

A Comparison of the Effects of a Six-Week Traditional Squat and Suspended Load Squat Program in Collegiate Baseball Players on Measures of Athletic Performance

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ABSTRACT

Background: Acute studies suggest that resistance training with an unstable load suspended from the barbell increases core muscle activation with negligible detrimental effects on phasic muscle activation and force production compared to traditional barbell loading, but the effect of a suspended load program on athletic performance is unclear. **Objective:** The purpose of this study was to assess the effect of a six-week program where the back-squat was performed with a suspended load (SL) on vertical jump (VJ), change of direction ability (COD), single-leg balance, and one repetition maximum squat load (1RM). **Methods:** Thirty-two collegiate baseball players (20.4 ± 1.4 y, 86.0 ± 11.0 kg, $1.82 \pm .065$ m) were assigned to perform the back-squat with SL or traditional loading (CON). Additional exercises were done with traditional loading. Athletes completed VJ, T-tests to measure COD, star excursion balance test (SEBT) to measure single-leg balance, and 1RM PRE and POST program. A MANOVA was used to assess the dependent variables. Significance was set to $p < .05$. **Results:** Effect of group \times time ($p = .152$) and group ($p = .095$) were not significant, indicating CON and SL had similar performance. Effect of time ($p < .0001$) was significant, suggesting POST performance improved relative to PRE. When groups were pooled, 1RM ($p < .0001$) and T-test ($p = .038$) improved, but VJ ($p = .255$) and SEBT ($p = .167$) did not improve. **Conclusion:** Performing squats with SL does not appear to be detrimental to development during a six-week program.

Key words: Resistance Training; Athletes; Baseball; Exercise; Muscle Strength; Athletic Performance

INTRODUCTION

Baseball players use a variety of exercise training programs designed to enhance skeletal muscle strength and size, motor programming, and sport specific skill. Evaluating the effectiveness of these programs is of great importance in the pursuit of maximized potential. While the foundation of a well-designed training program is generally agreed upon, a number of variations exist in the dose (e.g. frequency, intensity, volume) and mode of exercise (Ebben, Hintz, & Simenz, 2005; Medicine, 2009; Peterson, Rhea, & Alvar, 2004). Multi-joint exercises that target phasic muscle groups (e.g. hip extensors, knee extensors, knee flexors) are a staple of a well-designed training program (Medicine, 2009; Peterson et al., 2004). In fact, Major League Baseball (MLB) strength and conditioning professionals indicate that the squat, or variations of it, is anecdotally the most important exercise in their programs (Ebben et al., 2005).

Optimal athletic performance greatly depends on the ability to produce, transfer, and control force and motion from one bodily segment to the next as well as to attenuate perturbations and maintain an upright trunk posture (Kibler,

Press, & Sciascia, 2006; Sciascia, Thigpen, Namdari, & Baldwin, 2012; Yaggie & Campbell, 2006). This is particularly relevant in baseball because produced ground reaction forces are sequentially transferred to the terminal segment directing the force output to the ball or bat (Sciascia et al., 2012). Enhancement of these skills may be achieved through improved strength and coordination of the core skeletal muscles, which are comprised of the abdominal, oblique, gluteal, paraspinal, diaphragm, pelvic floor, and hip girdle (Bressel, Yonker, Kras, & Heath, 2007; Huxel Bliven & Anderson, 2013; Kibler et al., 2006; Willardson, 2007). Literature has suggested that strong core musculature creates a solid foundation for upper- and lower-extremity limb movement (Anderson & Behm, 2005; Behm & Anderson, 2006; Behm, Drinkwater, Willardson, & Cowley, 2010; Huxel Bliven & Anderson, 2013; Willardson, 2007).

Completing resistance training in unstable conditions, termed instability resistance training (IRT), may challenge the neuromuscular and neurovestibular systems and promote core skeletal muscle activation during whole body movements (Behm et al., 2010; Kibele & Behm, 2009; Willardson,

2007; Yaggie & Campbell, 2006). Studies have demonstrated that core skeletal muscle is activated to a greater degree during IRT when standing, sitting, or laying down on unstable surfaces compared to stable surfaces when the load or intensity is matched (Campbell, Kutz, Morgan, Fullenkamp, & Ballenger, 2014; Schwanbeck, Chilibeck, & Binsted, 2009). Although, IRT on unstable surfaces typically requires a substantially lower load for the safe completion of the exercise leading to reduced force generation and activation of phasic skeletal muscles. McBride, Cormie, and Deane (2006) revealed that ground reaction force and activation of knee extensor muscles was reduced ~45% and ~35%, respectively, when the squat was performed on an unstable surface compared to a stable surface (McBride, Cormie, & Deane, 2006). Despite this, some training studies have demonstrated that IRT on unstable surfaces may lead to similar performance improvements in untrained individuals compared to stable surfaces (Kibele & Behm, 2009; Sparkes & Behm, 2010). The magnitude of improvement may be linked to training status as it has been suggested that trained individuals may already possess the necessary stability (Wahl & Behm, 2008). In fact, a study using highly trained athletes revealed that training on unstable surfaces may blunt performance improvements (Cressey, West, Tiberio, Kraemer, & Maresh, 2007).

Perhaps a more externally applicable IRT training program for baseball players utilizes an unstable load instead of an unstable surface (Fletcher & Bagley, 2014; Kohler, Flanagan, & Whiting, 2010; Langford, McCurdy, Ernest, Doscher, & Walters, 2007; Lawrence & Carlson, 2015; Lee & Lee, 2002). This may relate better to athletics because the source of instability is in the load rather than the base of support. Squats performed in a traditional sense with a barbell is one example of an exercise with an unstable load, as the barbell is free to move in multiple planes. Investigations have demonstrated that squats performed with a barbell elicit greater phasic and core skeletal muscle activation compared to squats performed with the barbell allowed to move in only a single fixed plane (e.g. Smith machine) (Anderson & Behm, 2005; Fletcher & Bagley, 2014; Schwanbeck et al., 2009). Some strength and conditioning professionals have taken the unstable load a step forward by allowing the lifted object's mass to accelerate randomly during a squat (Cullen-Carroll, Larson, & Campbell, 2017; Fletcher & Bagley, 2014; Lawrence & Carlson, 2015). This is achieved by suspending a portion of the mass from the freely moveable barbell using straps or springs. These investigations have revealed that this stability challenge leads to greater core skeletal muscle activation compared to performing squats without a suspended load (Fletcher & Bagley, 2014; Lawrence & Carlson, 2015). More importantly, acute studies have suggested that this type of IRT leads to only small reductions in peak ground reaction force (Lawrence & Carlson, 2015) and potentially no change in the load lifted (Fletcher & Bagley, 2014) compared to traditional barbell squats. These acute response studies would suggest that chronic training programs using a suspended load may lead to similar improvements in phasic skeletal muscle strength and greater improvements in core

stability; though, the chronic effects of a training program of this nature has not been investigated substantially. To our knowledge, only a single study has investigated the chronic effects of a suspended load program on measures of athletic performance. Cullen-Carroll, Larson, and Campbell (2017) used a small sample of trained individuals and revealed that three repetition back-squat maximum load (3RM) improved similarly for those using suspended load after nine resistance exercise sessions over about 2.5 weeks compared to traditional barbell loading (Cullen-Carroll et al., 2017). Additional training studies using a larger sample and a longer program duration are needed to assess the chronic effect of training with a suspended load on measures of athletic performance. This will improve the strength and conditioning community's understanding of the effects of IRT programs using an unstable load on common measures of athletic performance, which may aid in practically applying these programs to athletes

Accordingly, the purpose of the present study was to determine the effects of performing the back-squat exercise using a suspended load (SL) compared to traditional barbell loading (CON) during a six-week resistance training program on measures of athletic performance including vertical jump (VJ), T-test, star excursion balance test (SEBT), and back-squat one repetition maximum load (1RM) in collegiate male baseball student-athletes. It was hypothesized that SL would elicit greater improvements in VJ, T-test, and SEBT compared to CON, and that 1RM improvements would be similar between SL and CON.

METHODS

Study Design

This randomized, experimental training study was designed to assess the effect of offseason, six-week SL and CON training programs on VJ, T-test, SEBT, and 1RM. Athletes' were assessed before the six-week program (PRE). Athletes were prescribed identical six-week resistance training programs, with the exception of loading type (e.g. SL or CON) during the back-squat exercise. All other exercises in the program were performed with traditional loading. Athletes' VJ, T-test, SEBT, and 1RM performance were re-assessed at the conclusion of the six-week program (POST).

Participants

Thirty-two male collegiate baseball players (20.4 ± 1.4 y, 86.0 ± 11.0 kg, $1.82 \pm .065$ m) playing in the North Star Athletic Association of the National Association of Intercollegiate Athletics participated in this interventional study. A sample size calculation was not conducted as this was a convenience sample of baseball players on a single team. Athletes were randomly assigned into SL ($n = 16$) or CON ($n = 16$). This sample was chosen because all the athletes had a minimum of eight-weeks of resistance training experience with the university coaching staff, and they recently completed an eight-week training period focused on muscular endurance and hypertrophy. Athletes were excluded from the study

if they were 17 years old or younger, could not complete testing, or were withheld from athletics participation at the time of enrollment by university athletic training staff. Athletes who attended less than 80% of the training sessions were also excluded from analyses. The North Dakota State University Institutional Review Board approved all aspects of this study prior to any data collection. In accordance with the use of human subjects in research policies, all athletes were informed about the experimental procedures, risks, and benefits, before providing their informed, written, voluntary consent to participate.

Procedures

Athletes had their height, mass, age, year in school, years of participation in a college athletic program, and years of resistance training experience recorded. PRE was conducted over two consecutive, two-hour days beginning four days prior to starting the six-week training program. On the first day of testing, athletes completed a five-minute warm-up consisting of light aerobic activity, dynamic stretching, and plyometric exercises followed by VJ, T-test, and SEBT testing.

The athletes lower-extremity impulse generation ability was assessed using VJ (Haff & Triplett, 2015). Athletes had their vertical reach assessed (VERTEC, Sports Imports, Hilliard, OH, USA) and then performed three VJ trials with a countermovement and arm swing. The greatest achieved jump height was recorded. VJ was calculated as the difference between the greatest achieved jump height and vertical reach. Athletes' change of direction (COD) ability was assessed using the T-test (Haff & Triplett, 2015). The T-test was timed using a timing system with a single photocell (Brower Speed Trap 2, Brower Timing Systems, Draper, UT, USA). Three cones were placed on a line 4.6 m from one another. A fourth cone was placed 9.1 m from the middle cone creating a "T". The athletes started at the bottom of the "T" in a two-point stance. The athletes sprinted 9.1 m to the middle cone, laterally shuffled 4.6 m to the right cone, laterally shuffled 9.1 m to the far-left cone, laterally shuffled 4.6 m to the right to the middle cone, and then backpedaled 9.1 m through the start cone to finish. Two T-test trials were completed and the fastest time of two trials was recorded.

Athletes' single-leg balance was assessed using the three-trial, four-direction SEBT (Demura & Yamada, 2010). Two intersecting, perpendicular lines were marked on the ground. Athletes were given three minutes of practice to familiarize themselves to the SEBT protocol before formal testing. Athletes stood shod with the middle of the plantar surface of the shoe on the center of the intersection on their dominant leg, which was determined as the leg they would kick a soccer ball with. Athletes then reached with the contralateral leg for three consecutive trials in the anterior, medial, posterior, and then lateral direction. The trial was discarded and repeated if the athletes' stance leg moved, reach foot fully touched the floor, or they failed to return to the starting position. Reach distance for each trial was marked and measured from the center of the intersection. The furthest reach in each direction was recorded and normalized as a percentage of leg length, which was measured

from the anterior superior iliac spine to the medial malleolus (Gribble & Hertel, 2003). The sum of the four normalized scores was used to create a single SEBT score (Bressel et al., 2007).

On the second PRE testing day, athletes completed the same five-minute warm-up followed by 1RM testing using standard 1RM testing protocols (Haff & Triplett, 2015). The athletes were monitored to ensure that they used proper technique and achieved sufficient squat depth, which was defined as the longitudinal axis of the thigh reaching a position that was at least parallel to the floor. Athletes incrementally increased the load over approximately five to eight single repetition attempts with at least three minutes of rest between attempts until failure to perform the squat with good technique and a parallel thigh position was reached. The greatest load in kg lifted correctly was used as a measure of 1RM. This load was then normalized to their body mass ($\text{kg}\cdot\text{kg}^{-1}$). POST was conducted over two consecutive, two-hour days beginning three days after the completion of the six-week training program using methodology identical to PRE.

The athletes were not participating in any other practice or training sessions during the six-week resistance training program. Athletes were randomized into SL and CON, which were matched based on the years of participation in a college athletic program. The six-week resistance training program used in this study was focused on general strength improvement. The program consisted of a two-day, upper- and lower-body split design with four training days per week (e.g. lower-body, upper-body, rest, lower-body, upper-body, rest, rest). Each resistance training session consisted of approximately 15 minutes of warm-up similar to the one that was completed prior to PRE and POST which included mobility exercises, 15 minutes of various speed, power, and agility drills, 45 to 60 minutes of resistance training (Table 1 and 2), and 15 minutes of flexibility training. The six-week program was divided into two, three-week microcycles. In the second microcycle, the program consisted of a lower number of repetitions per set and greater the number of sets compared to the first microcycle.

For the duration of the six-week training program, SL performed the back-squat exercise using non-elastic Stump Straps (Spud, Inc., Columbia, South Carolina, USA) to suspend all the weight plates from a standard ~20.4 kg barbell. This meant that the proportion of the load that was considered unstable was the mass of the weight plates used divided by the total mass of the weight plates and barbell combined. CON performed the back-squat exercise with traditional loading of weight plates on the barbell throughout the six-week training program. This difference in loading was only applied in the back-squat exercise. All additional exercises within the program were performed with identical traditional loading by both groups. Load was not prescribed relative to the athlete's 1RM assessed at PRE. Athletes were instructed to use a load that allowed them to complete the exact number of prescribed repetitions within a set, which observationally increased during the six-weeks. In theory, this meant that the athletes in SL and CON completed each resistance exercise including the squat with the same degree of maximal effort.

Table 1. Resistance training program for weeks 1-3. The control group (CON) performed the squat exercise with traditional barbell loading and the suspended load group (SL) performed it with the plates suspended from the barbell using non-elastic straps. All other exercises were performed with traditional loading, if applicable

Exercise	Sets	Repetitions
Monday		
Squat	4	4
Sumo Deadlift	4	6
Single-Leg Squat	3	6 each leg
Romanian Deadlift	3	6
Side Lunge	2	15 each leg
3-Way Shoulder Raise	3	10
Tuesday		
DB Bench Press	4	6
Pullups	3	Maximal
Pushup Combination	3	5 clap + 15
Barbell Rows	3	8
Dips	3	8
DB Rows	3	10
Thursday		
Deadlift	3	3
Squat	4	6
DB Single-Leg Romanian Deadlift	3	8 each leg
2-Way Lunge	3	10 each leg
Side Lunge	2	15 each leg
3-Way Shoulder Raise	3	10
Friday		
Pullups	4	Maximal
DB Incline Bench Press	3	8
Inverted Rows	3	Maximal
Pushup Combination	3	5 clap + 15
DB Rows	3	8
Dips	3	10

DB = Dumbbell.

Statistical Analysis

A statistics program (IBM SPSS Statistics for Windows v. 26, Armonk, NY, USA) was used to calculate descriptive statistics including means, standard deviations, mean difference from PRE to POST in CON and SL, and relative mean difference PRE to POST in CON and SL. The dependent variables of this study were VJ, T-test, SEBT, and 1RM. Q-Q plots were used to assess the normality of the data and Box's Test (Box's $M = 54.296$, $p = .360$) was used to assess the equality of the covariance matrices. A repeated measures multivariate analysis of variance (RM-MANOVA) was used to assess the between-subject effect of group (e.g. SL and CON) and the within-subject effects of time (e.g. PRE and POST). Bonferroni-adjusted post-hoc tests were used when

Table 2. Resistance training program for weeks 4-6. The control group (CON) performed the squat exercise with traditional barbell loading and the suspended load group (SL) performed it with the plates suspended from the barbell using non-elastic straps. All other exercises were performed with traditional loading, if applicable

Exercise	Sets	Repetitions
Monday		
Squat	4	3
Sumo Deadlift	4	5
Single-Leg Squat	4	4 each leg
Romanian Deadlift	4	6
Side Lunge	2	15 each leg
3-Way Shoulder Raise	3	12
Tuesday		
DB Bench Press	4	4
Pullups	4	Maximal
Pushup Combination	4	D/S/S/R
Barbell Rows	4	6
Dips	4	8
DB Rows	4	8
Thursday		
Deadlift	4	3
Squat	4	5
DB Single-Leg Romanian Deadlift	4	8 each leg
2-Way Lunge	4	5 each leg
Side Lunge	2	15 each leg
3-Way Shoulder Raise	4	12
Friday		
Pullups	4	Maximal
DB Incline Bench Press	4	6
Inverted Rows	4	Maximal
Pushup Combination	3	D/S/S/R
DB Rows	4	6
Dips	4	10

DB = Dumbbell, D/S/S/R = Diamond, Staggered Right Hand in Front, Staggered Left Hand in Front, Regular.

appropriate to identify the source of the effect. Significance was set to $p < .05$.

The smallest worthwhile change (SWC) is a representation of the smallest performance enhancement needed for that enhancement to be considered athletically meaningful (Hopkins, Hawley, & Burke, 1999). The SWC was calculated utilizing the pooled PRE VJ, T-test, SEBT, and 1RM from both groups using the an equation with the between player SD of each player's average performance and a small standardized change in the mean equal to 0.20 (Cohen, 1992): $SWC = \text{pooled between-athlete SD} \times 0.20$. Theoretically, a standardized improvement in time equal to 0.20 would move a player with a performance identical to the cohort mean from the 50th percentile to the 58th percentile (Hopkins

et al., 1999). When the observed improvement exceeds the SWC, the improvement may be considered “athletically meaningful”. Relative smallest worthwhile change (SWC%) was calculated by dividing the SWC by the pooled mean for both groups.

RESULTS

The RM-MANOVA did not demonstrate a significant time by group interaction ($F(4,27) = 1.830, p = .152, \eta^2 = .213$), suggesting that there was no evidence that the effect of time on athletic performance was not dependent on group (Figure 1). A significant effect of group was also not identified ($F(4,27) = 2.207, p = .095, \eta^2 = .246$), which means there is no evidence of a difference in athletic performance between CON and SL when the factor for group is adjusted for the factor of time.

The RM-MANOVA did reveal a significant effect of time ($F(4,27) = 7.620, p < .0001, \eta^2 = .530$), which indicates that there is evidence of a difference in athletic performance between PRE and POST when the factor for time is adjusted for the factor of group. Post-hoc tests revealed that when the results were pooled for both groups, the cohort improved their 1RM (.102 kg·kg⁻¹ [.060, .143], $p < .0001$) and T-test (-.110 s [-.007, -.214], $p = .037$), but did not improve their VJ (.0052 m [-.0034, .0137], $p = .229$) or SEBT (5.44 % [-2.41, 13.30], $p = 0.170$). The performances on each test pooled by group also revealed that the improvement from PRE to POST

in 1RM and T-test were athletically meaningful because the mean improvement exceeded the SWC, while the improvement in VJ and SEBT were not athletically meaningful (Table 3).

Table 3. Absolute and relative mean change in performance compared to smallest worthwhile change (SWC) for the vertical jump (VJ), T-test, star excursion balance test (SEBT), and back-squat 1 repetition maximum (1RM) for the suspended load (SL) and control (CON) group, and the pooled by group mean (POOLED)

Test	SL	CON	POOLED	SWC
Absolute				
VJ	0.014 m	-0.004 m	0.005 m	±0.017 m
T-test	-0.118 s	-0.102 s	-0.110 s *	±0.082 s
SEBT	2.39 %	8.50 %	5.44 %	±5.99 %
1RM	10.1 kg	6.96 kg	8.50 kg *	±5.33 kg
Relative				
VJ	2.23%	-0.69%	0.85%	±2.73%
T-test	-1.22%	-1.03%	1.11% *	±0.82%
SEBT	0.59%	2.09%	1.36%	±1.50%
1RM	6.50% *	4.29% *	5.67% *	±3.54%

* significant improvement from pre to post six-week training program, $p < .05$. VJ = vertical jump; SEBT = start excursion balance test; 1RM = back-squat 1 repetition maximum; SL = suspended load group; CON = control group; POOLED = suspended load and control group pooled.

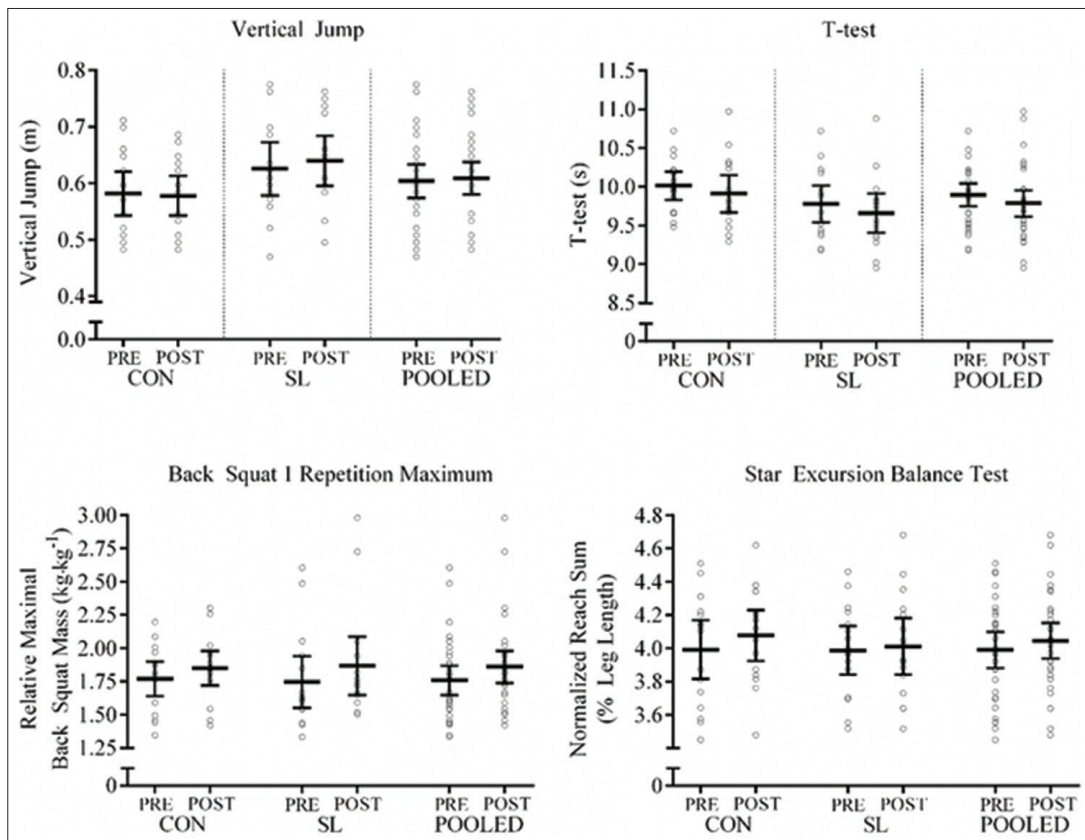


Figure 1. Performance results for the vertical jump, T-test, star excursion balance test, and back-squat 1 repetition maximum for suspended load (SL) and control (CON) group, and the pooled groups (POOLED) prior to (PRE) and after (POST) the completion of a six-week training program. Clear circles: individual athletes. Whiskers: 95% confidence interval. Center bar: mean

DISCUSSION

Baseball players use a wide variety of training methods, and as they continually strive to maximize their performance, it is important to assess available training methods. SL may be the ideal mode of IRT because the degree of instability is large enough to elicit greater activation of core skeletal muscles, yet low enough to allow for greater training loads, phasic skeletal muscle activation, and force production (Behm & Anderson, 2006). The purpose of the present study was to assess the effects of SL and CON during a six-week resistance training program on VJ, T-test, SEBT, and 1RM in collegiate male baseball student-athletes. It was hypothesized that SL would elicit greater improvements in VJ, T-test, and SEBT compared to CON, and that 1RM improvements would be similar between SL and CON. Important findings from this study are that athletic performance improved from PRE to POST and that the improvement in 1RM and T-test were athletically meaningful; however, the type of program did not influence these improvements because SL and CON responded similarly to the six-week training program.

Similar performances between groups may have occurred because the program included speed, power, and agility training and additional lower- and upper-body resistance exercises without SL. Thus, the adaptations produced by the programs performed by SL and CON may have been relatively similar when all stimuli are considered. A greater effect of SL may have been observed if more exercises were performed with SL or if back-squat was the only exercise performed during the entire training program; though, the real-world feasibility of implementing a training program of that nature is questionable. Nevertheless, the back-squat is considered a highly important exercise in a well-designed strength and condition program for baseball players (Ebben et al., 2005) and the results of this study suggest that altering the way the barbell is loaded by using SL does not blunt athletic performance improvement in a progressive program compared to CON. This is encouraging for strength and conditioning professionals that consider using this type of loading in their programming. Incorporating SL into the program may provide an additional means of variation, and athletically meaningful improvements in athletic performance can still occur in six weeks.

The similar improvement in 1RM by both SL and CON may indicate that the instability created by SL did not reduce training loads, phasic skeletal muscle activation, and force production below a threshold that would inhibit neuromuscular strength development and, in turn, 1RM improvement. A previous acute response study indicated that 1RM using a suspended load was surprisingly ~10 kg greater than when using traditional loading in untrained males (Fletcher & Bagley, 2014). This may have also been revealed in the present study had it been assessed. The present findings also agree with a previous training study that demonstrated in a small sample of trained individuals that 3RM improved similarly for those using suspended load after nine resistance exercise sessions over ~2.5 weeks compared to traditional loading (Cullen-Carroll et al., 2017). Furthermore, a previous acute response investigation demonstrated that peak

ground reaction forces were only reduced ~3% when using suspended load compared to traditional loading (Lawrence & Carlson, 2015). In that study, elastic straps were used to suspend the weight plates from the bar, which likely lead to a greater degree of instability compared to what was faced by the athletes in the present study who used non-elastic straps. In the present study it was observed that SL utilized a high degree of postural control when unracking the barbell, stepping backwards, and positioning themselves to perform the back-squat. This was likely due to the high degree of horizontal acceleration of the suspended weight plates. Once the athlete established their base of support, the plates horizontal acceleration likely dropped below an appreciable level. When the athlete performed the back-squat, much of the plates' acceleration was in the vertical direction, similar to CON, and the acceleration of the plates and barbell were likely similar. Since the acceleration of the plates and barbell were similar, the global degree of instability was possibly negligible compared to traditional loading. This may not occur when the plates are suspended from the bar using an elastic strap or spring (Fletcher & Bagley, 2014; Lawrence & Carlson, 2015).

A significant and athletically meaningful improvement in COD as measured by the T-test was also identified. Previous investigations have indicated that long-term strength training (e.g. > 2 years) will lead to faster COD compared to not performing strength training in field sport athletes (Keiner, Sander, Wirth, & Schmidtbleicher, 2014). Though, strength training alone does not appear to lead to improvements in COD because exercises that more closely mimic the demands of COD need to be incorporated (Brughelli, Cronin, Levin, & Chaouachi, 2008). The improvement in T-test in the present study may have occurred because the athletes improved their strength and the training programs performed by SL and CON included speed, power, and agility training components.

Lower-extremity impulse generation capacity as measured by the VJ did not improve in the present study. While peak force generation may be important, previous literature has suggested that the pattern of force application during a VJ is more associated with achieving greater height than peak force (Dowling & Vamos, 1993). While the athletes 1RM improved in the present study, which may indicate they can produce greater peak forces, it is possible that the pattern of force application did not change. To this effect, it intuitively would not seem that the pattern of force application would change substantially when using suspended load compared to traditional loading, though that could be an area of future study. If this phase of the athletes training was focused on maximal strength (e.g. ≤ 3 repetitions per set) and included additional Olympic lifting and plyometric exercises, it is possible greater effects of time on VJ performance would have been observed. Nevertheless, this finding is in agreement with a previous training study that demonstrated that VJ performance did not improve following nine sessions of SL and CON (Cullen-Carroll et al., 2017).

Contrary to our hypothesis that improvements in single-leg balance would be greater for SL, the effect of SL

on SEBT performance was indifferent from that of CON. Furthermore, when SL and CON were pooled, the cohort did not improve SEBT from PRE to POST. This finding could be due to several factors. It is possible that six-weeks of training was not a long enough time to elicit an improvement in single-leg balance. Previous IRT research has utilized training periods as short as four-weeks and as long as entire competitive seasons (Cressey et al., 2007; Kibele & Behm, 2009; Sparkes & Behm, 2010; Yaggie & Campbell, 2006). Additionally, the magnitude of instability associated with the SL, as previously discussed, may not have been high enough to warrant adaptations in single-leg balance.

It is also possible that SL had no effect on single-leg as measured by SEBT due to the differing demands imposed by each movement. During the back-squat exercise, the feet remain fixed and there is little if any movement of the limbs outside the base of support, while the SEBT requires a one-footed stance and single-leg reaching outside the base of support. Thus, the effect of SL may be contained to movements that require stability within the base of support. It is also possible that SEBT may not have been sensitive enough to detect changes in single-leg balance that may have occurred. If the SEBT included factors such as trunk applied perturbations, an external resistance greater than the athlete's own body weight, or required greater speed of movement it is possible that single-leg balance improvements would have been elucidated in SL. Simply, the demands faced during SEBT may not be great enough to utilize possible SL adaptations.

A strength of the present study is that it utilized collegiate baseball players in a real-world strength and conditioning program over six weeks. There are also some limitations to the present study. This study did not control for the load during the back-squat between SL and CON, though in theory intensity was similar between groups as each group was instructed to lift the maximal load that allowed for the completion of the exact number of repetitions prescribed per set in the back-squat. SL performed resistance exercises in addition to back-squat that were not performed with SL, thus any changes that occurred cannot be solely attributed to the type of loading used during the back-squat. It is also possible that six-weeks was not long enough to elucidate athletic performance improvements in trained college athletes regardless of the mechanism of loading. The VJ, T-test, SEBT, and 1RM were chosen because they are field tests that can be easily administered outside a laboratory setting and are practical methods of assessment that a strength and conditioning coach could administer; though, more precise measurement tools, such as a force plate or isokinetic dynamometer, could be used. Finally, this study only included highly trained males and therefore it can be generalized to an untrained or female population.

CONCLUSION

IRT methods are commonly utilized to promote core skeletal muscle activation, but acute and chronic responses seem to depend on the degree and source of instability. SL seems to

show promise as a form of IRT because the degree of instability is large enough to elicit greater activation of core skeletal muscles, yet low enough to allow for greater training loads, phasic skeletal muscle activation, and force production. Our results revealed that both SL and CON demonstrated similar improvements in athletic performance during the six-week program, and that this improvement was driven by athletically meaningful enhancements in 1RM and T-test. Thus, SL does not appear to be detrimental to the development of an athlete during a six-week progressive training program. Strength and conditioning coaches could incorporate this type of loading into their programming as a means of additional variation without the concern of diminishing athletic development.

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