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Comparative Effects of Deep Versus Shallow Squat and Leg-Press Training on Vertical Jumping Ability and Related Factors

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ABSTRACT

Young, previously untrained healthy men ($n = 10$) and women ($n = 8$) completed 9 weeks of periodized, machine-based squat training to determine if manipulating range of motion would have a differential effect on vertical jumping ability and related measures. Subjects were pretested and then randomly assigned to 1 of 3 groups: (a) deep squats ($n = 6$), (b) shallow squats ($n = 6$), and (c) controls ($n = 6$). Training took place 3 days per week. Pre- and posttesting included standing (RVJ) and depth (DVJ) vertical jumps for distance; machine deep and shallow squats for 1RM (1 repetition maximum) relative strength; and velocity-controlled squats at 0.51 $m \cdot s^{-1}$ for relative peak force and at 1.43 $m \cdot s^{-1}$ for relative peak power. Based on ANCOVA posttest results, the training protocols were ineffective in eliciting improved performance ($p > 0.05$) in VJ, slow-velocity squatting force, and moderately fast squatting power when performance was compared with the performance of control subjects. Conversely, the group training with deep squats was the only group to perform significantly ($p < 0.05$) better than controls for 1RM shallow squats and significantly ($p < 0.05$) better than both shallow-squat and control groups for 1RM deep squats. Furthermore, the coefficient of transfer for deep squats to both RVJ (2.32) and DVJ (1.68) was substantially greater than for shallow squats (0.31 and 0.11, respectively). It was concluded that deep-squat training appears to elicit the best improvement for both shallow- and deep-squatting performance. However, 9 weeks of machine-based, periodized squat training, regardless of depth, does not appear to appreciably enhance slow-velocity squatting force, moderately fast squatting power, or vertical jumping distance in previously untrained men and women.

Key Words: weight training, force, power

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Introduction

Vertical jumping ability plays an important role in the level of success attained by individuals participating in many sports and recreational activities. Each person's ability to jump depends on a combination of other physical attributes (e.g., power, strength, and body composition) as well as the nature of actions immediately preceding jumping (e.g., counter or non–countermovement, running or standing start, 1- or 2-legged takeoff). Because the requirements for various vertical jumps are different and each person's combination of physical attributes undergirding jumping is also different, the performance on 1 type of jump will not necessarily reflect performance on all types of vertical jumps. Weiss et al. (12, 13) identified several factors in young adults that account for much of the variability in 2 types of vertical jumps: a depth or box vertical jump (DVJ) and a restricted-motion standing vertical jump (RVJ). For DVJ (box height = 20 cm), the most important predictor was relative peak squatting power (peak power per body weight) at 1.43 $m \cdot s^{-1}$. Predicted DVJ was then attenuated using a constant for all female subjects. No such adjustment was made for male subjects. For RVJ, the most important predictor was also relative peak squatting power at 1.43 $m \cdot s^{-1}$, after which body fat percentage and relative peak squatting force (peak force per body weight) at 0.51 $m \cdot s^{-1}$ were used in that order to attenuate the predicted RVJ distance. Individuals experiencing changes in 1 or more of these predictors would be expected to simultaneously experience corresponding changes in jumping performance and vice versa.

Based upon the widely held premise of specificity of training, exercises having movement patterns most similar to vertical jumping should elicit the best improvements in jumping performance (2). The squat and possibly leg press exercises incorporate movement patterns at the ankle, knee, and hip that are similar to those used in vertical jumping. Furthermore, since the countermovement used in vertical jumping typically occurs through a limited range of motion, it follows that a shallow squat-training depth would likely elicit the best improvements in jumping performance. In practice, both deep and shallow squats are used for this purpose, and have been categorized by Baker (2) as ''general'' strength training. In this regard, he defined general strength-training exercises as ''those aimed at increasing the maximal strength of the muscles involved in jumping. Examples would be squats, front squats, split squats, and power shrugs (with a very slow eccentric dip to the knee).'' It appears general strength training in and of itself may elicit marginal or no improvements in jumping performance in elite athletes, even when strength is substantially improved (1). It may, however, elicit significant improvements in vertical jumping by lesser-trained individuals (3, 7).

Considering the aforementioned comments, the overall purpose of the current investigation was to determine if squatting depth during short-term, periodized squat training would differentially impact jumping performance and 1 or more predictors of VJ ability. More specifically, the purpose of this investigation was to determine the comparative effects of shallow versus deep squat training on vertical jumping performance (RVJ and DVJ), on variables reported to be significantly related to jumping, and on other factors associated with squatting strength.

Methods

Subjects

Healthy young male (n = 10) and female (n = 8) university students, averaging 23.7 years of age (SD = 6.1), weighing an average of 78.9 kg (SD = 24.4), and having a wide array of vertical jumping abilities voluntarily served as subjects in this investigation. Subjects had not engaged in any formal strength development program for a minimum of 1 year prior to the study. Subsequent to both written and verbal explanations of the specific nature of each volunteer's involvement in the study, a medical history questionnaire was completed and written informed consent was obtained as approved by the University's Institutional Review Board. Finally, all volunteers were screened by auscultation for both hypo- and hypertension prior to their designation as subjects.

Testing Protocols

Familiarization. Over a 2-week period and prior to pretesting, 6 50-minute familiarization sessions took place. During these sessions, subjects received instruction and practiced 2 styles of vertical jumping, 2 different velocity-controlled squats, and both shallow and deep dynamic constant external resistance (DCER) squats in an effort to stabilize the learning process that normally accompanies exposure to new motor skills (in this case, skills for which we assessed strength and power) (9).

Subsequent to the 9-week training period and immediately following the last training session, subjects practiced each of the aforementioned tests of muscle function. This procedure was used to refamiliarize the subjects (as well as the control group) with the standardized protocols they had not practiced for 9 weeks.

Body Fat Measurement. Body fat estimation was performed during pre- and posttesting periods. A 3-site, gender-specific skinfold test (8) was exclusively performed by the primary investigator to estimate body fat percentage. All sites were marked with water-soluble ink and subsequently measured 3 times in series. Skyndex calipers (Caldwell, Justice and Co., Fayetteville, AR) were checked for a ''zero'' starting position at every session in which skinfolds were obtained, although jaw-width calibration was not assessed. A Sterling electronic platform scale (Sterling Scale Co., Southfield, MI) was used to obtain body weight. The device was calibrated before and then checked daily during testing using a certified 50.00-kg weight. An interday coefficient of variation of 0.0% was found for calibration tests performed over a 10-day span. Subjects were weighed in their testing attire (shorts, socks, shoes, and a T-shirt).

Vertical Jumps. The depth or box jumps and the standing or restricted vertical jumps were performed as previously described (12, 13). For the DVJ, the subject stepped off a 20-cm box and rebounded from the floor to enhance the prestretch occurring during the eccentric or countermovement phase. (An analogous prestretch occurs when an individual takes a running start and ''blocks'' prior to jumping.) The RVJ also incorporated a countermovement but with substantially less intense prestretching. (A relatively smaller prestretch normally occurs when an individual chooses to jump without a running approach.) A Vertec device (Power Systems Inc., Knoxville, TN) was used for measuring vertical jumping distance to the nearest 0.5 inch (subsequently converted to meters).

Velocity-Limited Squats. Concentric-only squats (preceded by a nonresisted countermovement) were performed at slow (0.51 $m \cdot s^{-1}$) and moderately fast (1.43 $m \cdot s^{-1}$) velocities as previously described (11) using an Ariel 5000 multifunction dynamometer computerized exercise system (CES) (Ariel Dynamics Inc., San Diego, CA). Of primary interest were relative peak power generated at 1.43 $m \cdot s^{-1}$ and relative peak force generated at 0.51 $m \cdot s^{-1}$ because these variables were previously identified as significant predictors of vertical jumping performance (12, 13). Test administration was counterbalanced.

Table 1. Periodized training scheme for groups training with deep or shallow ranges of motion. All training schemes were preceded by warm-up and each training set was performed to failure.*

Week	Day: Monday	Day: Wednesday	Day: Friday
1	Familiarization	Familiarization	Familiarization
2	Familiarization	Familiarization	Familiarization
3	Pretesting	Pretesting	Pretesting
4	2 × 9–10RM Squat	2 × 9–10RM Squat	2 × 9–10RM Squat
5	3 × 9–10RM Squat	3 × 5–6RM Squat	3 × 9–10RM Squat
6	3 × 9–10RM Squat	3 × 5–6RM Squat	3 × 9–10RM Squat
7	3 × 9–10RM Squat	3 × 5–6RM Squat	3 × 9–10RM Squat
8	Transition (spring break)	Transition	Transition
9	3 × 5–6RM Squat	4 × 3–4RM Leg press	3 × 5–6RM Squat
10	3 × 5–6RM Squat	4 × 3–4RM Leg press	3 × 5–6RM Squat
11	4 × 3–4RM Squat	5 × 1–2RM Leg press	4 × 3–4RM Squat
12	4 × 3–4RM Squat	5 × 1–2RM Leg press	4 × 3–4RM Squat
13	Posttesting	Posttesting	Posttesting

* Values represent sets × repetitions maximum (RM).

Dynamic Constant External Resistance Squats. Deep and shallow squats were performed starting from the ''up'' position on a Bear machine (Powernetics, Riverside, TX). This plate-loaded device has padded shoulder rests and allows movement through only 1 plane of motion, thereby minimizing learning requirements for novices. A mechanical range-limiting device was used to individualize squatting depth. Deep squats were performed so that the tops of both thighs were parallel to the floor while shallow squats were performed at one-half of that depth. Upper torsos were maintained in an upright position throughout the lifts. A large grid (6 feet × 6 feet) was used in the background prior to pretesting to facilitate the establishment of the low position for the deep squat. Also, while subjects were in the standing position, ankles were in a neutral position as opposed to the dorsiflexed stance often used with this device.

Training Protocols

Groups. Following familiarization and pretesting, subjects were randomly assigned to 1 of 3 groups: (a) a deep squat group ($n = 6$), which performed squats with the tops of thighs parallel to floor; (b) a shallow squat group ($n = 6$), which performed squats to one-half of the depth of the deep squats; and (c) a control group ($n = 6$), which performed no strength or power training.

Training. Supervised training was periodized and took place 3 days per week for 9 weeks including a 1-week period during the fifth week (spring break) for active rest (Table 1). All squat training took place on the Bear machine. Training on Wednesdays during the 4 weeks subsequent to active rest and prior to posttesting was modified by substituting Nautilus plate-loaded leg presses (Nautilus, Huntersville, CA) using the same range of motion (based upon knee joint range of motion) used for the squats. Prior to this modification, severe shoulder girdle discomfort had become an increasing problem for several subjects and the adjustment enabled them to continue with the 3–day-per-week training schedule.

Statistical Analysis. Analysis of covariance (ANCOVA) was used to analyze posttest data using the respective pretest scores as covariates for all variables. For pretest data, body weight was significantly ($p \leq 0.05$) related to all dependent variables under consideration, except those variables expressed relative to body weight. Therefore, body weight was included as a second covariate for all but the ''relative'' variables. When significant ($p \leq 0.05$) F ratios were found, Tukey post hoc tests were performed. The coefficient of transfer (CT) as proposed by Zatsiorsky (14) was used to indicate the level of training effect that transferred from the training exercise to each of the performance measures. The following 2 formulas were used to calculate the coefficient of transfer:

Table 2. *P* value and statistical power from analysis of covariance for posttest data on each dependent variable.*

Variable	*P* value (Main effects)	Power
Restricted or standing vertical jump (RVJ)	0.137	0.85
Depth or box vertical jump (DVJ)	0.566	0.93
Relative peak power at 1.43 $m \cdot s^{-1}$	0.945	0.97
Percent body fat	0.033	0.89
Relative peak force at 0.51 $m \cdot s^{-1}$	0.181	0.74
Shallow relative 1RM	0.045	0.60
Deep relative 1RM	0.006	0.64

* 1RM = 1 repetition maximum.

$$CT = \frac{\text{result gain in nontrained performance}}{\text{result gain in trained performance}}$$

where

$$\text{result gain} = \frac{\text{performance gain}}{SD \text{ of final performance}}$$

Results

Each p value and its respective statistical power for main effects based upon ANCOVA are presented in Table 2. Results indicated that all 3 groups performed similarly ($p > 0.05$) on posttests for RVJ, DVJ, slow-velocity relative peak–squatting force, and moderately fast-velocity relative peak–squatting power. These results suggest the training protocols used were ineffective in eliciting changes in those particular variables. Conversely, for variables that produced significant ($p < 0.05$) *F* ratios, Tukey post hoc analyses indicated the group training with deep squats performed better ($p < 0.05$) than the control group for shallow squat 1 repetition maximum (1RM) relative strength, and better ($p < 0.05$) than both the control and shallow groups for deep squat 1RM relative strength (Figure 1). Groups were different ($p < 0.05$) on pretest body fat percentage (deep squat group = 13.9%; shallow squat group = 17.3%; control group = 21.1%). Using pretest body fat percentage and body weight as covariates, ANCOVA on posttest scores indicated the group training with shallow squats had significantly ($p < 0.05$) lower body fat than the control group (deep squat group = 17.3%; shallow squat group = 16.2%; control group = 17.8%).

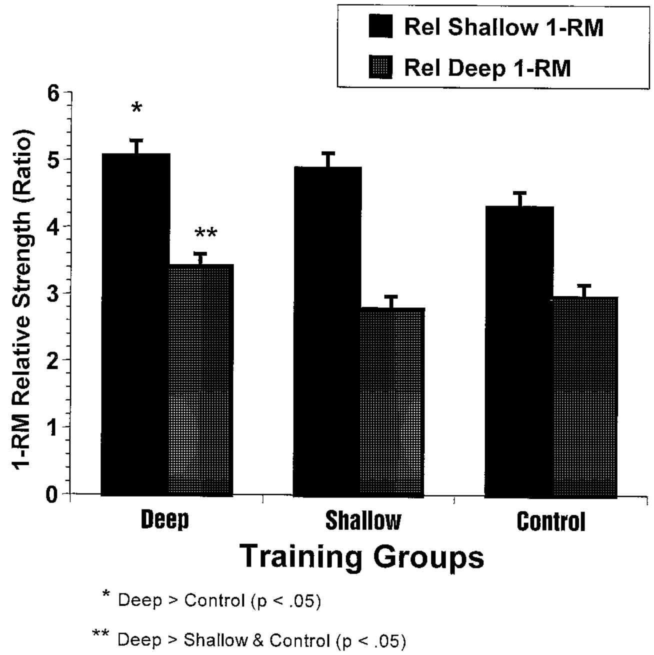

Figure 1. Posttest means adjusted for covariates (error bar indicates 1 positive standard error of the mean). These values represent the effects of squat training depth (deep vs. shallow) on relative strength (strength/body weight).

Zatsiorsky's (14) coefficient of transfer (Table 3) represents the relative transfer from the respective training variables to the various performance variables. In general, the deep squat–training group achieved the greatest amount of positive transfer and the least amount of negative transfer for performance variables.

Table 3. Coefficient of transfer from training variables to performance variables.*

Performance variable	Training group: Deep	Training group: Shallow
Restricted or standing vertical jump (RVJ)	2.32	0.31
Depth or box vertical jump (DVJ)	1.68	0.11
Relative peak squatting power at 1.43 $m \cdot s^{-1}$	−0.18	0.09
Relative peak squatting force at 0.51 $m \cdot s^{-1}$	−0.27	−1.37
1RM deep squat	1.0	−0.11
1RM shallow squat	1.7	1.0

* 1RM = 1 repetition maximum.

Discussion

This investigation was conducted to compare the effects of training using deep versus shallow machine-based squats on vertical jumping performance (RVJ and DVJ); predictors of performance (relative peak power at 1.43 $m \cdot s^{-1}$, percentage body fat, and relative peak force at 0.51 $m \cdot s^{-1}$) (12, 13); and related variables (relative DCER deep- and shallow-squat strength). Subjects included 10 men and 8 women who had no formalized weight-training engagement for a minimum of 1 year prior to the study. Experimental intervention consisted of periodized heavy-resistance training for 9 weeks subsequent to 2 weeks of test- and training-familiarization activities and 1 week of pretesting.

Because participants in the present investigation had been physically active but not formally strength trained prior to this investigation, our results appear to conflict somewhat with those reported by Häkkinen and Komi (7) and Baker et al. (3). Our subjects did not improve their jumping performances, whereas non-elite athletes in the study of Häkkinen and Komi (7) and highly conditioned athletes in the investigation by Baker et al. (3) improved their vertical jumps subsequent to heavy free-weight training. In contrast, Alen et al. (1) trained highly conditioned athletes with free weights and reported results similar to those of the present study: no changes in jumping ability occurred even though leg and hip strength increased ($p < 0.05$). It is noteworthy that the study by Alen et al. (1) also involved exogenous anabolic-androgenic steroid consumption.

Statistical power (Table 2) was quite high for both RVJ and DVJ, (0.85 and 0.93, respectively) in the present study, indicating that chances were only 15% and 7%, respectively, of group differences not being detected. The conventional, minimally accepted value of statistical power is 0.80, indicating that no more than a 20% chance exists that group or treatment effects have gone undetected (4). Based upon the current investigation, there is good reason to expect that neither deep nor shallow machine-based squat training using a 9-week periodized protocol will elicit significant improvements in vertical jumping ability by previously untrained, healthy young men and women. However, when the current and previous studies are considered, findings appear to be equivocal with regard to the effectiveness of short-term heavy-resistance training (involving free-weights, machine-based lifts, or both) for improving vertical jumping performance.

The primary predictor for both RVJ and DVJ, relative peak squatting power at 1.43 $m \cdot s^{-1}$ (12, 13), was unresponsive to either of the training programs used in this study (Table 2). Its statistical power was 0.97, indicating that there was only a 3% chance that group differences went undetected. Groups also performed similarly ($p > 0.05$) on the tertiary predictor of RVJ, relative peak force at 0.51 $m \cdot s^{-1}$ (12, 13). Statistical power was lower than desired for this variable, 0.74, indicating that there was a 26% chance that actual group differences went undetected.

The secondary predictor for RVJ, percent body fat, was lower ($p < 0.05$) on posttests for the group performing shallow squats compared with the control group. Although body fat was reduced in the shallow-training group by 1.1 % (posttest-pretest) and was 1.6 % lower (posttests for the shallow squat group vs. control group) than in the control group, these values were well within the 4.6% standard error of estimate for skinfold assessments used in this study (5), and consequently, may not be meaningful differences. Due to the nature of the training programs for both deep and shallow squats, body fat was expected to remain unchanged because of the short time span of the study (9 weeks), the limited training the subjects were performing (squats and leg presses), and the limited training volume (Table 1). Although statistical power was more than adequate (0.89), it is unlikely this low-volume work would consistently reduce body fat, especially over a relatively short time frame. It appears more likely that the observed difference was based upon inherent measurement error associated with skinfolds.

Findings in the present study indicate significant differences existed for posttest performance of squatting strength, but the nature of these differences depended upon the depth of the squat tested. For shallow squat relative strength, only the deep squat group performed better than the control group. The transfer coefficient (14) was higher for the group training with deep squats (2.32) than for the group training through a shallow range of motion (0.31). These findings were unexpected because the group training with shallow squats worked on the same exercise machine using the identical range of motion used for the test. The concept of specificity would certainly suggest that the strongest effect would occur for the group training in a manner identical to (except for repetition number) the manner of the testing protocol. The group training with deep squats used the identical machine but moved through twice the range of motion with a substantially lower load than would have been used for shallow–squat training. Perhaps perceived shoulder girdle discomfort (voiced by several participants) was disproportionately greater for subjects performing shallow squats due to their relatively greater loads. In fact, the training protocol was modified 1 day per week by substituting identical range-of-motion leg presses in response to these complaints. If shoulder girdle discomfort was a limiting factor for the load lifted, this may have selectively affected the performance of shallow squats such that training loads might have been less than optimal for achieving maximal results. Another possible explanation for these results could be inadequate statistical power (Table 2). For shallow squat relative strength, the chance of not detecting significant differences between groups was 40%, indicating that there is a relatively high chance that a type II error occurred.

For deep squat relative strength, the group that trained with deep squats outperformed both the shallow squat and control groups ($p < 0.05$). The transfer coefficient (14) was also higher for the deep squat group (1.68) as opposed to the shallow squat group (0.11). These findings were expected based on the concept of specificity of training. We also expected the shallow squat group to outperform the control group for deep squat performance. However, very little transfer occurred from shallow squat training to deep squat performance (0.11), and the control and shallow squat groups performed similarly ($p > 0.05$) on the deep squat. The relatively low statistical power (0.64) increased our probability of failing to detect group differences that actually existed.

The use of a Bear machine to perform squat training as opposed to the use of free-weight squats may have also contributed to the lack of significant improvements in some of the variables. The decreased role of guiding muscles during machine squats would likely lessen the general transferability of the training effect. Zatsiorsky's (14) coefficient of transfer is a unique tool for assessing this possible effect; however, because free-weight training was not a part of the current study, this conjecture remains unresolved. Furthermore, because a machine device was used for training, the results of the current study may apply only to that particular type of training. We recommend a follow-up training study comparing free- weight training and machine training to ascertain if the increased use of guiding muscles has a differential impact on vertical jump performance.

An absence of significant differences in posttest performance for slow-velocity relative peak force and moderately fast-velocity peak power are not very surprising given the relatively brief training duration (9 weeks) and the difference between training and testing devices (modality differences). These factors have been identified as potential problems in ''strength'' studies (6, 9, 10). The effects of squat training would need to be relatively great to impact these related but different tests because they are probably not particularly sensitive to marginal influences. However, because no improvement in vertical jumping occurred, drastic changes in both of these predictors (12, 13) would not be expected. Although the statistical power for relative peak power at 1.43 $m \cdot s^{-1}$ was quite high (0.97), the same was not the case for relative peak force at 0.51 $m \cdot s^{-1}$. For relative peak force, there was a 26% chance that group differences were undetected (Table 2). This value again raises the possibility that a type II error occurred.

It appears that if improved squatting strength is desired, heavy-resistance programs involving deep squatting would be the best way to train (Table 3). Nevertheless, when considering only the ''strength'' variables (shallow and deep squats and relative peak squatting force at 0.51 $m \cdot s^{-1}$), and their associated low values of statistical power, we recommend replicating the present investigation using a substantially larger number of subjects.

Practical Applications

If confounding factors can be ruled out, it appears deep, machine-based squat training is preferable to shallow, machine-based squat training for increasing squatting strength at any depth. It also appears that machine-based squats, by themselves, are of little value in improving vertical jumping performance. If these particular findings can be verified, then athletes and others performing partial range-of-motion squats in their training programs may need to reassess the effectiveness of this training. Those performing full squats may wish to reconsider the proportion of time spent on this particular activity once an adequate base of leg and hip strength has been established. However, as Baker (2) suggests, general strength exercises likely play an important fundamental role in preparing the muscles involved to perform specialized jump training.

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