training. But this suggestion is purely speculative and was not examined in this investigation.

The number of possible combinations of heavy and light loaded exercises within an exercise session is extensive. Therefore it is recommended that athletes experiment with different combinations and orders of exercises that may lead to an enhancement in power performance.

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