Comparison of weighted jump squat training with and without eccentric braking

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COMPARISON OF WEIGHTED JUMP SQUAT TRAINING WITH AND WITHOUT ECCENTRIC BRAKING

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ABSTRACT

The purpose of this study was to investigate the effect of weighted jump squat training with and without eccentric braking. Twenty male subjects were divided into two groups (n = 10 per group), Non-Braking Group and Braking Group. The subjects were physically active, but not highly trained. The program for Non-Braking Group consisted of 6 sets of 6 repetitions of weighted jump squats without reduction of eccentric load for 8 weeks. The training program for the Braking Group consisted of the same sets and repetitions, but eccentric load was reduced by using an electromagnetic braking mechanism. Jump and reach, countermovement jump, static jump, drop jump, one repetition maximum half squat, weighted jump squat, and isometric/isokinetic knee extension/flexion at several different positions/angular velocities were tested pre- and posttraining intervention. The Non-Braking Group exhibited greater improvement in peak torque during isokinetic concentric knee flexion at 300°/s [Non-Braking Group: (mean ± SD) 124.0 ± 22.6 Nm at pre- and 134.1 ± 18.4 Nm at posttraining, and Braking Group: 118.5 ± 32.7 Nm at pre- and 113.2 ± 26.7 Nm at posttraining]. Braking Group exhibited superior adaptations in peak power relative to body mass during weighted jump squat [Non-Braking Group: (mean ± SD) 49.1 ± 8.6 W/kg at pre- and 50.9 ± 6.2 W/kg at posttraining, and Braking Group: 47.9 ± 6.9 W/kg at pre- and 53.7 ± 7.3 W/kg at posttraining]. It appears that power output in relatively slow movement (weighted jump squat) was improved more in the Braking Group, however strength in high velocity movements (isokinetic knee flexion at 300°/s) was improved more in Non-Braking Group. This study supports load and velocity specific effects of weighted jump squat training.

KEY WORDS power, strength, landing impact, stretch shortening cycle, specificity

INTRODUCTION

To maximize power output during a given resistance-training exercise, it is recommended that an object (i.e., a barbell or an athlete’s body) be projected into the air so that undesirable deceleration is minimized (22). For this reason, weighted jump squat has attracted considerable attention among scientists and practitioners (15,16,21,28). During weighted jump squat, an athlete places a barbell on the shoulders or holds dumbbells in the hands, lowers to a comfortable depth (typically about 90° of knee flexion), and then jumps vertically for maximum height (propulsive phase), after which the athlete’s body and the weight (barbell or dumbbells) accelerates downward under the influence of gravity until the athlete contacts the ground again and initiates the landing phase. During the landing phase, an athlete is exposed to a considerable magnitude of ground reaction force (GRF) particularly the landing impact at initial contact, which can be quantified as the impulse over the first 50 ms (12). Humphries et al. (12) reported that the peak GRF at landing phase was 3.04 times body weight (BW), while the peak force during propulsive phase was 2.19 BW during weighted jump squat with 10 kg load.

During the landing phase of the weighted jump squat, muscle groups of the lower extremities work eccentrically (9). It has been well-documented that unaccustomed eccentric muscle actions cause greater muscle damage than concentric muscle actions (5,26). Thus, it is speculated that the eccentric muscle action during the landing phase of weighted jump squat causes considerable muscle damage in athletes unaccustomed to such exercise (9). Further, there are some unsubstantiated claims that landing impact may cause injuries to the athlete, such as cartilage degeneration, stress fractures, and tendinitis (12,25). To minimize impact force at the initial contact during weighted jump squat, previous studies investigating the effects of weighted jump squat training have used various braking mechanisms to control the momentum on landing and thus the impulse that must be applied to decelerate (15,16,21,28). For example, Humphries et al. (12) reported that an electromagnetic braking mechanism reduced the peak impact force at landing by 155%. In their study (12), the braking mechanism was activated only as the barbell descended, but it was not...
active during upward movement of the barbell in the propulsive phase.

However, any negative effects of reducing eccentric load or positive effects of exposure to landing impact have not been investigated fully in previous studies. Because a braking mechanism modifies the eccentric phase, a natural stretch-shortening cycle is not experienced. This may reduce the training stimulus, and therefore reduce the magnitude of neuromuscular adaptations. Eccentric muscle action during the landing phase may cause positive adaptations. Several studies (4, 6, 11, 13, 17) have reported that training emphasizing eccentric actions improves strength more than that of concentric actions only. Thus, once the athletes adapt to the exercise, the landing impact of the weighted jump squat may improve their strength without causing excessive muscle damage. If this eccentric muscle action initiates a positive adaptation, it is possible that weighted jump squats without a braking mechanism may be more beneficial than that with a braking mechanism. Therefore, the purpose of this study was to compare the effects of weighted jump squat training with and without a braking mechanism designed to reduce the eccentric load on strength, power and athletic performance under well-controlled conditions.

**METHODS**

**Experimental Approach to the Problem**

An overview of the timeline of this study is presented in Figure 1. Twenty physically active male subjects were equally divided into two groups, Non-Braking Group (NBG) and Braking Group (BG). There were two phases to this research, the first being a training intervention comparing neuromuscular adaptations to weighted jump squat training with braking versus without braking. The second phase was an investigation of the GRF kinetics of weighted jump squat with and without braking to investigate possible mechanisms for any differential training effects.

All subjects participated in a training program consisting of weighted jump squats twice a week for 8 weeks. Subjects in NBG performed weighted jump squat without a braking mechanism while subjects in BG performed weighted jump squat with a braking mechanism designed to produce an upward force during the descent phase. Strength, power and athletic performance were measured pre- and posttraining intervention. To familiarize subjects with the test measurements, subjects completed a familiarization session two weeks prior to the pretraining test. All subjects participated in a separate testing session at the completion of the training intervention to assess the kinetics of the two conditions. This phase of the study was completed at the end so that all subjects were very familiar with the weighted jump squat protocol and equipment.

**Subjects**

Twenty male subjects were recruited by advertising flyer and announcement in university lectures and tutorials. All subjects were regularly participating in some form of physical activity such as weight training, running, swimming, cycling, or ball games (e.g., soccer) 2 to 3 times per week on average, but were not competitive athletes. A subject inclusion criterion was that they had no injury or medical condition which would limit their training adaptation or place them at risk of injuries. To standardize initial strength level, the subjects were eliminated if their one repetition maximum (1RM) half squat was less than their body mass at the pretraining test. This criterion of strength level was chosen based on our previous study (28). The subjects height, body mass and sum of seven skinfolds (i.e. triceps, subscapular, biceps, supraspinale, abdominal, front thigh, and medial calf) are presented in Table 1 (23). These subjects were equally divided into 2 groups based on their 1RM half squat value pretraining intervention. Prior to the training intervention, independent sample t-tests did not reveal any significant differences in descriptive characteristics or dependent variables between

<table>
<thead>
<tr>
<th>TABLE 1. Descriptive subject data (mean ± SD).</th>
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<tr>
<td></td>
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<tr>
<td><strong>Non-braking group (n = 10)</strong></td>
</tr>
<tr>
<td><strong>Braking group (n = 10)</strong></td>
</tr>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td>23.7 ± 2.1</td>
</tr>
<tr>
<td>24.8 ± 5.0*</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>179.0 ± 5.0</td>
</tr>
<tr>
<td>177.3 ± 6.0</td>
</tr>
<tr>
<td>Body mass (kg)</td>
</tr>
<tr>
<td>81.1 ± 7.8</td>
</tr>
<tr>
<td>76.4 ± 7.0</td>
</tr>
<tr>
<td>Skinfolds (mm)</td>
</tr>
<tr>
<td>91.3 ± 24.5</td>
</tr>
<tr>
<td>87.7 ± 34.8</td>
</tr>
</tbody>
</table>

*Significant difference (P < 0.01).
Weighted Jump Squat Training

the groups except for their age. As shown in Table 1, age in BG was significantly higher than that of NBG \( (P < 0.01) \). Since the pretraining strength was considered the most important matching variable, grouping was based on 1RM half squat and the 1.1 years difference in age between groups acknowledged. This study was approved by the University's Human Research Ethics Committee. All subjects read an information letter explaining the procedure of the study, and signed an informed consent document.

Training Intervention

Subjects in both groups participated in training sessions consisting of weighted jump squat, 6 sets of 6 repetitions at 30% of 1RM half squat at pretraining test twice a week for 8 weeks. Throughout the 8-week training intervention, subjects were asked to maintain their lifestyle, and not alter their volume or intensity of physical activity in particular. No subjects reported any acute/chronic injuries during the training intervention. McBride et al. (15) compared the effects of weighted jump squat training using 30% vs. 80% of 1RM loads, and reported that the 30% loading was more effective than 80% to improve athletic performance. This has been used as the rationale for a 30% of 1RM load to be applied in the present study. The length of the training intervention was chosen based on previous studies (15, 21). In the weighted jump squat, subjects squatted down to a self-selected depth of approximately 90° of knee flexion, and jumped immediately as high as possible. Subjects performed 6 repetitions of weighted jump squat without any pause between repetitions. Subjects took at least 1 minute rest between sets, but they were allowed to take as much rest as they needed. The cable end of the electromagnetic braking mechanism (Ballistic Braking System, Fitness Technology, Adelaide, Australia) was attached to the middle of barbell.

Although the braking mechanism was attached for both groups during the weighted jump squat movement for consistency of training environment, the braking mechanism was active only during the downward movement for BG. The reduction of eccentric load for subjects in BG was controlled to be equal to the barbell weight. For example, if a subject in BG used a 50-kg barbell, the reduction of downward force was 490.5 N (mass \( \times \) gravity). In all testing and training sessions, subjects rode on a stationary bike for 5 minutes at 100 W intensity and 60 rpm for warm up.

Measurement of Strength, Power, and Athletic Performance

Pre- and posttraining tests were completed over 2 days, and administered in the following order; Day 1: Countermovement jump (CMJ), static jump (SJ), drop jump, jump and reach, and 1RM half squat, and Day 2: Weighted jump squat, and isometric and isokinetic unilateral knee extension and flexion.

Counter Movement Jump and Static Jump. Subjects were tested on two different types of jump; CMJ and SJ. In the CMJ, the subjects stood erect first, then squatted to a self-selected depth of approximately 90° of knee flexion, and jumped immediately as high as possible without pausing. In the SJ, subjects were instructed to squat to a self-selected depth of approximately 90° of knee flexion, pause 3 seconds in this position, and then jump as high as possible. During these jump movements, the subjects kept their hands on hips. The jumps were performed on a force platform (Quattro Jump – Type 9290 AD, Kistler, Switzerland) and vertical GRF was sampled at a rate of 500 Hz for 10 seconds using dedicated hardware and software (Ballistic Measurement System, Fitness Technology, Skye, Australia). Vertical velocity of the center of mass of the system (subject’s body and the barbell) was calculated from vertical GRF-time data using forward dynamics approach (7, 10). Peak power output in a vertical component was calculated as the product of vertical GRF and vertical velocity of the center of mass of the system (7, 10). This test was performed twice, and the highest peak power value was used for statistical analysis. In statistical analyses, both absolute value and value relative to body mass were used.

Drop Jump. The force platform (Quattro Jump – Type 9290AD, Kistler, Switzerland) was used to measure the subject’s performance during the drop jump. The subjects were asked to step off a 40-cm box and jump immediately after the landing, aiming to produce the maximum height while minimizing ground contact time. During this jump movement, the subjects’ hands were kept on their hips. The force-time data from the force platform system were used to measure flight and contact time. Flight time was divided by contact time to determine the reactive strength index (RSI) (19). The subjects performed drop jump twice, and the highest RSI value was used for statistical analysis.

Jump and Reach. Jump and reach test was included as a representative measurement of athletic performance since this test involves more natural movement compared to the CMJ and SJ (14). The test was administered by using a yard stick (Yard Stick II, Swift Performance Equipment, Lismore, Australia). First, the standing reach height was established by having the subjects stand flat footed and reach up to displace the markers of the yard stick using the subjects’ preferred hand. Then, the subjects were asked to jump as high as possible by using countermovement and arm swing, and displace the markers of the yard stick. The jump height was obtained as the reach height subtracted from the height of the marker that the subject displaced. The subjects were allowed to repeat the jump and reach test until the subject achieved his maximal height (typically less than 5 times) and the highest jump height was used for statistical analysis.

1RM Half Squat. The subjects performed two types of half squat; half squat concentric only (1RM Sq Con) and from eccentric to concentric (1RM Sq Ecc-Con). Subjects were tested for 1RM Sq Con first, then the 1RM Sq Ecc-Con second. Between these tests, subjects rested for at least 5 minutes. At the start of 1RM Sq Con, the barbell was placed on the
safety bar of the power rack at the height of the bottom position of half squat (90° of knee flexion), and the subjects stood up from this position. In 1RM Sq Ecc-Con, barbell was placed on a power rack at approximately 10 cm below the subjects’ shoulder height at the beginning of the test. The subjects positioned themselves under the barbell, stood up, stepped a few steps back, squatted down (90° knee flexion) and stood up. The subjects’ feet position and grip width were self-selected. Subjects placed the barbell on their upper trapezius muscles immediately below C7. From the subjects’ familiarization sessions, the investigator estimated the subject’s 1RM. The subjects started the warm up with sets of 1-5 repetitions with the bar only (20 kg), added weight of 20–40 kg each set until the load became about 60% of estimated 1RM, then added 5–10 kg until the load was 90% of estimated 1RM. After these sets were completed, the weight was increased by 2.5 or 5 kg each set until their 1RM was determined. Subjects were allowed to take as much rest as they needed between sets to minimize the effects of fatigue. The heaviest weight that the subjects successfully lifted was determined as their 1RM. The value of 1RM Sq Ecc-Con at pretraining test was used to determine the load of weighted jump squat for their training. In statistical analyses, both absolute value and value relative to body mass were used.

**Weighted Jump Squat.** Subjects performed weighted jump squat with 30% of 1RM Sq Ecc-Con obtained at each test. In the weighted jump squat, subjects squatted down to a self-selected depth of approximately 90° of knee flexion, and jumped immediately as high as possible. The loads for this test were chosen to match the training protocol. The braking mechanism (Ballistic Braking System, Fitness Technology, Skye, Australia) was not attached to the barbell during this measurement. The subjects’ feet position, barbell position and grip width were the same as described at 1RM Sq Con and 1RM Sq Ecc-Con. Peak power output during the propulsive phase was obtained as described for CMJ and SJ. This test was performed twice, and the highest power output value was used for statistical analyses. In statistical analyses, both absolute value and value relative to body mass were used.

**Isometric and Isokinetic Knee Extension and Flexion.** The subject was positioned on an isokinetic dynamometer (Biodex, System 3 Pro & MVP Model #830 210, Shirley, NY). Subjects’ movements were restricted using torso, pelvic, thigh, and shin straps, and they held the handles to stabilize themselves. Seat position was set so that the subjects’ hip joint angle was 95°. Torque during isometric knee extension and flexion were measured in the following order: knee angle (full extension = 0°) at 90, 70, 50, 30 and 10° (at each position, extension was followed by flexion). Only the left leg was tested due to constraints of time and to avoid subject test fatigue. At each position, subjects produced a 3-second sub-maximal effort, and two 3-second maximal efforts with a 30-second rest between repetitions. During the maximal effort set, the subjects were instructed to push the immovable shin pad as hard as possible. The highest peak torque value at each position was used for statistical analysis. For isokinetic knee extension and flexion, the subjects were tested in the following order of angular velocity: 60, 180, 300°/s (concentric action), and −60°/s (eccentric action). Subjects performed one sub-maximal set of 3 repetitions for warm-up and one set of 3 repetitions with maximal effort at each angular velocity with 60-second rest between sets. During the maximal effort sets, the subjects were instructed to push the shin pad as hard and as rapidly as possible through the entire range of motion. The highest peak torque at each angular velocity was used for statistical analysis.

**Comparison of Force-Time Characteristics Between Two Conditions**
All subjects performed weighted jump squat in Braking and Non-Braking Conditions on the force platform (Quattro

### Table 2: Intra-class correlation coefficients and coefficients of variation of measurements.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>ICC</th>
<th>CV</th>
<th>Measurements</th>
<th>ICC</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ</td>
<td>0.97</td>
<td>2.2</td>
<td>IQ 30°</td>
<td>0.76</td>
<td>8.1</td>
</tr>
<tr>
<td>SJ</td>
<td>0.95</td>
<td>3.6</td>
<td>IH 30°</td>
<td>0.92</td>
<td>6.9</td>
</tr>
<tr>
<td>DJ</td>
<td>0.41</td>
<td>8.8</td>
<td>IQ 10°</td>
<td>0.71</td>
<td>8.4</td>
</tr>
<tr>
<td>J&amp;R</td>
<td>0.97</td>
<td>2.3</td>
<td>IH 10°</td>
<td>0.84</td>
<td>9.0</td>
</tr>
<tr>
<td>Sq Con</td>
<td>0.98</td>
<td>3.9</td>
<td>CQ 60°</td>
<td>0.84</td>
<td>6.0</td>
</tr>
<tr>
<td>Sq Ecc-Con</td>
<td>0.97</td>
<td>4.6</td>
<td>CH 60°</td>
<td>0.86</td>
<td>4.8</td>
</tr>
<tr>
<td>WJS</td>
<td>0.97</td>
<td>2.7</td>
<td>CQ 180°</td>
<td>0.83</td>
<td>6.4</td>
</tr>
<tr>
<td>IQ 90°</td>
<td>0.88</td>
<td>7.1</td>
<td>CH 180°</td>
<td>0.78</td>
<td>8.6</td>
</tr>
<tr>
<td>IH 90°</td>
<td>0.89</td>
<td>6.3</td>
<td>CQ 300°</td>
<td>0.86</td>
<td>6.0</td>
</tr>
<tr>
<td>IQ 70°</td>
<td>0.93</td>
<td>4.9</td>
<td>CH 300°</td>
<td>0.89</td>
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</tr>
<tr>
<td>IH 70°</td>
<td>0.89</td>
<td>6.7</td>
<td>EH 60°</td>
<td>0.92</td>
<td>5.9</td>
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<tr>
<td>IQ 50°</td>
<td>0.87</td>
<td>6.4</td>
<td>EQ 60°</td>
<td>0.84</td>
<td>7.6</td>
</tr>
<tr>
<td>IH 50°</td>
<td>0.94</td>
<td>6.0</td>
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</tbody>
</table>

**CMJ = countermovement jump; SJ = static jump; DJ = drop jump; J&R = jump and reach; Sq Con = 1RM squat concentric only; Sq Ecc-Con = 1RM squat eccentric to concentric; WJS = weighted jump squat; IQ = isometric quadriceps strength; IH = isometric hamstring strength; CQ = concentric quadriceps strength; CH = concentric hamstring strength; EH = eccentric hamstring strength.**
Jump – Type 9290 AD, Kistler, Switzerland). The subjects warmed up by riding a stationary bike for 5 minutes, and then performed weighted jump squat for 2 sets of 6 repetitions with maximum effort at the same load as used in the training intervention in each condition. The order of the two conditions was randomized. Prior to the maximum effort set, subjects completed several warm-up sets to adequately familiarize themselves with each different condition. Vertical GRF during maximum effort sets was sampled at a rate of 500 Hz for 15 s. Foot contact time, mean force, impulse, and impulse for the first 50 ms in 2nd to 6th jump of 2 maximum effort sets (10 foot contacts per subject) in each condition were averaged. While the 1st jump started from a static standing position, the 2nd to 6th jumps were performed consecutively immediately after landing from the previous repetition, thus the 1st jump was different from 2nd to 6th jumps. That is the rationale why the 2nd to 6th jumps were analyzed, but not the 1st jump. Impulse was calculated as the product of mean force and foot contact time. Impulse for first 50 ms has been considered as a measurement of the risk of injuries due to the landing impact (12,25), and that is why we included this measurement.

Statistical Analyses
To examine the reliability of test measurements, subjects (n = 20) were tested twice for all measurements a week before the pretraining tests, and intraclass correlation coefficients (ICC) and coefficients of variance (CV) were calculated (Table 2). To compare the effects of 2 different training interventions, group (NBG and BG) × time (pre- and posttraining) interactions were examined by using a repeated measures 2-way analysis of variance (ANOVA) for all dependent variables (n = 10 in each group). Paired samples t-tests were used to examine time effects pre- to posttraining intervention within each group (n = 10) as well as for the two groups pooled (n = 20). In addition, paired samples t-tests were used to compare the force-time characteristics, such as foot contact time, mean force, impulse, and impulse for first 50 ms for the Braking versus Non-Braking conditions (n = 20, since all subjects in both groups were tested). Criterion for significance was set at P ≤ 0.05 for all analyses.

Results
The majority of performance measures in jump tests (jump and reach, CMJ, SJ, weighted jump squat, and drop jump) and squat tests (IRM Sq Con and Sq Ecc-Con) exhibited significant improvement from pre- to postintervention for both BG and NBG, as well as for all subjects pooled together (Tables 3–6). However, very few of the isometric/isokinetic knee extension/flexion measurements exhibited any significant time effects.

There was a significant interaction between groups for three variables: peak power relative to body mass during weighted jump squat (Figure 2), peak torque during isometric knee extension at 10° (Figure 3) and peak torque during isokinetic concentric knee flexion at 300°/s (Figure 4) indicating a differential effect of the training stimuli.

Comparing the landing kinetics for the Non-Braking versus Braking conditions, there was no difference between foot contact time of the two conditions. However, mean force,

<table>
<thead>
<tr>
<th>Table 3. Jump tests (mean ± SD).</th>
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<tbody>
<tr>
<td>Group</td>
</tr>
<tr>
<td>CMJ (W)</td>
</tr>
<tr>
<td>BG</td>
</tr>
<tr>
<td>Pooled</td>
</tr>
<tr>
<td>CMJ</td>
</tr>
<tr>
<td>Relative</td>
</tr>
<tr>
<td>(W/kg)</td>
</tr>
<tr>
<td>SJ (W)</td>
</tr>
<tr>
<td>BG</td>
</tr>
<tr>
<td>Pooled</td>
</tr>
<tr>
<td>SJ</td>
</tr>
<tr>
<td>Relative</td>
</tr>
<tr>
<td>(W/kg)</td>
</tr>
<tr>
<td>WJS (W)</td>
</tr>
<tr>
<td>BG</td>
</tr>
<tr>
<td>Pooled</td>
</tr>
<tr>
<td>WJS</td>
</tr>
<tr>
<td>Relative</td>
</tr>
<tr>
<td>(W/kg)‡</td>
</tr>
<tr>
<td>DJ</td>
</tr>
<tr>
<td>BG</td>
</tr>
<tr>
<td>Pooled</td>
</tr>
<tr>
<td>J&amp;R (cm)</td>
</tr>
<tr>
<td>BG</td>
</tr>
<tr>
<td>Pooled</td>
</tr>
</tbody>
</table>

*Significant difference from pre (P < 0.05).
†Significant difference from pre (P < 0.01).
‡Significant interaction (P < 0.05).
NB = Non-Braking Group; BG = Braking Group; CMJ = countermovement jump; SJ = static jump; WJS = weighted jump squat; DJ = drop jump; J&R = jump and reach.
% changes are obtained as (post value – pre value)/pre value × 100.
impulse and impulse for first 50 ms in Non-Braking condition were significantly higher than Braking condition (Table 7). Typical examples of force-time curves during a foot contact in each condition (i.e., with and without eccentric braking) obtained from a representative subject are presented in Figure 5.

**DISCUSSION**

The purpose of this study was to compare the changes in strength, power, and athletic performance resulting from weighted jump squat training with and without eccentric braking applied. Further, to quantify the acute effects of the eccentric braking, force-time characteristics of landing were measured over a set of six weighted jump squats.

As we observed differential effects over time for the two conditions, the characteristics of the training stimuli will be discussed first. As presented in Table 7 and Figure 5, mean force, impulse, and impulse for first 50 ms were significantly lower for jumps performed with eccentric braking. This is a result of mechanically reducing the load during the eccentric phase by means of an electromagnetic braking mechanism. The effect is to reduce the preloading of the stretch shortening cycle and, as reported by Walshe et al. (27), which will reduce the total impulse and thus jump height achieved. As can be observed from Figure 5, the impact spike was effectively removed by the eccentric braking. Impulse for first 50 ms was also significantly reduced, and this supports previous research (12) suggesting that such systems may be effective for reducing injury risk. Changes in performance adaptations will now be discussed with reference to the kinetic differences between the two conditions.

When the two groups were pooled, there were significant improvements in all performance measures for jump and squat tests of between 3.5% and 13.3%, which is similar to other training studies involving weighted jump squats (15, 21). Interestingly, none of isometric or isokinetic measurements showed significant improvement. This most likely reflects the specificity of training in which weighted jump squat (multiple joint, closed kinetic chain task) is much more similar to the jump and squat tests than isometric/isokinetic knee extension/flexion (single joint, open kinetic chain task). Certainly, the weighted jump squat training did not transfer well to seated knee extension/flexion performance, even though training and testing involve the same muscle groups. The isometric/isokinetic knee extension/flexion testing was designed to tease out neuromuscular changes in the hamstrings and quadriceps resulting from training with Braking versus Non-Braking conditions and in particular eccentric and concentric strength changes as it was hypothesized that the training in Non-Braking condition would have much larger effect on eccentric strength. However, these tests appear unable to detect such specific adaptations to the training.

Despite these comments, there was significant interaction between groups in peak torque during isokinetic knee flexion at 300°/s (Figure 4). It could be speculated that exposure to the landing impact caused rapid hamstrings muscle action and this resulted in increased hamstrings contraction strength at the higher isokinetic velocity. Also, high force output at the beginning of the concentric phase might be another reason why NBG improved this measurement more than BG. Bobbert et al. (3) has discussed why jump height for CMJ is higher than SJ, and stated the higher force at beginning of concentric phase allows CMJ to achieve higher velocity at the end of concentric phase. Since force applied to ground at the beginning of concentric phase should be higher in NBG, thus the velocity at the take off might be higher in this group than BG. If these speculations were true, such rapid muscle action might strengthen the ability to exert high torque during high velocity activity in NBG. However, comparison between the two conditions in terms of angular velocity in hip and knee joints were not made in the present study, thus we cannot make more definitive conclusions.

If the above speculations are true, then a further question is why there was no group × time interaction in peak torque during knee extension at 300°/s. Since the action of weighted jump squat mainly consists of hip and knee extension, the fact there were no effects on knee extensor strength was...
results require us to reject this hypothesis and accept that at least in these relatively untrained subjects, reduced eccentric load does not inhibit neuromuscular adaptations.

The characteristics of stimuli were clearly different between the two conditions (Table 7 and Figure 5). As a result, we speculate slightly different mechanisms of adaptation. First, training in Non-Braking condition would enhance the strength at high velocity due to higher velocity than in Braking condition. Second, the training in Braking condition would enhance the strength at moderate/low velocity, and isometric condition due to higher contractile force output while the Non-Braking condition relies more on the power generated from stretch shortening cycle mechanisms.

To examine whether there was any difference between the adaptations to two different conditions, the present study included several combinations of the test measurements that emphasized different muscle actions (i.e., either concentric or eccentric actions). These combined measurements involved similar muscle groups, range of motion, and velocity, such as CMJ and SJ (Table 3), IRM Sq Con and SQ Ecc-Con (Table 4), and isokinetic knee extension and flexion in concentric action and eccentric action at 60°/s (Table 6). However, repeated measures 2-way ANOVA did not find significant time × group interaction in any of these measurements. It was hypothesized that BG would not improve CMJ, IRM Sq Ecc-Con, isokinetic eccentric knee extension, and flexion strength as much as NBG, due to the eccentric braking during the landing phase. However, the results require us to reject this hypothesis and accept that at least in these relatively untrained subjects, reduced eccentric load does not inhibit neuromuscular adaptations.

The characteristics of stimuli were clearly different between the two conditions (Table 7 and Figure 5). As a result, we speculate slightly different mechanisms of adaptation. First, training in Non-Braking condition would enhance the strength at high velocity due to higher velocity than in Braking condition. Second, the training in Braking condition would enhance the strength at moderate/low velocity, and isometric condition due to higher contractile force output than in Non-Braking condition. While the mechanism of adaptation might be different between groups, however, the present study could not detect the difference in adaptation

unexpected, although the hamstrings role as hip extensor is quite significant. It may be that quadriceps exhibit a higher trained level compared to hamstrings due to the more frequent use during daily activity, and that is why the training intervention in the present study resulted in changes in hamstring strength, but not quadriceps strength.

On the other hand, BG exhibited larger improvements in peak power relative to body mass during weighted jump squat and peak torque during isometric knee extension at 10° (Figures 2 and 3). In addition, it is noteworthy that there was significant improvement in power output during CMJ (both absolute and relative to body mass) in BG, but not in NBG. Possibly, this result was because reduced eccentric load requires greater muscle active force to produce the subsequent jump. Without braking, a subject can utilize the stretch shortening cycle more effectively. They attain a higher preload (Figure 5), and this facilitates the concentric phase

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre (Nm)</th>
<th>Post (Nm)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ 90°</td>
<td>BG 249.1 ± 48.7</td>
<td>242.5 ± 48.4</td>
<td>-2.6</td>
</tr>
<tr>
<td></td>
<td>NBG 221.2 ± 43.6</td>
<td>231.0 ± 41.0</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>Pooled 235.1 ± 47.2</td>
<td>236.8 ± 44.0</td>
<td>0.7</td>
</tr>
<tr>
<td>IH 90°</td>
<td>BG 89.6 ± 24.5</td>
<td>99.3 ± 28.4</td>
<td>10.8</td>
</tr>
<tr>
<td></td>
<td>NBG 90.2 ± 22.2</td>
<td>97.2 ± 22.2</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>Pooled 89.9 ± 22.9</td>
<td>98.3 ± 24.8</td>
<td>9.3</td>
</tr>
<tr>
<td>IQ 70°</td>
<td>BG 266.8 ± 64.6</td>
<td>261.2 ± 68.4</td>
<td>-2.1</td>
</tr>
<tr>
<td></td>
<td>NBG 232.6 ± 42.5</td>
<td>236.5 ± 48.4</td>
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</tr>
<tr>
<td></td>
<td>Pooled 249.7 ± 56.0</td>
<td>248.9 ± 59.0</td>
<td>-0.3</td>
</tr>
<tr>
<td>IH 70°</td>
<td>BG 105.2 ± 29.2</td>
<td>105.8 ± 22.5</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>NBG 100.2 ± 27.0</td>
<td>103.9 ± 25.7</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>Pooled 102.7 ± 27.5</td>
<td>104.9 ± 23.5</td>
<td>2.1</td>
</tr>
<tr>
<td>IQ 50°</td>
<td>BG 216.5 ± 48.4</td>
<td>202.1 ± 54.6</td>
<td>-6.7</td>
</tr>
<tr>
<td></td>
<td>NBG 192.7 ± 34.8</td>
<td>192.1 ± 32.0</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>Pooled 204.6 ± 42.8</td>
<td>197.1 ± 43.9</td>
<td>-3.7</td>
</tr>
<tr>
<td>IH 50°</td>
<td>BG 115.5 ± 32.7</td>
<td>116.1 ± 30.1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>NBG 107.4 ± 30.2</td>
<td>115.2 ± 33.9</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>Pooled 111.4 ± 30.9</td>
<td>115.6 ± 31.2</td>
<td>3.8</td>
</tr>
<tr>
<td>IQ 30°</td>
<td>BG 149.0 ± 28.3</td>
<td>141.5 ± 30.0</td>
<td>-5.0</td>
</tr>
<tr>
<td></td>
<td>NBG 138.7 ± 24.4</td>
<td>139.6 ± 22.3</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Pooled 143.9 ± 26.3</td>
<td>140.5 ± 25.7</td>
<td>-2.4</td>
</tr>
<tr>
<td>IH 30°</td>
<td>BG 122.9 ± 32.2</td>
<td>121.7 ± 30.4</td>
<td>-1.0</td>
</tr>
<tr>
<td></td>
<td>NBG 118.3 ± 29.3</td>
<td>122.5 ± 30.1</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>Pooled 120.6 ± 30.0</td>
<td>122.1 ± 29.4</td>
<td>1.2</td>
</tr>
<tr>
<td>IQ 10°</td>
<td>BG 85.0 ± 16.6</td>
<td>81.8 ± 15.6</td>
<td>-3.8</td>
</tr>
<tr>
<td></td>
<td>NBG 70.0 ± 10.4</td>
<td>77.2 ± 12.9*</td>
<td>10.3</td>
</tr>
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<td></td>
<td>Pooled 77.5 ± 15.6</td>
<td>79.5 ± 14.2</td>
<td>2.6</td>
</tr>
<tr>
<td>IH 10°</td>
<td>BG 122.5 ± 33.4</td>
<td>125.1 ± 28.1</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>NBG 118.6 ± 24.3</td>
<td>124.1 ± 28.3*</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>Pooled 120.5 ± 28.5</td>
<td>124.6 ± 27.4</td>
<td>3.4</td>
</tr>
</tbody>
</table>

*Significant difference from pre (P < 0.05).
†Significant interaction (P < 0.05).
NBG = Non-Braking Group; BG = Braking Group; IQ = Isometric quadriceps strength; IH = Isometric hamstring strength.

% changes are obtained as (post value – pre value)/pre value × 100.
except for three variables (i.e., power output relative to body mass during weighted jump squat, isometric peak torque during knee extension at 10°, and isokinetic concentric knee flexion at 300°/s). In the present study, subjects trained for only 8 weeks. However, it could be possible to detect separation in training effect if the period of training intervention was longer. Realistically, practitioners prescribe training programs based on the theory of periodization (24). Thus, exercise, volume and intensity are altered every mesocycle in a given macrocycle, but a similar mesocycle is usually repeated in subsequent macrocycle in a cyclic manner (24). It is highly unlikely that practitioners prescribe exactly the same type of training more than two consecutive mesocycles in a given macrocycle, but a similar mesocycle is usually repeated in subsequent macrocycle in a cyclic manner (24). Thus, it is important to note that athletes in the practical setting might exhibit more specific adaptation to the two different conditions of weighted jump squat training over the longer term (i.e., over several mesocycles, typically multiple years).

In the present study, 8 weeks of weighted jump squat training resulted in significant improvements in 1RM half squat measurements (5.2–7.0%) and 9.3–12.6% in NBG and BG (Table 4). This finding supports McBride et al. (15) which used a similar training protocol. In general, it is believed the training modality emphasizing power is not really effective to enhance maximum strength, and that is why practitioners need to take account of both maximum strength and power in their programs (19, 20, 21, 28). However, if the trainee does not have a background of resistance training, then introduction of such exercise represents a novel stimulus and possibly will enhance multiple strength qualities concurrently. This finding would be useful information for practitioners working for developmental level athletes. Although there was no statistical significance of group × time interaction, there was a tendency for BG to improve 1RM half squat more than NBG. It is suggested that this due to the same reasons why NBG improved power output during weighted jump squat and peak torque during isometric knee extension. The reduced eccentric load and thus inhibited stretch shortening cycle required greater reliance on contractile force development and thus increased stimulus to strength development.

The results for the drop jump should be discussed with caution (Table 3) as reliability of this measurement was not high (ICC = 0.41, Table 2). However, a previous study involving highly trained athletes (21) reported this test was reliable (ICC > 0.99). The reason why drop jump test in the present study was so unreliable could be due to the subjects’ limited drop jump training background. Unlike trained volleyball players, the subjects in the present study had not experienced the task such as “develop maximum jump height with minimal ground contact” in their normal activities. Thus, to examine the true effect of the weighted jump squat training with and without eccentric braking on drop jump performance, future studies need to involve subjects more accustomed to this test.

To our knowledge, the study reported by Hoffman et al. (9) is the only study thus far on this topic. They compared the effects of weighted jump squat training with and without eccentric braking on strength, power, and athletic

<table>
<thead>
<tr>
<th>Table 6. Isokinetic strength tests (mean ± SD).</th>
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<tr>
<td>Group</td>
</tr>
<tr>
<td>CQ 60°/s (Nm)</td>
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<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td>CH 60°/s (Nm)</td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>CQ 180°/s (Nm)</td>
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<td></td>
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<tr>
<td></td>
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<tr>
<td>CH 180°/s (Nm)</td>
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<tr>
<td>CQ 300°/s (Nm)</td>
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<td>CH 300°/s (Nm)</td>
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<td>EH 60°/s (Nm)</td>
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<tr>
<td>EQ 60°/s (Nm)</td>
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</tbody>
</table>

*Significant difference from pre ($P < 0.05$).
†Significant difference from pre ($P < 0.01$).
‡Significant interaction ($P < 0.05$).
NB = Non-Braking Group; B = Braking Group; CQ = concentric quadriceps strength; CH = concentric hamstring strength; EQ = eccentric quadriceps strength; EH = eccentric hamstring strength.
% changes are obtained as (post value – pre value)/pre value × 100.
and reported that the weighted jump squat without the braking was more effective than that with the braking to improve 1RM power clean and squat. In the present study, improvement in 1RM half squat measurements in NBG was not superior to BG, so our results do not support that of Hoffman et al. (9). However, it is difficult to directly compare these two studies since there are marked differences such as: i) the subjects in Hoffman et al. (9) were highly trained football players while the subjects in the present study were untrained students; ii) the training intervention in Hoffman et al. (9) was combined with normal football strength and conditioning program while
subjects in the present study did not participate in any competitive sport training; iii) the movement of weighted jump squat performed in Hoffman et al. (9) was controlled by machine while the subjects in the present study used free weights and controlled their movement using their synergist and antagonist muscle groups; and iv) The subjects in Hoffman et al. (9) used 70% of 1RM load while subjects in the present study used 30% of 1RM load. Some or all of these factors may explain the different results to that of Hoffman et al. (9) and the present study. Particularly, if one training mode is combined with other types of training, the adaptation of combined training modes could be different from the one training mode alone (1, 8, 20). Since weighted jump squat training is often combined with other types of resistance-training exercises such as traditional weight-training exercises (e.g., squat, power clean) and plyometric exercises in the practical setting (9), it is not definitive that the finding of the present study can be directly applied to the practical setting. Hence, future studies bridging the gap between controlled laboratory based experiments and realistic training scenarios are warranted.

In summary, this study compared the effects of two different conditions of weighted jump squat training, with and without an eccentric braking mechanism. The force-time characteristics of the exercise were markedly different with regard to mean force, impulse and impulse for first 50 ms, and this explains the differential training effects. Interestingly, while isometric strength (peak torque during isometric knee extension at 10°) and power output during relatively slow movement (weighted jump squat) improved more in BG, strength at high velocity (peak torque during isokinetic knee flexion at 300°/s) improved more in NBG. It is speculated that the use of the braking mechanism during eccentric phase decreases velocity of the movement but emphasizes contractile force production during concentric phase of weighted jump squat. This further supports the highly specific nature of training adaptation.

**Practical Applications**

In the position statement from National Strength and Conditioning Association (18), it is documented that “only athletes who have already achieved high levels of strength through standard resistance training should engage in plyometric drills.” Since weighted jump squat training without eccentric braking has similar characteristics to plyometric drills (i.e., utilization of stretch shortening cycle and absorption of high landing impact), practitioners should carefully consider the training background of athletes and whether the athletes would tolerate the landing impact during the weighted jump squat. While the subjects in the present study tolerated the 30% of 1RM half squat load without any injuries, one must remember this load is not necessarily safe for everybody if weighted jump squat is performed without eccentric braking. Particularly for competitive athletes playing sports with chronic injuries, even 30% of 1RM half squat load may possibly aggravate their injuries. Therefore, practitioners should consult with their medical staff and monitor the athletes closely especially when they first introduce weighted jump squat training without eccentric braking. If any symptoms of injuries appear, such athletes should either reduce loads or utilize eccentric braking. Humphries et al. (12) suggested the
possible risk of injuries due to the landing impact in weighted jump squat without eccentric braking, and encourage use of the braking mechanism to reduce eccentric load during landing phase for injury prevention and these findings are supported by the current study. Thus, until athletes acquire a certain level of strength, practitioners should consider reducing eccentric loading during landing phase by using braking mechanisms or other training modifications as it appears that comparable improvements in jump performance are attained, at least over a relatively short 8-week period. Then, once the athletes attain a certain level of strength, practitioners may select the training mode to meet their training purposes. On one hand, during the general preparation phase, weighted jump squat with a braking mechanism may cause larger adaptation in strength at low/moderate velocity. On the other hand, during the specific preparation phase, weighted jump squat without a braking mechanism may cause larger adaptation in strength at high velocity. Once a practitioner decides to introduce weighted jump squat without eccentric braking, it would be wise to start with light loads and allow the athletes to adapt to this new stimulus. Baker and Nance

![Figure 5. Force-time curves during a foot contact in each condition.](image)

<table>
<thead>
<tr>
<th>Table 7. Foot contact time, mean force and impulse.</th>
<th>Non-braking condition</th>
<th>Braking condition</th>
<th>% Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot contact time (s)</td>
<td>0.79 ± 0.10</td>
<td>0.81 ± 0.11</td>
<td>2.5</td>
</tr>
<tr>
<td>Mean force (N)*</td>
<td>1660 ± 247</td>
<td>1494 ± 188</td>
<td>-10.0</td>
</tr>
<tr>
<td>Impulse (Nm)*</td>
<td>1301 ± 165</td>
<td>1196 ± 165</td>
<td>-8.1</td>
</tr>
<tr>
<td>Impulse for first 50 ms (Nm)*</td>
<td>35.6 ± 8.5</td>
<td>23.2 ± 6.4</td>
<td>-34.8</td>
</tr>
</tbody>
</table>

*Significant difference \( P < 0.01 \).

% differences are obtained as (Non-Braking condition – Braking condition)/Non-Braking condition × 100.
(2) suggested there should be a minimal risk of injuries due to this form of exercise as long as the application of overload is gradual and progressive. For example, if an athlete’s 1RM half squat is 200 kg, the practitioner may spend the first few sessions with 20 kg, another few sessions with 40 kg, and then increase the load up to 60 kg (i.e., 30% of 1RM).

ACKNOWLEDGMENTS

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REFERENCES