TITLE: THE IDENTIFICATION OF THE OPTIMAL COMPLEX TRAINING RESISTIVE LOAD IN MALE RUGBY PLAYERS.

Running title: Optimal complex training resistive load

KEYWORDS: drop jump, leg spring stiffness, postactivation potentiation, stretch-shortening cycle, sledge

Date of re-submission: 16th March 2006

ABSTRACT

Alternating a resistance exercise with a plyometric exercise is referred to as complex training. This study examined the effect of various resistive loads on the biomechanics of performance of a fast stretch shortening cycle activity and determined if an optimal resistive load exists for complex training. Twelve elite level rugby players performed three drop jumps before and after three back squat resistive loads of 65%, 80% and 93% of 1RM. 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 ANOVA found that all resistive loads significantly reduced ($p < 0.01$) flight time, but lifting at the 93% load caused a significant 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, postactivation potentiation, stretch-shortening cycle, sledge

Introduction:

Complex training involves the completion of a resistance exercise prior to 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). Postactivation potentiation (*PAP*) is the physiological rationale for complex training (Docherty *et al.*, 2004). *PAP* results in an enhancement in the explosive capability of the muscle due to prior contractile activity (Docherty *et al.*, 2004; Robbins, 2005). Examples of contractile activity that have been used in *PAP* research include maximum voluntary contractions, *MVCs*, (Güllich and Schmidtbleicher, 1996; French *et al.*, 2003) and the execution of resistance exercises (Radcliffe and Radcliffe, 1996; Young *et al.*, 1998; Evans *et al.*, 2000). Two mechanisms have been put forward to explain the workings of *PAP*. Firstly 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 attributed to the *PAP* (Paasuke et al., 1996; Sale, 2002). Docherty et al. (2004) noted, however, that it is possible that *PAP* is the result of interactions between both the neural and muscular mechanisms.

Ambiguity exists in complex training research regarding the optimal load that needs to be lifted in the resistance exercise in order to maximise the benefits of *PAP*. Traditionally research studies on complex training have used a 5 repetition maximum (RM) protocol where the subjects lifted 85% of their 1RM for five repetitions followed by a plyometric exercise, such as a drop jump (*DJ*) or counter-movement jump (*CMJ*). The results using this type of protocol have varied. Some researchers have found that this resistive load had a significant effect on the performance of the plyometric exercise (Radcliffe and Radcliffe, 1996; Young *et al.*, 1998; Evans *et al.*, 2000). Others found the 5RM 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). While no significant difference was found, the researchers commented that the 5RM load did not have a negative effect on plyometric performance provided the subjects did not perform the plyometric exercise immediately following the resistance training (Jensen and Ebben, 2003).

Only two studies were found that used a resistive load other than the 5RM load (Baker, 2003; Gourgoulis *et al.,* 2003). Baker (2003) investigated the effect of lifting six repetitions at 65% of 1RM for the bench press on an explosive bench press-style throw (plyometric exercise) and showed 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 may differ to lower-body studies due 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. Subjects performed *CMJ* before and after a protocol of five sets of half squats of two repetitions each at 20%, 40%, 60%, 80% and 90% of 1RM. 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%). While 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.

There has been a paucity of research examining the effect of prior contractile activity on a fast stretch-shortening cycle (*SSC*) exercise, for example the drop jump. A fast or short, as it is also referred to as, *SSC* is characterised by small angular displacements in the hip, knee and ankle joints and lasts between 100 and 250 ms (Schmidtbleicher, 1986). Only three studies were found that used the drop jump as the criterion jump (French *et al.*, 2003; Güllich and Schmidtbleicher, 1996; Jones and Lees, 2003) and of these only Jones and Lees (2003) used weight lifting as the prior contractile activity. Güllich and Schmidtbleicher (1996) and French *et al.* (2003) used *MVCs* as opposed to weight lifting. Both studies found an increase in jump height following a *MVC* protocol. French *et al.* (2003) found a significant increase in jump height (5.03%), maximal force (6.12%) and acceleration impulse (9.49%)

for the drop jump following three repetitions of three-second *MVCs*. Güllich and Schmidtbleicher (1996) reported that the subjects improved their *DJ* height by an average of 1.4 cm (4.1%). These increases in jump height would be greater than typical errors in jump measurement. *MVCs* however 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 5RM back squatting on *CMJ*s and *DJ*s that were performed immediately, 3, 10 and 20 minutes post-lifting. There were no significant main effects of the resistance exercise on *DJ* take-off velocity, jump height, peak ground reaction force, peak power output and ground contact time. While no performance enhancing effect was evident on *DJ* 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 et al., 2002; Radcliffe & Radcliffe, 1996; Jensen & Ebben, 2003; Scott & Docherty, 2004; Young et al., 1998). No attempt appears to have been made on the effects of *PAP* on the biomechanical performance (process) of the plyometric exercise. Subsequently, the present study employed vertical leg spring stiffness, k_{vert}, as a dependent variable. By analysing the biomechanical components of the drop jump, such as k_{vert}, as opposed to relying on a single performance outcome measure, such as height jumped, a greater understanding of the effects of *PAP* are gained. It is hypothesised that this may provide further insight into the theoretical rationale for *PAP*.

Ambiguity exists on the effect of prior contractile activity in the form of weight lifting, including the effect of different resistive loads, on the kinematics of a fast *SSC* 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 purpose of this study therefore, was to examine the effect of three resistive loads on the biomechanics (process) of performance of a fast *SSC* activity (*DJ*). In addition, the study aimed to examine if an optimal resistive load exists for complex training.

Methods:

Participants

Prior to the recruitment of participants, statistical power analyses were conducted on pilot study data based on the recommendations of Cohen (1988). These analyses indicated that twelve subjects would be enough to identify any true effect. Consequently, twelve elite male rugby players participated in this study (see table 1). They were all professional players contracted to the National Rugby Football Union. All were proficient with the technique of the back squat exercise and drop jumping and could squat in excess of 1.5 times bodyweight (mean ± SD): 2.0 ± 0.3. Ethical approval for this study was granted from the University research ethics committee and informed consent was obtained in writing from all subjects. Prior to participation in the testing procedure, the subjects completed a Physical Activity Readiness Questionnaire (PAR-Q).

Instrumentation

All *DJ*s were single-legged jumps and were performed from a height of 30 cms on a specially built sledge apparatus as described by Harrison *et al.* (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 30º. 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 (i.e. normal to the force platform). The subject 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 *DJ* trials were recorded on 50 Hz SVHS videocassettes via a Panasonic AGDP800 camera.

Test procedures

The testing took place over two sessions with seven days between each session. The same day of the week and time were used for reliability reasons and to control for circadian variation (Atkinson and Reilly, 1996). Güllich and Schmidtbleicher (1996) reported that fatigue can negatively affect neural activation, therefore, prior to testing on both days, the subjects were required to refrain from high-intensity exercise, especially strength and plyometric training. Testing session one began with a warm-up that consisted of three minutes of low intensity jogging followed by static stretching that included one exercise for each of the quadriceps, hamstrings, triceps surae, gluteals and hip adductors with stretches held for 15 seconds. The subjects' 1RM was tested using the procedure outlined by Earle (1999) and then they completed three sets of three familiarisation trials of the single-legged *DJ* with their preferred leg. The subjects were instructed to minimise their contact time on the force platform and maximise their subsequent jump height.

A similar warm-up procedure was done before session two, but it also included an activity specific warm-up of one set of three *DJ*s. Three minutes rest was given and the subjects then completed the three baseline *DJ* 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 subjects then performed a specific back squat warm-up consisting of five repetitions at 50% of 1RM and three repetitions at 60% of 1RM. When the warm up was completed, the subjects performed three repetitions of one of the resistive loads (65%, 80% or 93% of 1RM), followed four minutes later by three *DJ*s. 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 minutes 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 subject. A cool-down (light jogging and static stretching) was completed at the end of the testing session.

According to the percentage of 1RM-repetition relationship outlined by Baechle *et al.* (2000) the load for three repetitions of the back squat is 93% of the 1RM. For this reason 93% was chosen as the heaviest load. An intermediate load of 80% was then selected and 65% was used as a representation of a light load. Four minutes was chosen as the rest interval between the weight lifting and the drop jumps as previous research that used such a rest interval found an ergogenic advantage for the plyometric exercise (Güllich 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 GRF, *FT* and *CT* for each jump. Reactive strength index (*RSI*) has been defined as the ability to change quickly from an eccentric to a concentric contraction and it is calculated by dividing the height jumped by the *CT* (Young, 1995). Before calculating *RSI*, jump height was first needed. Due to the 30º inclination of the sledge apparatus, jump height was approximated from *FT* using the expression $(9.81 \times FT^2)/16$.

A spring-mass model was used to analyse the control of vertical leg spring stiffness (k_{vert}), which has been defined as the ratio of the peak force in the spring, *GRF*, to the displacement of the spring, ΔL, at the instant that the leg spring is maximally compressed. Due to the spring-like nature of the leg during *DJ*s, the peak ground reaction force and the peak leg-spring displacement both occur simultaneously at 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 *DJ*. The SVHS video recordings (50Hz) were digitised 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 of dependent variables, *CT*, *FT*, *RSI*, k_{vert} and peak *GRF*. The GLM ANOVA had two within-subjects factors, namely condition with four levels (baseline, 65%, 80% and 93% load) and trials with three levels. Effect sizes using partial eta^2 (η_p^2) were also obtained for each dependent variable using the formula $\eta_p^2 = SS_{effect} / (SS_{effect} + SS_{error})$, where SS_{effect} = effect variance and SS_{error} = error variance. Interpretation of effect size was based on the scale for effect size classification by Hopkins (2002). This scale is based on **f**-values for effect size and these were converted to η_p^2 use by the formula $\mathbf{f} = (\eta_p^2 / (1- \eta_p^2))^{0.5}$. Consequently the scale for classification of η_p^2 was <0.04 trivial; 0.041 to 0.249 small; 0.25 to 0.549 medium; 0.55 to 0.799 large; >0.8 very large.

Results:

The mean baseline scores for each dependent variable, which can be seen in table 2, were subtracted from their corresponding mean scores for the *DJ*s completed after the different resistive loads. The results for *CT*, k_{vert}, *FT*, *RSI* and peak *GRF* are presented in Figures 2, 3, 4, 5 and 6 respectively. For the variables that were significantly different to the baseline, the percentage change is reported. In all Figures, the x-axis represents the baseline. The GLM ANOVA results for *CT* showed a significant reduction ($p < 0.05$) for the 93% load (Figure 2). The k_{vert} statistical results indicated a significant increase in k_{vert} after the 93% load ($p < 0.05$), see Figure 3. *FT* is considered the jump performance measure and the results of the GLM ANOVA reported a significant reduction in *FT* post-lifting for all three resistive loads ($p < 0.01$), see Figure 4.

In Figure 5 it is evident that a reduction occurred in *RSI* after lifting at 65% of 1RM and the statistical analysis showed that this reduction was significant ($p < 0.05$). While the mean *RSI* score after the 93% load was slightly higher than the mean baseline score, the difference was not significant ($p \geq 0.05$). The GLM ANOVA results for peak *GRF* (Figure 6), showed no significant difference ($p \geq 0.05$). There was a slight reduction in mean *GRF* after the 65% load and an increase in mean *GRF* following the 80% and 93% loads.

The η_p^2 values can be seen in table 3. The effect size values for the variables that were significantly difference to the baseline are either large or medium, indicating that altering the load results in considerable change to the dependent variable.

Discussion and Implications:

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

The results of this study have provided further insight into the mechanisms behind *PAP*. There appears to be evidence in the results to support the increased neural excitability theoretical rationale for *PAP*. 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 due to the prior contractile activity. It may be that the increased activation levels resulted in the player 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 the jumping resulting in the fast *SSC* activity being performed quicker and with a shorter and stiffer leg spring action. The percentage changes were of a relatively large magnitude. 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 *SSC* activity, such as hopping and sprinting (Farley *et al.* 1991; Farley *et al.*, 1996; Arampatzis *et al.*, 1999). 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 *et al.* (1996) revealed that the stiffness of the leg spring in running increased 2.3-fold between the lowest and highest stride frequencies investigated. In addition, it has been shown that sprinters have high leg spring stiffness (Bret *et al.*, 2002; Harrison *et al.*, 2004).

The analysis of the *RSI* data indicated an improvement after lifting the 93% load. *RSI* 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 weight lifting (93% of 1RM) increased the muscle tendon unit stiffness and thus decreased the ground contact time. This in turn may have contributed to the significant reduction in flight time. The *RSI*, however, provides a clearer indication of how these two variables inter-relate. The fact that the subject's mean *RSI* was slightly higher after lifting the 93% load and at the same time the ground contact time and the leg stiffness were significantly improved, would support the view that for rugby players there is an acute enhancement in the biomechanics of the DJ performance following a heavy resistance exercise. The heavy lifting will enhance the speed of the fast *SSC* performance, making it stiffer and more elastic.

The 65% resistive load results, especially the significant reduction in the mean *RSI* score (7.9% reduction), indicate that this load may hinder fast SSC performance. These data 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 and the results appear to contradict the present findings. A significant improvement in power output on an explosive bench press throw exercise was found in Baker's study. However, the difference in findings could be due to the fact Baker (2003) examined upper-body complex training while the present study focused on lower-body complex training. In addition, the experimental group in Baker's study performed 6 repetitions at 65% of 1RM whereas in this study the subjects performed 3 repetitions at 65% of 1RM.

Examination of the literature reveals only one study that used weight lifting as the prior contractile activity and *DJ* as the criterion jump (Jones and Lees, 2003). The results of Jones and Lees (2003), contrast with the present study. Using a load of 85% of 1RM for the back squat, Jones and Lees (2003) found that 5RM squatting had no significant affect on *DJ* jump height, take-off velocity, peak ground reaction force, peak power output and ground contact time. The significant improvements in *DJ* ground contact time and leg stiffness in the present study were only observed at the heaviest load (93% of 1RM) and this could in part, account for the discrepancy in findings between the studies. Jones and Lees (2003) also used two legged drop jumps performed form a box whereas the present study used a sledge apparatus to provide controlled loading on single legged *DJ's*. Previous complex training research that using the *DJ* (Güllich and Schmidtbleicher, 1996; French *et al.*, 2003; Jones and Lees, 2003) as the test jump has failed to control 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 *DJ*s could enhance jump height and the accuracy of *DJ* drop height can be varied by the subject jumping up off the box as opposed to stepping off it while performing drop jumps. Some of the studies attempted to control these factors by instructing the subjects to place their hands on their hips during the performance of the jumps (French *et al.*, 2003; Jones and Lees 2003) and instructing the subjects to step off and not jump off the box for the drop jumps (Jones and Lees, 2003). However, these instructions alone cannot fully eliminate the contributions of the arm and upper body movement to jump height and subsequently to influencing the results of the studies. The sledge apparatus provides greater control of drop height, 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 *DJs* with the *DJ* performed following 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 seems to be beneficial when the plyometric exercise is a fast *SSC* activity, such as drop jumping. The results indicate a change in the biomechanics of performance of the fast *SSC* activity. The stiffer leg spring action, which follows heavy lifting, may benefit performance of rapid *SSC* 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 utilising back squatting at 93% of 1RM and drop jumping will produce any long term adaptations to muscle function. Docherty et al. (2004) have indicated that there is a lack of research investigating the chronic adaptations of complex training programmes. In addition, the results of the present study do not provide us with information about the extent to which the increase in leg stiffness in drop jumping would carry over to an increase in sprinting on the rugby field. All of this needs to be taken into consideration when deciding whether to include complex training strategies into 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 *SSC* component of complex training that the player demonstrates correct technique, focuses on short ground contact times and landing with pre-tensed leg muscles to enhance leg stiffness response. The coach should observe the technical proficiency of the activity by watching and listening. He/ she should listen for an elastic rebounding action which is characterised 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 joints on ground contact.

Conclusions:

In summary, lifting three repetitions of the back squat at 93% of 1RM appears to significantly reduce ground contact time and leg spring stiffness. The performance outcome (flight time) is reduced. The changes observed in *CT* and k_{vert} will be more beneficial as research has demonstrated that increases in leg stiffness and reductions in *CT* are associated with faster stride frequencies and running velocities. The results suggest that 93% of 1RM may be the optimal resistive load for lower-body complex training. The 65% load demonstrated no improvement in *DJ* performance and elicited a significant reduction in *FT* and *RSI*. It would seem that a 65% resistive load has a negative effect on *DJ* performance. The results have shown that lifting a 93% of 1RM load for the back squat will alter the way the drop jump is performed in an acute setting. It is unknown, however, if these changes observed will lead to chronic adaptations after a prolonged training intervention.

Finally, the improvements observed in *CT* and k_{vert} are important findings that past research has failed to illustrate due to an over-reliance on performance outcome measures. This may have resulted in the true effects of the weight lifting component on plyometric performance being overlooked in previous studies. Future complex training research studies need 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.

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TABLES

Table 1 Physical characteristics of the subjects

Age (years)	Height (m)	Mass (kg)	1RM (kg)
23.3 ± 2.5	1.82 ± 0.06	94.6 ± 11.5	191.7 ± 35.4

Table 2 Baseline means (± SD) for the dependent variables.

Dependent Variable	**Baseline values**
Contact time (s)	0.439 ± 0.072
Leg spring stiffness (kN.m^{-1})	10.8 ± 2.8
Flight time (s)	0.770 ± 0.019
Reactive Strength Index	0.86 ± 0.18
Ground Reaction Force (N)	1977.3 ± 234.7

Table 3 η_p^2 values for the dependent variables and classification of the magnitude of the effect size according to Hopkins (2002). ** Significant difference between base and load ($p < 0.01$); * Significant difference between base and load ($p < 0.05$).

Dependent Variable	**65% Load**	**80% Load**	**93% Load**
CT	0.270×10^{-4}; trivial	0.126; small	0.375; medium*
k_{vert}	0.124×10^{-3}; trivial	0.040; trivial	0.386; medium*
FT	0.574; large**	0.629; large**	0.581; large**
RSI	0.369; medium*	0.121; small	0.014; trivial
GRF	0.118; small	0.001; trivial	0.257; small

FIGURE CAPTIONS

Figure 1 Photograph of the set-up of the sledge and force platform apparatus showing a subject about to perform a single-legged DJ.

Figure 2 Mean ± SD ground contact time differences between the baseline jumps and the jumps done after 65%, 80% and 93% loads.

* Significant difference between base and load ($p < 0.05$).

Figure 3 Mean ± SD leg stiffness differences between the baseline jumps and the jumps done after 65%, 80% and 93% loads.

* Significant difference between base and load ($p < 0.05$).

Figure 4 Mean ± SD flight time differences between the baseline jumps and the jumps done after 65%, 80% and 93% loads.

** Significant difference between base and load ($p < 0.01$).

Figure 5 Mean ± SD RSI differences between the baseline jumps and the jumps done after 65%, 80% and 93% loads.

* Significant difference between base and load ($p < 0.05$).

Figure 6 Mean ± SD peak GRF differences between the baseline jumps and the jumps done after 65%, 80% and 93% loads.

Figure 1

Figure 2

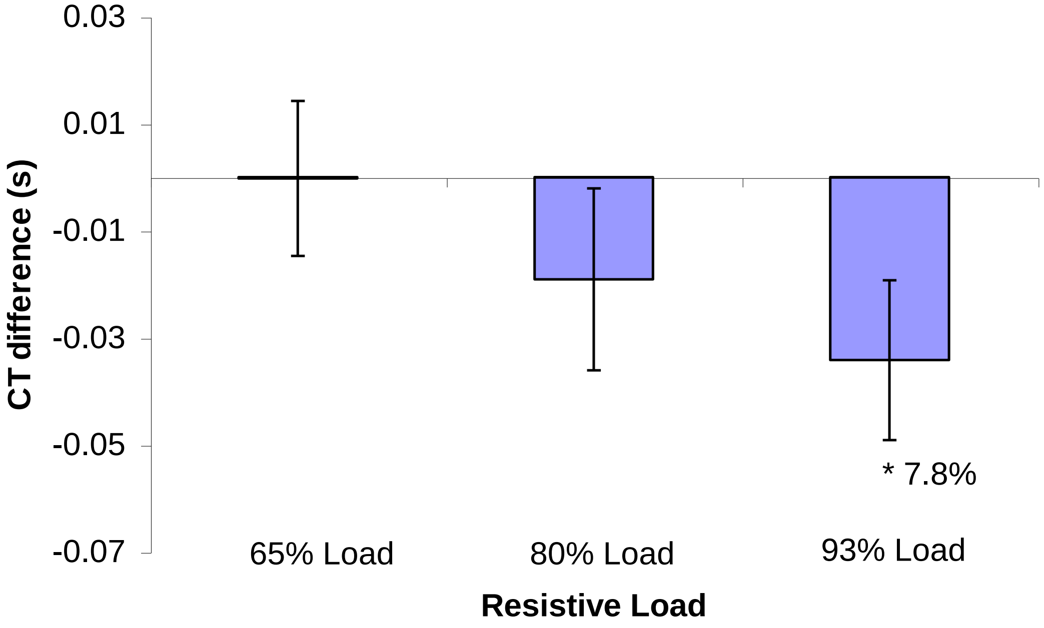

0.03
0.01
-0.01
-0.03
-0.05
-0.07
CT difference (s)
* 7.8%
65% Load
80% Load
93% Load
Resistive Load

Figure 3

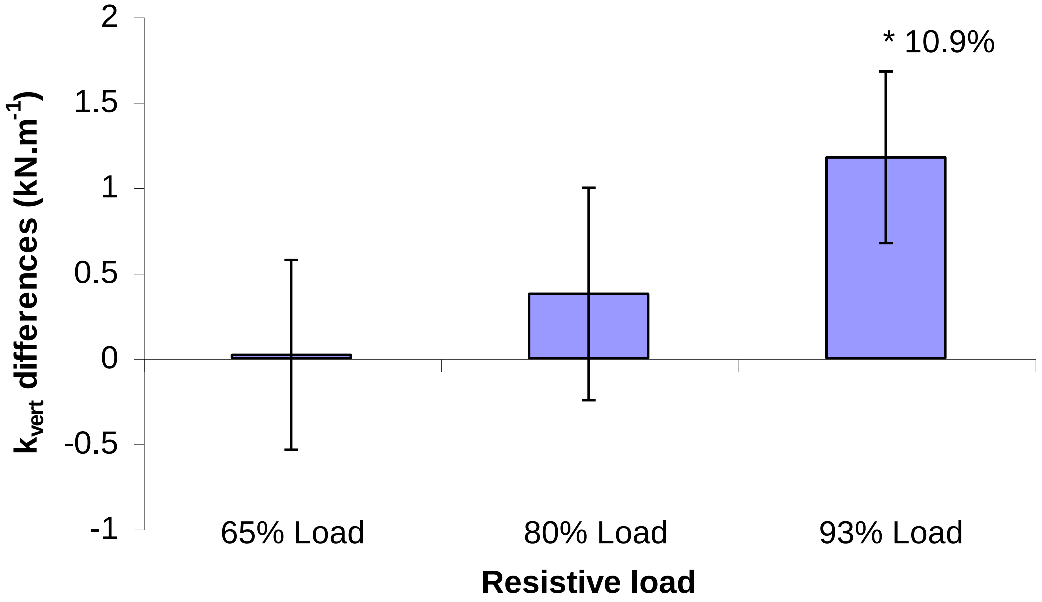

2
1.5
1
0.5
0
-0.5
-1
k_{vert} differences (kN.m^{-1})
* 10.9%
65% Load
80% Load
93% Load
Resistive load

Figure 4

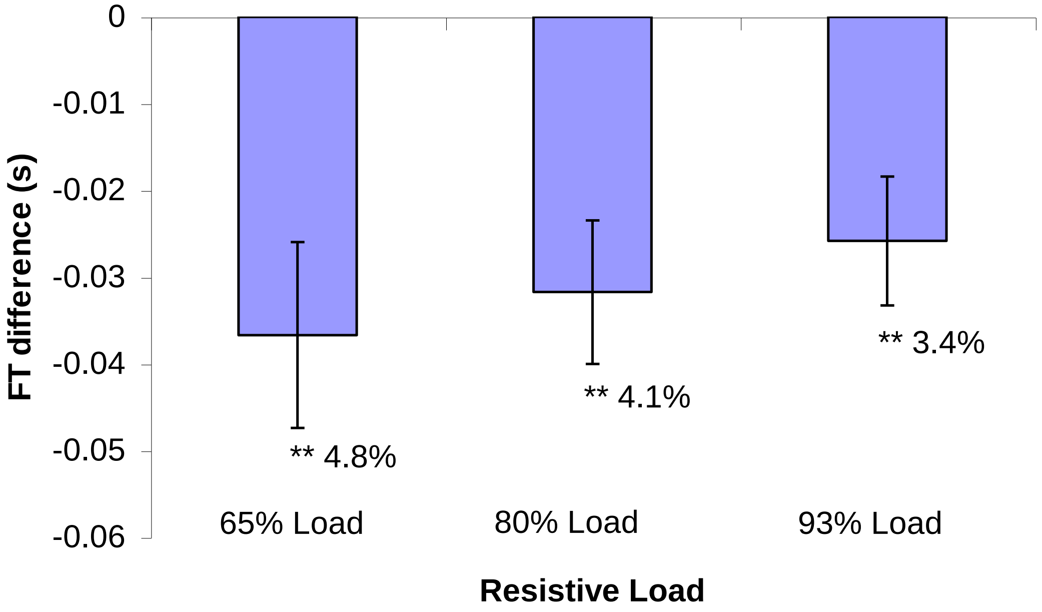

0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
FT difference (s)
** 4.8%
** 4.1%
** 3.4%
65% Load
80% Load
93% Load
Resistive Load

Figure 5

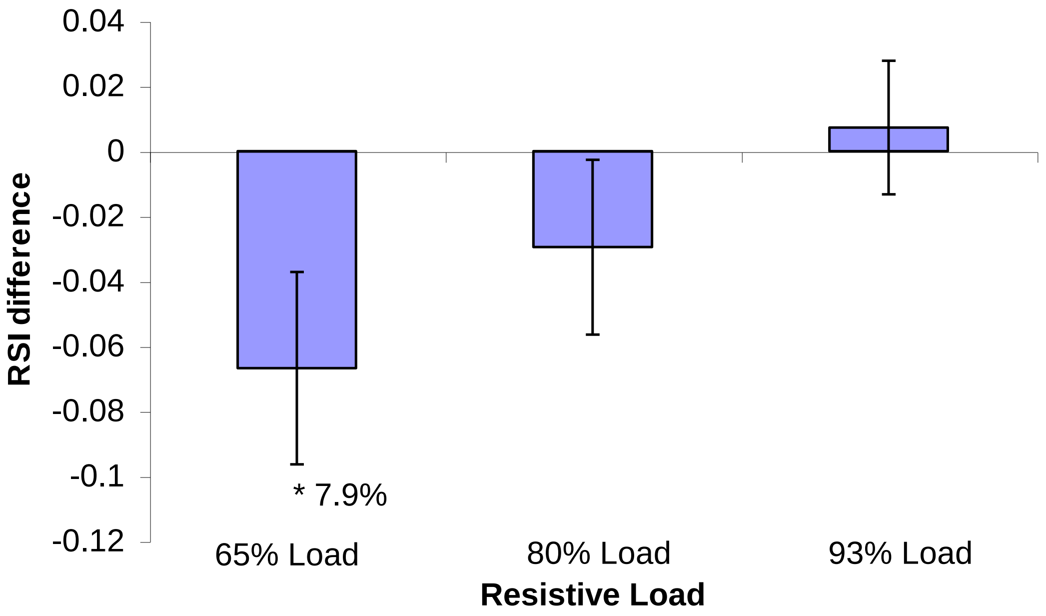
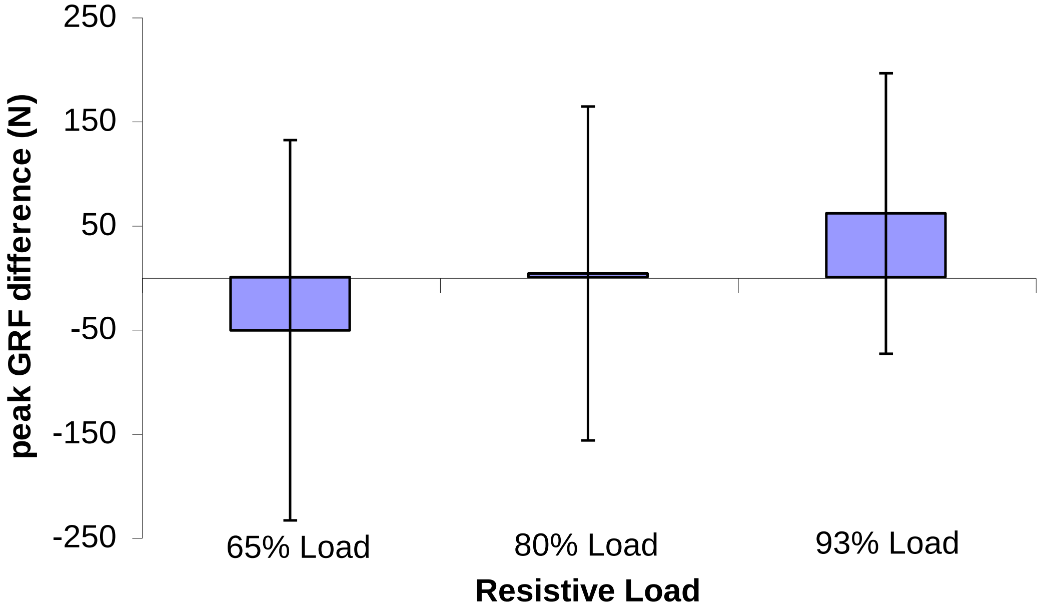

0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
RSI difference
* 7.9%
65% Load
80% Load
93% Load
Resistive Load

Figure 6


250
150
50
-50
-150
-250
peak GRF difference (N)
65% Load
80% Load
93% Load
Resistive Load