Identifying the optimal resistive load for complex training in male rugby players

THOMAS M. COMYNS¹, ANDREW J. HARRISON¹, LIAM HENNESSY², & RANDALL L. JENSEN³

¹Department of Physical Education and Sport Sciences, University of Limerick, Limerick, Ireland, ²Irish Rugby Football Union, Dublin, Ireland, and ³Department of Health, Physical Education and Recreation, Northern Michigan University, Marquette, USA

Abstract
Alternating a resistance exercise with a plyometric exercise is referred to as “complex training”. In this study, we examined the effect of various resistive loads on the biomechanics of performance of a fast stretch–shortening cycle activity to determine if an optimal resistive load exists for complex training. Twelve elite rugby players performed three drop jumps before and after three back squat resistive loads of 65%, 80%, and 93% of a single repetition maximum (1-RM) load. All drop jumps were performed on a specially constructed sledge and force platform apparatus. Flight time, ground contact time, peak ground reaction force, reactive strength index, and leg stiffness were the dependent variables. Repeated-measures analysis of variance found that all resistive loads reduced (P < 0.01) flight time, and that lifting at the 93% load resulted in an improvement (P < 0.05) in ground contact time and leg stiffness. From a training perspective, the results indicate that the heavy lifting will encourage the fast stretch–shortening cycle activity to be performed with a stiffer leg spring action, which in turn may benefit performance. However, it is unknown if these acute changes will produce any long-term adaptations to muscle function.

Keywords: Drop jump, leg spring stiffness, post-activation potentiation, sledge, stretch–shortening cycle

Introduction
Complex training involves the completion of a resistance exercise before a biomechanically similar plyometric exercise. It is postulated that the resistance exercise will have a performance-enhancing effect on the plyometric activity (Ebben and Watts, 1998). Post-activation potentiation is the physiological rationale for complex training (Docherty, Robbins, and Hodgson, 2004). Post-activation potentiation results in an enhancement in the explosive capability of the muscle owing to prior contractile activity (Docherty et al., 2004; Robbins, 2005). Examples of contractile activity that have been used in post-activation potentiation research include maximum voluntary contractions (MVCs) (French, Kraemer, and Cooke, 2003; Güllich and Schmidtbleicher, 1996) and the execution of resistance exercises (Evans, Hodgkins, Durham, Berning, and Adams, 2000; Radcliffe and Radcliffe, 1996; Young, Jenner, and Griffiths, 1998). Two mechanisms have been proposed to explain
post-activation potentiation. First, the enhancement in plyometric performance after performing the contractile activity may be due to an increase in neural excitability (Güllich and Schmidtbleicher, 1996). Alternatively, the phosphorylation of the myosin light chain has been proposed as a mechanism to explain post-activation potentiation (Paasuke, Ereline, and Gapeyeva, 1996; Sale, 2002). Docherty et al. (2004) noted that post-activation potentiation is possibly the result of interactions between both the neural and muscular mechanisms.

Ambiguity exists in complex training research about the optimal load that needs to be lifted in a resistance exercise to maximize the benefits of post-activation potentiation. Traditionally, research studies on complex training have used a five-repetition maximum (5-RM) protocol where the participants lifted 85% of their single-repetition maximum (1-RM) for five repetitions followed by a plyometric exercise, such as a drop jump or counter-movement jump. The results using such a protocol have varied. Some researchers have found that this resistive load had a significant effect on the performance of the plyometric exercise (Evans et al., 2000; Radcliffe and Radcliffe, 1996; Young et al., 1998). Others found that the 5-RM did not produce statistically significant results for the dependent variables associated with the plyometric exercise (Hrysomallis and Kidgell, 2001; Jensen and Ebben, 2003; Jones and Lees, 2003; Scott and Docherty, 2004). Although no significant differences were observed, the researchers commented that the 5-RM load did not have a negative effect on plyometric performance provided the participants did not perform the plyometric exercise immediately after the resistance training (Jensen and Ebben, 2003).

We found only two studies that used a resistive load other than 5-RM (Baker, 2003; Gourgoulis, Ageloussis, Kasimatis, Mavromatis, and Garas, 2003). Baker (2003) investigated the effect of lifting six repetitions at 65% of 1-RM for the bench press on an explosive throw that resembled a bench press (plyometric exercise), and observed a significant increase of 4.5% in power output from pre- to post-test for the experimental group. This finding is important, as it suggested that a relatively light load of 65% could produce an enhancement in performance in a subsequent plyometric exercise. However, this was an upper-body complex-training study that used specially loaded equipment for the plyometric exercise, and the results might differ from lower-body studies owing to the differences in limb muscle architecture and the testing protocol.

Gourgoulis et al. (2003) conducted a study of the effect of a warm-up programme of submaximal half-squats on vertical jumping ability. Their participants performed counter-movement jumps before and after a protocol of five sets of half squats of two repetitions each at 20%, 40%, 60%, 80%, and 90% of 1-RM. The results showed a 2.4% improvement in jump height after the five sets of half-squats. The high strength group improved their jump height post-test (4.0%) more than the low strength group (0.4%). Although the protocol used by Gourgoulis et al. (2003) showed an improvement, it is possible that a combination of heavy and light loads produced the effect rather than one specific load. In addition, the small changes reported in jump height are somewhat questionable because some of the changes in strength reported were smaller than typical measurement errors in jump height.

Very little research has examined the effect of prior contractile activity on a fast stretch–shortening cycle exercise such as the drop jump. A fast or short, as it is also referred to as, stretch–shortening cycle is characterized by small angular displacements in the hip, knee, and ankle joints and lasts between 100 and 250 ms (Schmidtbleicher, 1986). We could find three studies only that used the drop jump as the criterion jump (French et al., 2003; Güllich and Schmidtbleicher, 1996; Jones and Lees, 2003); of these, only Jones and Lees (2003) used weightlifting as the prior contractile activity. Güllich and Schmidtbleicher (1996) and French et al. (2003) used maximum voluntary contractions (MVCs) as opposed to
weightlifting. Both studies found an increase in jump height after a MVC protocol. French et al. (2003) observed a significant increase in jump height (5.03%), maximal force (6.12%), and acceleration impulse (9.49%) for the drop jump after three repetitions of 3-s MVCs. Güllich and Schmidtbleicher (1996) reported that their participants improved their drop jump height by an average of 14 mm (4.1%). These increases in jump height would be greater than typical errors in jump measurement. However, MVCs are not generally used in the applied training environment and the stimulus obtained from them may not be the same as that obtained from the traditional weight training exercises used in complex training. Jones and Lees (2003) investigated the effect of 5-RM back squatting on countermovement jumps and drop jumps that were performed immediately after and 3, 10, and 20 min after lifting. There were no significant main effects of the resistance exercise on drop jump take-off speed, jump height, peak ground reaction force, peak power output, or ground contact time. Although no performance-enhancing effect was evident on drop jump performance, it was also noted that no adverse effects occurred.

Past complex training research has tended to focus primarily on the effect of the contractile activity on the performance outcome measures of the plyometric exercise, such as height jumped (Duthie, Young, and Aitken, 2002; Jensen and Ebben, 2003; Radcliffe and Radcliffe, 1996; Scott and Docherty, 2004; Young et al., 1998). No attempt appears to have been made to study the effects of post-activation potentiation on the biomechanical performance (process) of the plyometric exercise. Consequently, the present study used vertical leg spring stiffness as a dependent variable. By analysing the biomechanical components of the drop jump, such as vertical leg spring stiffness, as opposed to relying on a single performance outcome measure, such as height jumped, a greater understanding of the effects of post-activation potentiation should be gained. We hypothesized that this might provide further insight into the theoretical rationale for post-activation potentiation.

Ambiguity exists on the effect of prior contractile activity in the form of weightlifting, including the effect of different resistive loads, on the kinematics of a fast stretch–shortening cycle activity. Docherty et al. (2004) have commented that the relationship between the magnitude of the prior contractile activity and the explosive performance needs clarification. The aim of this study, therefore, was to examine the effect of three resistive loads on the biomechanics (process) of performance of a fast stretch–shortening cycle activity (drop jump). In addition, we wished to determine if an optimal resistive load exists for complex training.

Methods

Participants

Before the recruitment of participants, statistical power analyses were conducted in a pilot study. These analyses indicated that 12 participants would be enough to identify any true effect. Consequently, 12 elite male rugby players were recruited to the study (see Table I). They were all professional players contracted to the National Rugby Football Union. All were

| Table I. Physical characteristics of the participants (mean ± s). |
| --- | --- | --- | --- |
| Age (years) | Height (m) | Body mass (kg) | 1-RM (kg) |
| 23.3 ± 2.5 | 1.82 ± 0.06 | 94.6 ± 11.5 | 192 ± 35 |
proficient with the technique of the back squat exercise and drop jumping and could squat in excess of 1.5 times body weight (mean $\pm s$: 2.0 $\pm$ 0.3). Ethical approval for this study was obtained from the university research ethics committee and informed consent was obtained in writing from all participants. Before testing, the participants completed a Physical Activity Readiness Questionnaire (PAR-Q).

**Instrumentation**

All drop jumps were single-legged jumps and were performed from a height of 0.3 m on a specially built sledge apparatus as described by Harrison, Keane and Coglan (Harrison, Keane, and Coglan, 2004). The apparatus consisted of three main components: a sledge frame, a sliding chair, and a force platform (see Figure 1). The sledge frame was constructed from box steel with sledge rails inclined at 30°. The chair was mounted on the rails on low-friction steel rollers. The force platform (AMTI OR6-5) was mounted at right angles to the sledge apparatus and sampled at 1000 Hz to give values for vertical ground reaction force, the component normal to the force platform. The participant was secured to the chair with a harness and Velcro straps at the waist and shoulders to prevent any upper body movement during the jumps. All drop jump trials were recorded on 50-Hz SVHS video-cassettes using a Panasonic AGDP800 camera.

Figure 1. Set-up of the sledge and force platform apparatus showing a participant about to perform a single-legged drop jump.
Test procedures

The testing took place over two sessions with 7 days between sessions. The same day of the week and time were used for reliability and to control for circadian variation (Atkinson and Reilly, 1996). Gülich and Schmidtbleicher (1996) reported that fatigue can have a negative effect on neural activation. Therefore, before testing on both days, the participants were required to refrain from high-intensity exercise, particularly strength and plyometric training. Test session 1 began with a warm-up that consisted of 3 min of low-intensity jogging followed by static stretching that included one exercise for each of the quadriceps, hamstrings, triceps surae, gluteal, and hip adductor muscle groups with stretches held for 15 s. The participants’ 1-RM was tested using the procedure outlined by Earle (1999); they then completed three sets of three familiarization trials of the single-legged drop jump with their preferred leg. The participants were instructed to minimize their contact time on the force platform and maximize their subsequent jump height.

A similar warm-up procedure was done before session 2, but it also included an activity-specific warm-up of one set of three drop jumps. Three minutes’ rest was given and the participants then completed the three baseline drop jump trials. These jumps served as a control for examining the influence of the resistive loads on the performance of the jumps done after each load. The participants then performed a specific back squat warm-up consisting of five repetitions at 50% of 1-RM and three repetitions at 60% of 1-RM. When the warm-up was completed, the participants performed three repetitions of one of the resistive loads (65%, 80% or 93% of 1-RM), followed 4 min later by three drop jumps. This was considered to be one complex pair. Six minutes’ rest was given before the start of the next complex pair. This resulted in a minimum of 10 min rest between back squat lifts. Three complex pairs were completed in total to cater for the three resistive loads. The order of the resistive loads was randomly assigned for each participant. A cool-down involving light jogging and static stretching was completed at the end of the test session.

According to the percentage of 1-RM–repetition relationship outlined by Baechle and Earle (2000), the load for three repetitions of the back squat was 93% of the 1-RM. For this reason, 93% was chosen as the heaviest load. An intermediate load of 80% was then selected and 65% was used to represent a light load. Four minutes was chosen as the rest interval between the weightlifting and the drop jumps, as previous research that used such a rest interval found an ergogenic advantage for the plyometric exercise (Gülich and Schmidtbleicher, 1996; Radcliffe and Radcliffe, 1996; Young et al., 1998).

Calculation of the dependent variables

The force platform data were used to obtain peak ground reaction force, flight time, and contact time for each jump. The reactive strength index has been defined as the ability to change quickly from an eccentric to a concentric contraction; it is calculated by dividing the height jumped by the contact time (Young, 1995). Before calculating the reactive strength index, jump height was first needed. Owing to the 30° inclination of the sledge apparatus, jump height was approximated from flight time using the expression $(9.81 \times \text{flight time}^2)/16$.

A spring-mass model was used to analyse the control of vertical leg spring stiffness, which has been defined as the ratio of the peak force in the spring, the ground reaction force, to the displacement of the spring at the instant that the leg spring is maximally compressed. Owing to the spring-like behaviour of the leg during drop jumps, the peak ground reaction force and the peak leg-spring displacement both occur simultaneously in the middle of the ground
contact phase (Ferris and Farley, 1997). Stiffness measures were calculated by dividing the peak force by the displacement of the chair from landing to full crouch for each drop jump. The SVHS video recordings (50 Hz) were digitized using Peak Motus® (Peak Performance Technologies, Colorado, USA) to calculate the displacement of the sledge.

Statistical analyses

All statistical analyses were conducted using SPSS for Windows, Release 11.0.1. Differences between the baseline scores and the scores after the various resistive loads for each dependent variable were evaluated using a two-way analysis of variance (ANOVA) with repeated measures. The analysis was carried out separately for each dependent variable: contact time, flight time, reactive strength index, vertical leg spring stiffness, and peak ground reaction force. The ANOVA had two within-individual factors, namely condition with four levels (baseline, 65%, 80%, and 93% load) and trials with three levels. Effect sizes using partial $\eta^2$ were also obtained for each dependent variable using the formula: $\eta^2_p = \frac{SS_{effect}}{SS_{effect} + SS_{error}}$, where $SS_{effect} = \text{effect variance}$ and $SS_{error} = \text{error variance}$. Interpretation of effect size was based on the scale for effect size classification of Hopkins (2002). This scale is based on $f$-values for effect size and these were converted to $\eta^2_p$ using the formula: $f = (\eta^2_p/(1 - \eta^2_p))^{0.5}$. Consequently, the scale for classification of $\eta^2_p$ was $<0.04 = \text{trivial}$, $0.041$ to $0.249 = \text{small}$, $0.25$ to $0.549 = \text{medium}$, $0.55$ to $0.799 = \text{large}$, and $>0.8 = \text{very large}$.

Results

The mean baseline scores for each dependent variable, which are given in Table II, were subtracted from their corresponding mean scores for the drop jumps completed after the different resistive loads. The results for contact time, vertical leg spring stiffness, flight time, reactive strength index, and peak ground reaction force are presented in Figures 2, 3, 4, 5, and 6 respectively. For the variables that were significantly different from baseline, the percentage change is reported. In all figures, the x-axis represents the baseline. The ANOVA results for contact time showed a significant reduction ($P < 0.05$) for the 93% load (Figure 2). The statistical results for the vertical leg spring stiffness indicated a significant increase in that variable after the 93% load ($P < 0.05$; see Figure 3). Flight time is
Figure 3. Leg stiffness ($k_{vert}$) differences between the baseline jumps and the jumps done after 65%, 80%, and 93% loads (mean ± i). * Significant difference between baseline and load ($P < 0.05$).

Figure 4. Flight time (FT) differences between the baseline jumps and the jumps done after 65%, 80%, and 93% loads (mean ± i). ** Significant difference between baseline and load ($P < 0.01$).

Figure 5. Reactive strength index (RSI) differences between the baseline jumps and the jumps done after 65%, 80%, and 93% loads (mean ± i). * Significant difference between baseline and load ($P < 0.05$).
considered the jump performance measure and the results of the ANOVA reported a significant reduction in flight time post-lifting for all three resistive loads ($P < 0.01$; see Figure 4).

From Figure 5 it is evident that there was a reduction in the reactive strength index after lifting at 65\% of 1-RM and the statistical analysis showed that this reduction was significant ($P < 0.05$). Although the mean reactive strength index score after the 93\% load was slightly higher than the mean baseline score, the difference was not significant ($P > 0.05$). The ANOVA results for peak ground reaction force (Figure 6) showed no significant difference ($P > 0.05$). There was a slight reduction in mean ground reaction force after the 65\% load and an increase in mean ground reaction force after the 80\% and 93\% loads.

The partial $\eta^2$ values are shown in Table III. The effect sizes for the variables that were significantly different from baseline are either large or medium, indicating that altering the load results in considerable change to the dependent variable.

Table II. Baseline values for the dependent variables (means $\pm s$).

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Baseline values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact time (s)</td>
<td>0.439 $\pm$ 0.072</td>
</tr>
<tr>
<td>Leg spring stiffness (kN/m)</td>
<td>10.8 $\pm$ 2.8</td>
</tr>
<tr>
<td>Flight time (s)</td>
<td>0.770 $\pm$ 0.019</td>
</tr>
<tr>
<td>Reactive strength index</td>
<td>0.86 $\pm$ 0.18</td>
</tr>
<tr>
<td>Ground reaction force (N)</td>
<td>1980 $\pm$ 230</td>
</tr>
</tbody>
</table>

Table III. Partial $\eta^2$ values for the dependent variables and classification of the magnitude of the effect size according to Hopkins (2002).

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>65% Load</th>
<th>80% Load</th>
<th>93% Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact time</td>
<td>0.270 $\times 10^{-3}$; trivial</td>
<td>0.126; small</td>
<td>0.375; medium*</td>
</tr>
<tr>
<td>Vertical leg spring stiffness</td>
<td>0.124 $\times 10^{-3}$; trivial</td>
<td>0.040; trivial</td>
<td>0.386; medium*</td>
</tr>
<tr>
<td>Flight time</td>
<td>0.574; large**</td>
<td>0.629; large**</td>
<td>0.581; large**</td>
</tr>
<tr>
<td>Reactive strength index</td>
<td>0.369; medium*</td>
<td>0.121; small</td>
<td>0.014; trivial</td>
</tr>
<tr>
<td>Ground reaction force</td>
<td>0.118; small</td>
<td>0.001; trivial</td>
<td>0.257; small</td>
</tr>
</tbody>
</table>

** Significant difference between baseline and load ($P < 0.01$). * Significant difference between baseline and load ($P < 0.05$).
Discussion and implications

The flight time for all loads showed a significant reduction compared with the baseline jumps. These results suggest that performing back squat lifting at 65%, 80%, and 93% of 1-RM before drop jumping had a negative effect on the jump performance. In contrast to other studies, we also examined the effect of back squatting on drop jump ground contact time, reactive strength index, peak ground reaction force, and leg stiffness. The results for these variables provide a greater understanding of the effect that back squat lifting at different loads has on the biomechanics of a fast stretch–shortening cycle activity such as drop jumping. By relying only on the performance outcome measure of flight time as the dependent variable, the true effects of weightlifting on drop jumping could have been overlooked.

The results of this study have provided further insight into the mechanisms behind post-activation potentiation. There is evidence to support the theoretical rationale of increased neural excitability for post-activation potentiation. The significant reduction in contact time and improvement in leg stiffness after lifting the 93% load could be due to an increase in neuromuscular activation owing to the prior contractile activity. It could be that the increased activation resulted in the participant being able to modulate leg spring stiffness and, in turn, this contributed to a reduction in ground contact time.

The changes observed in leg stiffness and ground contact time illustrate how a heavy resistance may alter the way the muscle tendon unit behaved during jumping, resulting in the fast stretch–shortening cycle activity being performed quicker and with a shorter and stiffer leg spring action. The percentage changes were relatively large. There was a 7.8% reduction in contact time and a 10.9% increase in leg stiffness. An increase in leg stiffness is associated with increased leg cadence of a fast stretch–shortening cycle activity, such as hopping and sprinting (Arampatzis, Brüggeman, and Metzler, 1999; Farley, Blickhan, Saito, and Taylor, 1991; Farley and González, 1996). Arampatzis et al. (1999) found that leg stiffness increased with increasing running speed. Farley et al. (1991) found that the stiffness of the leg spring can increase as much as twofold to accommodate faster hopping frequencies. Similarly, Farley and González (1996) revealed that the stiffness of the leg spring in running increased twofold to threefold between the lowest and highest stride frequencies investigated. In addition, it has been shown that sprinters have high leg spring stiffness (Bret, Rahmani, Dufour, Messonnier, and Lacour, 2002; Harrison et al., 2004).

The analysis of the reactive strength index data indicated an improvement after lifting the 93% load. The reactive strength index is a measure of the ability to change from an eccentric to a concentric contraction (Young, 1995). It is calculated from jump height, which is derived from the flight time, and the contact time. A shorter ground contact time may result in a reduction in flight time and, subsequently, jump height. The heavy weightlifting (93% of 1-RM) increased the muscle tendon unit stiffness and decreased the ground contact time. This, in turn, may have contributed to the significant reduction in flight time. The reactive strength index, however, provides a clearer indication of how these two variables interrelate. The participant’s mean reactive strength index was slightly higher after lifting the 93% load and, at the same time, the ground contact time and the leg stiffness were significantly improved. These findings support the view that, for rugby players, there is an acute enhancement in the biomechanics of the drop jump performance after a heavy resistance exercise. The heavy lifting will enhance the speed of the fast stretch–shortening cycle performance, making it stiffer and more elastic.

The 65% resistive load results, particularly the significant (7.9%) reduction in the mean reactive strength index score, indicate that this load may hinder fast stretch–shortening cycle
These results suggest that rugby players should not combine lifting at a 65% load with drop jumping. Baker (2003) investigated the effect of upper body complex training using a 65% load on rugby players; his results appear to contradict the present findings. Baker observed a significant improvement in power output on a throw exercise similar to an explosive bench press. However, the difference in findings could be due to Baker (2003) examining upper body complex training, whereas the present study focused on lower body complex training. In addition, the experimental group in Baker’s study performed six repetitions at 65% of 1-RM, whereas in this study the participants performed three repetitions at 65% of 1-RM.

Examination of the literature reveals only one study that used weightlifting as the prior contractile activity and drop jump as the criterion jump (Jones and Lees, 2003). The results of Jones and Lees (2003) contrast with those of the present study. Using a load of 85% of 1-RM for the back squat, Jones and Lees (2003) found that 5-RM squatting had no significant effect on drop jump height, take-off velocity, peak ground reaction force, peak power output or ground contact time. The significant improvements in drop jump ground contact time and leg stiffness in the present study were only observed at the heaviest load (93% of 1-RM); this could, in part, account for the discrepancy in findings between the studies. Jones and Lees (2003) also used two-legged drop jumps performed from a box, whereas the present study used a sledge apparatus to provide controlled loading on single-legged drop jumps. Previous complex training research that used the drop jump (French et al., 2003; Gülich and Schmidtbleicher, 1996; Jones and Lees, 2003) as the test jump failed to control for factors that could contribute to the jump performance and mask the true affects of the intervention. For example, the use of the arms and upper body in a swinging motion during the performance of the drop jumps could enhance jump height, and the accuracy of drop height can be varied by the participant jumping up off the box as opposed to stepping off it while performing drop jumps. Some studies have tried to control for these factors by instructing participants to place their hands on their hips when performing the jumps (French et al., 2003; Jones and Lees, 2003) and telling them to step off and not jump off the box (Jones and Lees, 2003). However, these instructions alone cannot completely eliminate the contributions of the arm and upper body movement to jump height. The sledge apparatus provides greater control of drop height and impact velocities and isolates the leg action from interferences such as upper body movement (Harrison et al., 2004). This, therefore, provided a well-controlled and valid comparison of the baseline drop jumps with the drop jumps performed after the resistive loads.

The results of this study have practical implications for the coach and athlete. From an applied perspective, using complex training with rugby players appears to be beneficial when the plyometric exercise is a fast stretch–shortening cycle activity, such as drop jumping. The results indicate a change in the biomechanics of performance of the fast stretch–shortening cycle activity. The stiffer leg spring action, which follows heavy lifting, may benefit performance of rapid stretch–shortening cycle activity, such as running or hopping, by increasing leg cadence. However, the changes reported here are due to an acute intervention and it is unknown if a complex training programme of back squatting at 93% of 1-RM and drop jumping will produce any long-term adaptations to muscle function. Docherty et al. (2004) have indicated a lack of research into the chronic adaptations of complex training programmes. In addition, the results of the present study do not provide information about the extent to which the increase in leg stiffness in drop jumping would carry over to an increase in sprinting performance on the rugby field. All of these points to be taken into consideration when deciding whether to include complex training strategies in the strength and conditioning programmes of rugby players. However, if complex training is used, it
should be reserved for injury-free players who are adequately conditioned. It is important when performing the fast stretch–shortening cycle component of complex training that the player demonstrates correct technique, focuses on short ground contact times, and lands with pre-tensed leg muscles to enhance leg stiffness response. The coach should observe the technical proficiency of the activity by watching and listening and should listen for an elastic rebounding action, which is characterized by a relatively quiet impact sound with no banging or slapping noises. In addition, the coach should watch to ensure that the athlete does not sink very deeply or “go soft” on landing, by examining the hip, knee, and ankle joint angles at ground contact.

**Conclusion**

In conclusion, lifting three repetitions of the back squat at 93% of 1-RM appears to reduce ground contact time and leg spring stiffness significantly. The performance outcome – flight time – is reduced. The changes observed in contact time and leg spring stiffness will be more beneficial, as research has demonstrated that increases in leg stiffness and reductions in contact time are associated with faster stride frequencies and running velocities. The results suggest that 93% of 1-RM may be the optimal resistive load for lower body complex training. The 65% load demonstrated no improvement in drop jump performance and elicited a significant reduction in flight time and the reactive strength index. It would appear that a 65% resistive load has a negative effect on drop jump performance. The results show that lifting a load equivalent to 93% of 1-RM for the back squat will alter the way the drop jump is performed in an acute setting. It is unknown, however, if the changes observed will lead to chronic adaptations after a prolonged training intervention.

Finally, the improvements observed in contact time and leg spring stiffness are important findings that past research has failed to illustrate owing to an over-reliance on performance outcome measures. This may have resulted in the true effects of the weightlifting component on plyometric performance being overlooked in previous studies. Future research on complex training needs to examine the effect of the prior contractile activity on the biomechanics of performance (process) as opposed to the performance outcome measures, such as height jumped.

**References**


