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The Effects of Using Knee Wraps on Back Squat and Vertical Jump Performance.

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THE EFFECTS OF USING KNEE WRAPS ON BACK SQUAT AND VERTICAL JUMP PERFORMANCE

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ABSTRACT

Using knee wraps (KW) as an ergogenic aid has been commonly practiced in various sports such as powerlifting, strongman, and Olympic weightlifting. There is limited research investigating the effects of using KW during back squat (BS) and none regarding vertical jump (VJ). This dissertation investigates the effects of wearing KW on BS and VJ performance through a series of studies. The first study was designed to observe acute and long term effects of using KW on VJ performance. VJ performance decreased when KW were worn and was not considered an ergogenic aid for VJ. The second study was designed to observe the effects of wearing KW on BS performance and the effects of two BS protocols on VJ performance by measuring VJ immediately before and after the completion of each BS protocol. Force, velocity and power characteristics of the BS improved after repeated testing and training BS protocols. The protocols had no effect on VJ performance. The third study required participants to perform the BS protocols with and without KW with a heavier training load and repetition volume as well as perform more post-exercise VJ tests compared to the second study. Observations suggest wearing KW improves BS performance and that VJ is unaffected by BS protocols designed for strength. Observations regarding wearing KWs during the BS and VJ include: 1) reduced VJ height, 2) increased BS concentric force, velocity, and power, 3) reduced BS eccentric velocity, 4) prevent decreases in BS concentric velocity and power in protocols with heavy training loads. These studies had several limitations including: 1) small sample sizes in each study (eight to twelve subjects completed each study), 2) fitness/athleticism of population (recreationally active college age males), 3) accuracy of measuring devices used during data collection of the VJ height (Vertec ± 1 inch) and BS performance (linear position transducer: distance ± 1cm, time ± 0.001s), 4) using one knee wrap material and technique across three studies. Future studies should test: 1) stronger more athletic populations, 2) BS and VJ protocols with varying intensity, volume and rest times, 3) a variety of knee wrap materials and techniques.

CHAPTER I: INTRODUCTION

Strength based sports such as powerlifting, Olympic weightlifting, and strongman have used knee wraps (KW) in practice and competition for several decades. However, social stigmas about their use such as limiting unassisted (raw) strength performance/gains, physical discomfort, and perceived increased risk of injury have contributed to declines in KW usage among strength athletes. The knee is wrapped when in extension and stores elastic energy during knee flexion. This elastic energy is released during knee extension. In previous studies, investigators applied KW treatments as an ergogenic aid for back squat (BS) (1-4) and isometric squat (5, 6).

Early literature investigated the mechanical assistance known as "carry over" of KW. Harman & Frykman (1) observed increased vertical force at the feet when participants wore KW during the BS. Participants performed the BS on a scale while suspended from a parachute harness. This method was used to quantify the amount of force needed to lower participants to the bottom position of BS with and without KW. The difference in reported scale weight (lbs) between conditions was considered significant (KW-82.1±12lbs, UW-57.1±9lbs, $p<0.01$).

Godawa and colleagues (3) observed significant increases in BS strength when powerlifters wore KW. The study consisted of two training groups: 1) powerlifters who wore KW during BS one repetition maximum (1RM) testing and BS training, 2) powerlifters who didn't wear KW during 1RM testing and training. Over the 10 weeks of training, the powerlifters who wore KW experienced a significant increase in their BS 1RM (Pre-511±112lb, Post-542±113lb; $p<0.05$). Powerlifters who trained without KW for ten weeks also experienced a significant increase in BS 1RM 1RM (Pre-339±116lb, Post-347±122; $p<0.05$). Pre/post group differences in 1RM were compared and not found to be significantly different ($p<0.10$). A limitation in the study was that no crossover design was used during BS 1RM testing or during the training period. However, BS protocols were matched between groups for relative load, set, and repetition training schemes for the duration of the 10 week training study.

Lake and colleagues (2) published a study examining the acute effects of wearing KW on BS performance and observed improved BS performance during a single training session when lifters wore KW. Using a within subjects design, participants performed the BS for 3 sets with KW and 3 sets without KW (UW) during the same training session in an order that was randomized and counter balanced.

Significant differences were observed between BS conditions with regards to peak power (KW-2121±1038W, UW-1841±835W; $p<0.05$, ES-1.1) and lifting vertical impulse (KW- 192±81N/s, UW-169±66N/s; $p<0.05$, ES-1.12).

Another KW study examined the effects of wearing KW on BS performance at multiple intensities (4). Gomes and colleagues (4) observed significant decreases in vastus lateralis (VL) surface electromyography (sEMG) activity at 90%1RM (Δ% 19.7, $p<0.05$, ES-0.64) and peak knee flexion angle at 60%1RM (Δ%-13, $p<0.001$, ES-1.38) and 90%1RM (Δ%-9.7, $p<0.05$, ES-0.86) when performing the BS wearing KW.

Despite the listed advantages described, the literature also discourages the use of KW due to discomforting effects of the KW. The treatment can cause lifters to experience immediate discomfort in the form of skin irritation, bruising, and restricted movement (1). Godawa and colleagues (3) observed complete occlusion when wearing a combination of squat suit and KW, which can cause loss of tactile sensation in the distal region of the leg. Another concern of using KW is the risk for injury during sessions requiring high intensity loads (>80%1RM). Lake and colleagues (2) expressed concerns that KW limited the contribution of hip flexors/extensors when performing the BS with KW.

In contrast, Harman & Frykman (1) proposed benefits of using KW such as: direct mechanical assistance when stretched over the knee, which aids knee extension by providing force, increased pliability and warming of the tissues in the knee via enhanced blood flow, increased proprioception (awareness) of knee joint angle possibly improving motor control and technique, and maintaining proper patellar tracking during the BS. The last proposed benefit is of greatest importance since it provides a biomechanical explanation of how to prevent knee injury when maximal forces are exerted on the knee joint. If a person has asymmetrical strength distribution in the quadriceps; specifically vastus lateralis and vastus medialis, their patella may be susceptible to pulling to one side when all muscles are producing their individual maximal force. Without KW, a great deal of motor control and neural inhibition would be needed to prevent the unnecessary patellar medial or lateral movement. Using KW may prevent the need for such neural inhibition and allow greater muscular force to be exerted when maximal weights are lifted (1).

Previous studies used different KW brands and techniques. Therefore, the validity of comparing the results of previous literature is confounded. In order to maximize similarity between studies for this dissertation: the brand (Titan Support Systems) and model (Max RPM) of knee wrap were the same in each study. In addition, the wrapping technique known as the "figure eight" or "X" used in previous studies 1, 2) was utilized in all three studies. Additionally, the same investigator applied the KW treatments to all participants for all familiarization periods and exercise protocols involving KW use.

Unfortunately, previous literature related to KW usage measured BS performance differently in each study. Harman & Frykman (1) only reported effects of vertical lifting force at the feet. Lake and colleagues (2) reported BS performance using a force plate to measure peak power and vertical impulse. Godawa and colleagues (3) measured 1RM strength of the BS during powerlifting competitions. Gomes and colleagues (4) measured surface electromyography (sEMG) activity of the vastus lateralis and gluteus maximus during the BS. Two recent KW studies measured force output on a load cell during the isometric squat (5, 6).

The purpose of this dissertation is to present a series of experiments to inform readers on the benefits of wearing KW during the BS. The series of studies in this investigation will use similar methodologies and measure similar performance variables allowing results between studies to be compared. Along with BS, VJ performance affected by KW use will also be investigated. VJ has a similar movement pattern to the BS when a countermovement is used to initiate the jump. Previous literature has established strong correlations between BS and VJ performance. Only one study has investigated the effects of using biomechanical ergogenic aids to improve VJ performance. Kraemer and colleagues (7) observed enhanced vertical jump performance when participants wore compression garments. VJ performance characteristics were reported as force, velocity, and power output. However, VJ height was not reported. For studies in this dissertation, VJ performance was measured with a Vertec device and BS performance was measured with a linear position transducer (Tendo Power Analyzer).

Using a three study model, this investigation examined: 1) the effects of wearing KW on VJ performance, 2) the effects of wearing KW on BS training and subsequent VJ performance, and 3) the effects of wearing KW on BS, post-exercise performance and performance recovery.

CHAPTER II: THE EFFECTS OF USING KNEE WRAPS ON VERTICAL JUMP PERFORMANCE

Introduction

The vertical jump (VJ) involves a complex synchronization of hip, knee, and ankle flexion followed by extension and must be coordinated with optimum efficiency and explosiveness in order to achieve maximum performance. Kraemer and colleagues (7) subjected elite college volleyball players to wearing compression shorts during VJ testing and measured force output in Newtons (N). Males wearing compression shorts experienced significant increases ($p<0.05$) in mean force (Control: 2047±50N, Compression Shorts: 1951±45N) and peak force (Control: 1937±1358N, Compression Shorts: 2208±651N) when performing the VJ.

To our knowledge, this is the only publication that reported improved VJ performance while using a biomechanical ergogenic aid. Compression shorts incase the hip joint and provide passive support to the hip extensors. Compression shorts are stretched during the hip flexion countermovement. The elastic energy stored during the countermovement is released during the concentric phase of the VJ. Knee wraps (KW) works under similar principle of storing elastic energy during knee flexion and releasing energy during knee extension. Since hip and knee extension are synchronized during the VJ, using KWs during VJ would have effects similar to wearing compression shorts in the study completed by Kraemer et al (2). However, the differences in the structure, anatomical location, and muscle mass associated with the hip versus knee joint makes it difficult to predict the effects of using KWs during VJ. In addition, Impellizzeri and colleagues (8) observed differences in force output between the left and right leg during VJ. Therefore based on previous research, it’s difficult to predict the effects of using KW on VJ performance when accounting for asymmetrical differences in left/right and hip/knee dominance during VJ.

Currently, we are unaware of previous studies examining the effect of short-term KW jump training on VJ performance. Therefore, the current experiment investigated the effects of a short-term knee wrapped jump training protocol on vertical jump performance. This investigation included three main purposes: 1) examine VJ performance through repeated measures (i.e. does VJ performance improve

over multiple sessions), 2) determine if the use of KW during VJ improves VJ performance versus without KW, 3) investigate the effects an extended training period with or without KW on VJ performance.

It was hypothesized that VJ performance without KW will not improve over multiple sessions while VJ performance with KW will improve over multiple sessions. In addition, it was hypothesized that using KW will not improve VJ performance. The KW technique used in this study is intended for the BS exercise. The KW has been observed as advantageous during the knee angle achieved in the lowest portion of the BS exercise which is <90 degrees. To date no published research has reported benefits of using KW during unloaded VJ, where knee angles achieved during countermovement phase of the VJ are ≥90 degrees. Lastly, it was hypothesized that VJ training with KW may cause further improvements in VJ performance, but VJ performance without KW will still be greater.

Methods

Experimental Approach to the Problem

Previous studies have used force plates (7, 8, 10, 11, 12, 13, 14, 15, 16), jump mats (17, 18), video cameras (10, 11, 17), and Vertec devices (17, 19, 20) to measure VJ performance. Force plates have traditionally been used to analyze peak force and peak power during the initial take off phase of the VJ. However, the force plate method does not directly measure VJ height; instead it estimates VJ height using calculations based off combinations of force, velocity, and/or power measurements recorded by the computer. Jump mats are similar to force plate measurements with regards to the direct measurements of VJ performance characteristics (force, velocity, power) and flight time; take off phase until initial landing phase. The Vertec device requires participants to make direct contact with marked tabs that are measured at increments of one inch or 2.54 centimeters(cm). VJ height is directly estimated by recording the difference between the highest tablet moved with an outstretched hand at maximal height during flight time and the maximal height that a participant can move with an outstretched hand while standing on both feet. Thus, the Vertec device was proposed as the most direct measurement of VJ height with regards to this study.

Previous studies observed favorable test-retest reliability when performing VJ tests on two separate days (17, 19). . Participants performed the VJ test with and without KW on the same day on three separate days using a timeline based on a previous study that compared lower limb performance at

different velocities using an isokinetic dynamometer (21). The set and repetition scheme for the VJ test in this experiment was used in a previous study (9). This VJ test was also used to evaluate fatigue induced by BS protocols in subsequent studies of this dissertation.

The VJ test was performed on three separate days was to determine if an extended training period with or without KW affects VJ performance. A training timeline and protocol used by Prevost and colleagues (21) was applied to VJ training and carried out between the second and final VJ test. The timeline for the training period is considerably shorter than training periods used in previous studies which lasted several weeks (10, 22). However, if using KW does significantly enhance VJ performance, subsequent studies could use shorter training periods to as familiarization periods for subsequent studies. If VJ improves from $Test_1$ or $Test_2$ to $Test_3$, future studies would only need a two day familiarization period to improve VJ performance with KW. However, if VJ performance improves from $Test_1$ to $Test_2$, subsequent studies would only require one session of training as a familiarization period for using KW to improve VJ.

Participants

Adult males (mean age 27 ± 3 years) who participated in at least 30 minutes of physical activity per week and were free of lower body injuries for at least two years were recruited for this study. Eight participants volunteered to participate in the present study. Participant characteristics are presented in table 2.1. To be considered for participation, individuals were required to complete a physical activity readiness questionnaire (PAR-Q) to ensure they did not have any contraindications for exercise. All procedures were explained verbally and in written form prior to giving informed consent. Procedures and consent forms were approved by Institute Review Boards at Louisiana State University (LSU) and Kent State University (KSU). Participants were also required to demonstrate their ability to perform VJ and receive the KW treatment prior to entry into the study.

Procedures

After meeting the requirements to pass the PAR-Q and providing informed consent, participants underwent a familiarization session where they practiced the VJ with and without KW. During this time, baseline characteristics for height, weight, and body composition were measured. Height was measured to the nearest millimeter via a stadiometer. Mass was measured to the nearest 0.1 kilograms using a

balance beam scale (Health O Meter, Chicago, IL). Body composition was measured using a 7-site skinfold test to estimate body density (23) and the Brozek equation was used to quantify% body fat (24). Within the week of completing VJ familiarization, all participants performed three VJ tests and two VJ training sessions over an eleven day time period.

Participants performed VJ test protocols on day 1 ($Test_1$), 4 ($Test_2$), and 11 ($Test_3$) during the experiment. Participants were randomly assigned to a group that trained VJ with KW (TW) or without KW (TU) for 2 sessions ($Train_1$ and $Train_2$) between $Test_2$ and $Test_3$. The timeline displayed in Figure 2.1 is similar to a learning model that was used in a study by Prevost and colleagues (21).

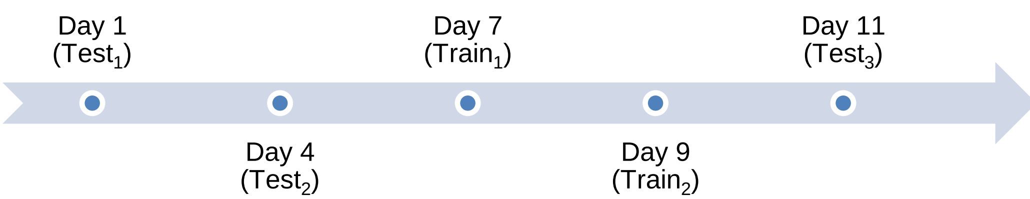

Figure 2.1: Timeline for vertical jump test and training days

<u>KW Treatment:</u> The knee wraps used in this study (Max RPM, Titan Support Systems) are two meters in length. The technique used on all participants; known as the “figure 8” or “X”, has been used in previous studies (1, 2). Participants were wrapped with seven revolutions using a technique established by previous studies. Knee wraps were secured with a slipknot that was created with the assistance of the participant using a lifting strap. Participants were able to remove the KW quickly by pulling the exposed tail of the knee wrap towards the foot; which untied the slipknot. Depicted below (Figure 2.3) from left to right top to bottom is the demonstration of the knee wrap technique and the procedure to secure the KW with a slipknot.

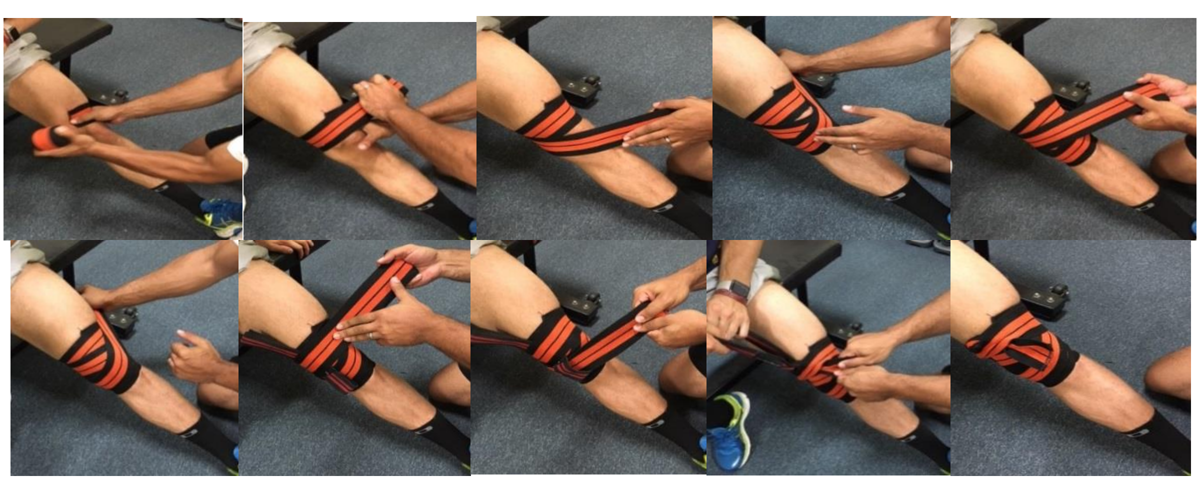

Figure 2.2: Arranged left to right, top to bottom is a demonstration of the knee wrap technique and slipknot procedure used to secure the knee wrap.

Measures

VJ Performance: As instructed by National Strength and Conditioning Association (NSCA) guidelines (25), participants started in an athletic stance directly below the Vertec. The VJ was initiated when participants flexed at the hip, knee, and ankle into a partial squat position while moving the arms down and back. When self-selected depth was reached, participants jumped with maximal effort reaching for the highest possible tab on the Vertec device with their dominant hand. The difference between highest tab reached standing and the highest tab reached during the jump was recorded as VJ. Tabs on the Vertec were separated by increments of one inch (2.54 centimeters). An illustration of the standing reach, counter movement, and jump are all depicted below in Figure 2.3.

Figure 2.3: Arranged left to right are the standing reach, counter movement, and jump positions associated with vertical jump.

Exercise Protocols

VJ Test Protocol: Participants rested in a seated position for ten minutes. Then, participants performed one set of five VJ without KW (Set_1) with twenty seconds rest between jumps. After a five minute rest period, participants performed one set of five VJ with KW (Set_2).

VJ Training Protocol: Participants rested in a seated position for ten minutes. Then, participants performed three sets of ten VJ with twenty seconds rest between jumps and five minutes rest between each set of ten. Participants were randomly assigned to a group that trained all sets with KW (TW) or without KW (TU).

Statistics

A three-way repeated measure Analysis of Variance (ANOVA) was used to compare training time ($Test_1$, $Test_2$, $Test_3$), set (UW=Set_1, KW=Set_2), groups (TW, TU) for VJ height. Significance for ANOVAs was set at alpha level $p<0.05$. Partial Eta^2 was used to interpret effect sizes of ANOVAs. Effects sizes were defined as small (0.10), medium (0.25), and large (0.40) based on a previous study also using a small sample size (26). Post-hoc analysis was done with a Bonferroni correction using paired sample and independent t-tests to investigate within subject interactions and between subject interactions, respectively. Because each post-hoc analysis required varying numbers of t-tests, the alpha level required for significance during post-analysis also varied. Test-retest reliability between $Test_1$ and $Test_2$ was established with intra-class correlation coefficients. Statistical analysis was performed with SPSS Statistics 21. All data are presented as mean ± standard deviation.

Results

Baseline Characteristics

There were significant ($p \leq 0.05$) main effects of group for training group such that the UW group had significantly higher body fat percent than the KW group. However, group differences were not observed with regards to fat mass ($p=0.06$) and fat-free mass ($p=0.57$). Thus, groups were considered matched for both fat and fat free mass, and age.

Table 2.1 Baseline Characteristics

Group	TU (n=5)	TW (n=5)	Significance
Age (yr)	28 ± 2	27 ± 4	p=0.76
Height (m)	1.81 ±0.07	1.74 ±0.01	p=0.09
Mass (kg)	94.7 ± 14.6	86 ± 16.3	p=0.36
Sum of 7 Skinfolds(mm)	158.7 ± 64.2	104.34 ± 39.1	p<0.05
%Body Fat	28.5 ± 12.7	17.6 ± 7.8	p<0.05
Fat Free Mass (kg)	67.7 ± 6.9	70.9 ± 5.9	p=0.57
Fat Mass (kg)	27 ± 14.7	15.1 ± 11	p=0.06

TU-Unwrapped training group, TW- Knee wrapped training group

Vertical Jump

VJ failed to pass Mauchly's test of spherity ($p=0.003$), and the GG correction factor revealed significant main effects for day ($p<0.001$), and interactions for day*set ($p<0.001$), day*group ($p<0.001$),

and day*set*group ($p<0.01$). Small effect sizes were observed in main effect for day (Partial Eta^2=0.2), day*set interactions (Partial Eta^2=0.143), day*group interactions (Partial Eta^2=0.16). Meanwhile, the effect size was observed in day*group*set interactions (Partial Eta^2=0.064) was considered less than small, therefore its significance is questionable. The results of the ANOVA are tabulated in table 2.2.

Table 2.2 Vertical Jump ANOVAs

Effects	F	Significance	Partial Eta^2
Day	23.802	p<0.001	0.200
Day*Set	15.796	p<0.001	0.143
Day*Group	18.941	p<0.001	0.166
Day*Group*Set	6.536	p=0.003	0.064

Post-hoc analysis for day*set interaction required a total of nine paired samples t-tests (Figure 2.4). This resulted in the alpha level being reduced from $p<0.05$ to $p<0.0056$. A day*set interaction was observed such that on all test days, Set_1 ($Test_1$- 59.0±7.7cm, $Test_2$- 59.2±8.7cm, $Test_3$- 59.9±9.1cm) was significantly greater ($p<0.001$) than Set_2 ($Test_1$- 38.8±12.1cm, $Test_2$- 44.3±14.5cm, $Test_3$- 47.0±19.6cm). In addition, Set_2 of $Test_1$ was significantly less ($p<0.001$) than $Test_2$ and $Test_3$. Set_1 did not change significantly over time for either group. In addition test-retest reliability for using the Vertec (Test1:Test2) was high (ICC=0.945).

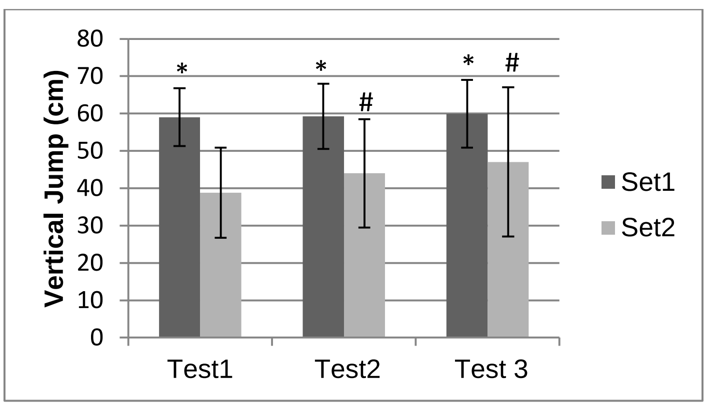

Figure 2.4: Mean (±SD) vertical jump grouped by day ($Test_1$, $Test_2$, and $Test_3$) and set (Set1-Without knee wraps, Set2- With knee wraps). * indicates Set_1 is significantly greater ($p<.001$) than Set_2 within the same test. # indicates Set_2 of $Test_1$ is significantly less ($p<0.001$) than Set_2 of $Test_2$ and $Test_3$.

Post-hoc analysis of the three way interaction (day*set*group) required a total of 24 t-tests effectively reducing the alpha level from $p<0.05$ to $p<0.0021$. Set_1 was observed to be significantly different ($p=0.002$) between groups on $Test_3$ (TW- 63.8±7.7cm, TU- 56.1±8.9cm). The TW group improved VJ on Set_2 every test day such that VJ on Set_2 for $Test_1$ (37.8±11.7cm) was significantly less

(p<0.01) than $Test_2$ (46.3±16.0cm) and $Test_3$ (52.5±18.8cm). In addition, Set_2 of $Test_2$ was considered significantly less (p<0.001) than $Test_3$. The most important result is that both groups experienced a significant decrease in VJ (p<0.001) during Set_2 on all three test days.

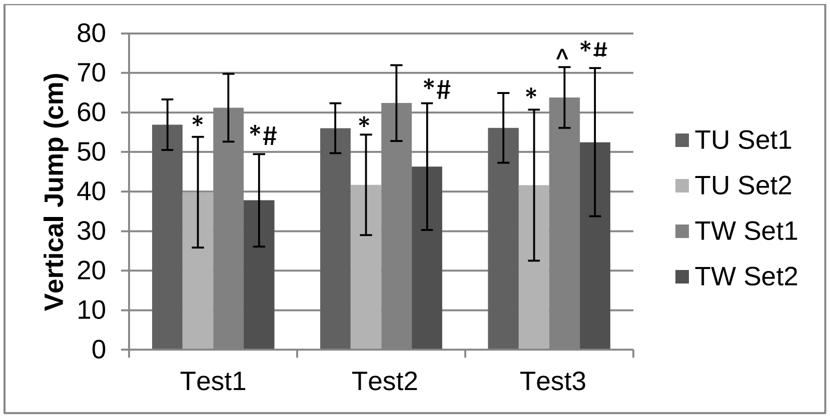

Figure 2.5: Mean (±SD) vertical jump grouped by day ($Test_1$, $Test_2$, $Test_3$), set (Set_1, Set_2), and training group (Training unwrapped=TU, Training with knee wraps=TW). * indicates a significant difference (p<0.001) from Set_1 within the same training group. # indicates a significant difference (p<0.001) between test days for Set_2 in group TW. ^ indicates a significant difference (p=0.002) between training groups during Set_1 on $Test_3$.

VJ percent change between sets [VJ%Δ=(Set_2-Set_1)/Set_1] was analyzed using repeated measures ANOVA in order to account for the difference in baseline (Set_1) VJ performance on $Test_3$. Using VJ%Δ as a dependent variable to test for main effect of day and day*group interaction, a main effect for day was still observed (p<0.05, Partial Eta^2-0.315) but no day*group interaction was detected (p=0.179). Paired samples t-tests revealed a significant difference (p<0.05) in VJ%Δ between $Test_1$ (-34.8±16.1%) and $Test_2$ (-26.1±19.5%), but not $Test_3$ (-24.4%).

Discussion

The sample population consisted of 8 healthy active college age males whose average VJ without KW was 59±8cm. Previous studies that used the same VJ technique and measured with a Vertec device reported lower VJ heights of approximately 39cm (17) and 51cm (19). According to the NSCA, the population sampled in this study had a VJ score that was similar to recreational college athletes (61cm) (25). A recent study observed greater VJ scores in track athletes (62cm) and football players (68cm) (20). Competitive athletes spend more time training to increase their VJ and might respond differently to the KW treatment during VJ testing or training. In addition, competitive powerlifters might respond differently to KW treatments because they have more experience with using KW applied extremely tight.

Competitive powerlifters and athletes also tend to have different body compositions compared to participants from this study if matched for body mass. Therefore, future research should investigate the effects of using KW on populations such as competitive athletes and powerlifters.

Of the eight participants who volunteered to participate in the study, two of them underwent testing in both training groups while six participants completed only one of the training groups (three in TW and three in TU). Therefore with regards to a between subjects design, a total of five participants belonged to each training group. Separate analyses of baseline characteristics and VJ of eight participants completing the study once is in Appendix IV.

The observation of decreased performance is different from previous studies by Harman & Frykman (1) and Lake et al (2). The investigator applied maximum tension while wrapping the participants' knees and was unable to complete nine revolutions similar to the study by Lake and colleagues (2). Thus, the KW material (Max RPM, Titan Support Systems) used in this studies was stiffer compared to KW material used in previous literature. It is possible that the two extra revolutions allowed the KW to be more resistant to stretch. This increase in stiffness could have then yielded a greater stored elastic energy and thus, a greater stored elastic energy return. Having two fewer revolutions also reduced potential surface area that was covered. Harman & Frykman (1) referenced standards of international powerlifting competitions; which specify that coverage may not exceed 15cm above or below the center of the knee. This means total coverage must not exceed 30cm from the most superior edge to the most inferior edge of KW coverage. This study adhered to these guidelines, so perhaps 30cm may not have covered enough surface area to provide sufficient leverage to the knee joint. Future studies examining the use of knee wraps on jump performance should compare different brands of knee wrap material as well as different knee wraps techniques. A pattern known as the spiral technique is mentioned in two recent studies (4, 6), but it was not reproducible via their description. Without knowing the exact method of the spiral technique the spiral could be performed at least four different ways starting superior/inferior to the patella and wrapping in a circular pattern in a medial to lateral/lateral to medial direction. The "X" pattern was demonstrated with both pictorial and written instruction in two previous studies (1, 2). Thus, it was chosen to be used for all studies involved in this dissertation.

In conclusion, VJ performance can be improved when wearing KW when practiced for multiple sessions. However, the reduction in VJ performance; compared to VJ without KW, on all three test days suggests that participants did not benefit from wearing KW to enhance VJ performance. In addition, the group that trained with KW (TW) experienced a significant increase in VJ with KW (Set_2) between $Test_1$:$Test_2$ and $Test_2$:$Test_3$. Practicing VJ without KW for multiple sessions did not improve VJ performance. In conclusion, future studies should not use KWs as biomechanical ergogenic aids for VJ. The VJ test used in this study had high test-retest reliability (ICC=0.945) and should be used to estimate VJ in future research.

CHAPTER III: THE EFFECTS OF USING KNEE WRAPS ON BACK SQUAT AND VERTICAL JUMP PERFORMANCE.

Introduction

Widespread use of KW during back squat training in power-lifting and Olympic weight-lifting athletes has raised questions regarding the effectiveness of this practice as an ergogenic aid. Researchers suggest using knee wraps during back squats can cause alterations in force output (1, 5, 6), power output (2), 1RM (3), and muscle activation (4). Unfortunately, the few BS studies that have focused on using KW as an ergogenic aid for BS have used dissimilar methods to measure performance. For example, Harman and Frykman (1) used a scale to measure vertical force (pounds) from applied from the feet while participants descended to the bottom position of the BS. Later KW studies (5, 6) used a load cell to measure force; expressed as Newtons(N), while participants performed an isometric squat from the bottom position. Godawa and colleagues (3) evaluated BS 1RM using a between subjects design to compare the BS with KW versus without. Additionally, BS 1RM was not assed in a laboratory setting for this study. Instead two USA Powerlifting sanctioned competitions were used to measure BS 1RM before and after a ten week resistance training program. In addition to KW, powerlifting competitions allow lifters to wear squat suits, wrist wraps, erector shirts, and lifting belts during competition. Because Godawa and colleagues (3) did not isolate the effects of KW in their study, it is difficult to quantify the contribution of KW to BS performance as measured by 1RM. Gomes and colleagues (4) published the most recent study related to KW and BS performance and they measured BS performance via surface electromyography (sEMG) activity of lower body musculature(vastus lateralis, gluteus maximus), peak flexion angles of the knee and hip during BS descent, and vertical barbell displacement. Investegators of the study by Gomes and colleagues (8) mentioned using a force plate and video camera to collect kinematic and kinetic data of BS performance. However, no data was published in their results with regards to force, velocity, and power characteristics. Thus far, only one study by Lake and colleagues (2) has investigated the effects of KW using measurement techniques that quantify BS performance as power. They used force plate readings; which measures vertical ground reaction force, to calculate power. Unfortunately power is not an absolute measurement, but an expression of force multiplied by velocity (2). Force and velocity characteristics of the BS were not

published by Lake and colleagues (2) so it is unclear which components of power (force or velocity) are affected by KW. Last of all, no studies have tested the effects using KW on BS performance characteristics using a repeated measures design. Thus, it is difficult to determine the reliability of published result in literature related to KW and BS performance.

In summary, previous literature is unable to explain the benefits of using KW as an ergogenic aid for the BS. Therefore, the purpose of this study was to: 1) examine BS performance (with and without KW) through repeated measures, 2) determine if using KW during BS improved performance characteristics (force, velocity, power), 3) determine if an extended training period (with or without KW) affected BS performance characteristics, 4) determine if BS protocols with single and multiple repetition sets can cause fatigue observed as a decline in vertical jump (VJ) from pre to post-exercise.

It was hypothesized that BS performance would improve regardless of condition (with and without KW). It w also hypothesized that using KW would improve BS within the same session. In addition, it was also hypothesized that an extended training period for BS (with or without KW) would improve performance. Lastly, it was hypothesized that BS protocols used in this study would not induce fatigue as reflected by a decline in VJ performance from pre to post-exercise. The BS protocols used in this study were not designed to fatigue participants. They were designed to be performed with maximal force, velocity, and power output; regardless the number of sets or repetitions.

Methods

Experimental Approach to the Problem

BS performance testing was performed on three separate days ($Test_1$, $Test_2$, $Test_3$) using a timeline that was similar to the VJ study discussed in Chapter II and repeated measures study published by Prevost and colleagues (21). Training loads for BS protocols in this study were based on 1RM. Thus, the timeline for this study was extended to eighteen days. This allowed for BS 1RM to be assessed using a repeated measures design. BS performance characteristics were measured with and without KW on the same day using a model established by Lake and colleagues (2) was used in a repeated measures design. To investigate the effects of extended training period with or without KW, participants carried out the extended training period between the second ($Test_2$) and final ($Test_3$) BS test. A randomized training group assignment determined if participants performed BS training with KW (TW) or without KW (TU). To

test the ability of BS testing and training protocols to induce fatigue participants, a VJ test was carried out before starting (Pre) and after the completion (Post) of BS protocols. VJ has been used in previous studies to quantify fatigue induced by BS protocols (9, 14, 15, 16, 20).

Participants

Healthy adult males (mean age 25±5 years) who had been performing lower body resistance training for at least 3 months and were free of lower body injury for 2 years were recruited for this study. Nine participants volunteered for this study. After receiving oral and written explanations of all procedures related to the study, participants gave their informed consent. All procedures and consent forms were approved by Institute Review Boards at Louisiana State University and Kent State University.

Procedures

After participants gave informed consent, they underwent familiarization. During this time, baseline characteristics for height, weight, and body composition were measured. Height was nearest centimeter (cm) via a stadiometer. Weight was measured to the nearest kilogram using a balance beam scale (Health O Meter, Chicago, IL). Body composition was measured using a 7-site skinfold test to estimate body density (23) and the Brozek equation was used to quantify % body fat (24). The familiarization period lasted one session and consisted of practicing the VJ technique for five repetitions and, the BS technique with KW for two repetitions. Before practicing either movement, participants received the KW treatment and repeated the process until they felt comfortable with practicing the BS with KW. After familiarization, participants were randomly assigned to a group that trained with (TW) or without KW (TU) during the BS training protocols.

Within one week of familiarization, participants performed two BS 1RM tests. Each 1RM test was separated by three days, such that the first test ($1RM_1$) occurred on day one and the second test ($1RM_2$) occurred on day four. The greatest 1RM achieved regardless of session was used to establish training loads for the next two weeks of BS testing and training. BS testing occurred on three separate days, such that the first test ($Test_1$) occurred on day eight, the second test ($Test_2$) occurred on day eleven, and the final test ($Test_3$) occurred on day eighteen. BS training days occurred on two separate days, such that the first training day ($Train_1$) occurred on day fourteen and the second training day ($Train_2$) occurred

on day sixteen. This set up is similar to the learning model established by Prevost and colleagues (21). The timeline used for scheduling BS sessions for participants is listed below in figure 3.1.

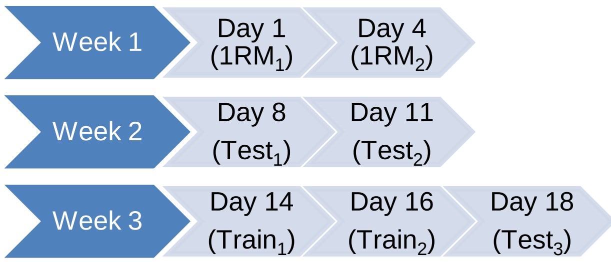

Figure 3.1 Timeline for Back Squat Testing and Training Sessions

KW Treatment: All aspects of the KW treatment described in Chapter II and demonstrated in Fig. 2.2 were used in all protocols required participants to perform the BS with KW. The experimenter, type of KW (Titan Support Systems, Max RPM, 2m length), and technique ("X" pattern for seven revolutions and secured with slipknot) used to apply the KW treatment were consistent among all subjects.

BS Technique: During all protocols participants were handled by at least two trained spotters and BS depth was performed to the standards of the NSCA guidelines (25). Participants performed the BS in a reinforced steel power rack that had safety pins set to catch the barbell if the lifter failed an attempt and/or descended below a parallel depth. To initiate the BS, participants supported a loaded barbell with the shoulders, trapezius, and hands and stand up with the barbell from racked position. Participants would walked at least 2 steps backwards and place their feet in their preferred squat stance. After optimal foot placement was achieved, participants descended to a parallel position; the top of the thighs parallel with the floor (2, 25). Participants then ascended with maximal force, velocity, and power during the BS exercise. During working sets of BS Testing and BS Training protocols, participants would attach a linear position transducer; specifically the Tendo Power Analyzer (TPA), to the waist band of their shorts. Examples depicting the standing and parallel position of the BS with the TPA attached to the waist band are displayed below (Figure 3.2).

Figure 3.2: The standing and parallel position of the back squat exercise. Participants were always monitored by two trained spotters.

Measures

BS Performance: The TPA was used to evaluate multiple performance characteristics of the BS exercise. The TPA samples absolute measurements of vertical displacement (0.01m) and time (0.001s) to calculate force, velocity, and power. Velocity (±0.01m/s) is calculated as displacement divided by time and expressed as average concentric velocity (AV), average eccentric velocity (EV), and peak concentric velocity (PV). Force (±1N) is calculated as the difference of two velocities (V_2-V_1) divided by the difference of two time points when respective velocities were sampled (T_2-T_1) and expressed as peak concentric force (PF). Power (±1W) is calculated as the product of force multiplied by velocity and is expressed as average concentric power (AP) and peak concentric power (PP). The TPA was used to record BS performance characteristics during BS testing and training protocols. Data that was recorded was saved to a password protected computer. A previous study has established the use of the TPA as a valid and reliable measuring device for BS performance (28). Validity was lower in PP (ICC=0.853) and PV (ICC=0.963) compared to AV (ICC=0.985) and AP (ICC=0.966) when measured with the TPA according to Garnacho-Castano and colleagues (28). However, test-retest reliability during the BS, was reported as high for AV (ICC=0.982), AP (ICC=0.966), PV (ICC=0.969), and PP (ICC=0.922). Traditionally barbell displacement has been used to measure power during the BS. A recent study by Lake and colleagues (28) reported that calculating power based on measurements of barbell velocity causes overestimations of power applied to center of mass when compared to velocities of the trunk and thigh. Lake and colleagues (28) reported velocities of the barbell to be 57% greater thigh velocity and 14-19% greater trunk velocity. The waistline is positioned between the trunk and thigh, thus displacement

was tracked at the participants' waistline instead of the barbell. An example of the TPA and bluetooth device which sends performance data wirelessly is displayed below (Figure 3.3).

Figure 3.3: The Tendo Power Analyzer consisting of a bluetooth, microcomputer, tripod stand, and weight lifting mat which is positioned under the participant to record back squat performance.

<u>VJ Performance:</u> A VJ test established in our previous research was used in this study to assess the ability of BS protocols to fatigue participants. As displayed in Fig 2.3, participants performed a countermovement then jumped with maximal effort reaching towards the highest tab on a Vertec device using their dominant hand. VJ was recorded as the difference of the highest tab reached during VJ and the highest tab reached in standing position.

<u>Exercise Protocols</u>

<u>BS 1RM Test:</u> Warm up sets and all 1RM attempts were performed without KW. The warm up portion of the protocol was similar to previous studies with regards to set and repetitions schemes (2, 29). Differences in the protocol include using five minute rest periods for warm up sets and 1RM attempts as well as allowing five attempts to achieve a 1RM instead of three attempts as used in previous studies (2, 3, 28). The protocol for the 1RM Test is displayed below.

- (0 min.)- Sit quietly for 10 minutes.
- (10 min.)- Perform 10 repetitions of BS with 50% of estimated 1RM.
- (15 min.)- Perform 5 repetitions of BS with 70% of estimated 1RM.
- (20 min.)- Perform 3 repetitions of BS with 80% of estimated 1RM.
- (25 min.)- Perform 1 repetition of BS with 90% of estimated 1RM.
- (30-50 min.)- Perform 1 repetition of BS with estimated 1RM. Each repetition counted as an attempt. Lifters rested 5 minutes between attempts and were allowed up to 5 attempts per session.

<u>BS Testing:</u> A previous study (2), established a way to test BS power using single repetition sets and observed a significant difference ($p<0.05$, ES-1.10) in BS power when wearing KW (PP-2121±1038W)

compared to not wearing KW (PP- 1841±835W). Lake and colleagues (2) performed this protocol once on ten participants. In addition to the BS test protocol, participants performed a VJ test before and after the protocol. The purpose of the two VJ tests was to test the ability of the BS Testing protocol to induce a level of fatigue that would jeopardize participants' performance. The time line for the BS protocol is displayed below.

- (0 min.)- Weigh in and sit quietly for 10 minutes.
- (10 min.)- Perform 5 repetitions of VJ with 20 seconds rest between jumps.
- (15 min.)- Perform 10 repetitions of BS with 50% 1RM.
- (20 min.)- Perform 5 repetitions of BS with 70% 1RM.
- (25-35 min.)- Perform 3 single repetition sets of BS without KW. Each set was separated by 5 minutes.
- (40-50 min.)- Perform 3 single repetition sets of BS with KW. Each set was separated by 5 minutes rest.
- (51 min.)- Perform 5 repetitions of VJ with 20 seconds rest between jumps.

BS Training: The purpose of this protocol was to practice the BS with one training condition (with or without KW) for all sets. Participants were randomly assigned to one training condition for both days. Similar to the BS Test protocols, a VJ test was administered before and after the training protocol in order to assess the ability of BS Training protocols to induce a level of fatigue that would jeopardize participants' performance.

- (0 min.)- Weigh in and sit quietly for 10 minutes.
- (10 min.)- Perform 5 repetitions of VJ with 20 seconds rest between jumps.
- (15 min.)- Perform 10 repetitions of BS with 50% 1RM.
- (20 min.)- Perform 5 repetitions of BS with 70% 1RM.
- (25-50 min.)- Perform 3 repetition sets for 6 sets with 80%1RM. Participants were randomly assigned to perform all sets either with or without KW.
- (51 min.)- Perform 5 repetitions of VJ with 20 seconds rest between jumps.

Statistics

VJ performance was analyzed using repeated measures ANOVA to test for effects of day ($Test_1$, $Test_2$, $Training_1$, $Training_2$, $Test_3$), group (TU=UW Training, TU= KW Training), and set (Pre-Ex= Set_1,

Post-Ex=Set_2). To determine normality, Mauchly's test of sphericity was used. If the p-value was <0.05, the Greehouse-Geisser (GG) correction factor was applied. Test-retest reliability of the Vertec during test days ($Test_1$:$Test_2$) and training days ($Train_1$:$Train_2$) were examined with ICCs.

BS performance for testing and training protocols had to be tested in separate repeated measures ANOVAs. GG correction factor was applied to any performance variables that did not pass Mauchly's test of sphericity. BS testing protocols were analyzed by day ($Test_1$, $Test_2$, $Test_3$), group (KW training, UW training), and condition (BS with KW= KW, BS without KW= UW). Significant ($p<0.05$) day*group interactions were examined with independent samples T-tests while day*condition interactions were analyzed with paired samples t-testing. BS training protocols were also analyzed for day ($Train_1$, $Train_2$), group (KW training, UW training), and set (1-6) interactions. Independent samples t-tests were used to examine day*group interactions and paired samples t-tests to examine day*set interactions. In addition, test-retest reliability of BS performance characteristics during test days ($Test_1$:$Test_2$) and training days ($Train_1$:$Train_2$) were examined with ICCs.

Significance for ANOVAs was set at alpha level $p<0.05$. Partial Eta^2 was used to interpret effect sizes of ANOVAs, defined as small (0.10), medium (0.25), and large (0.4). Post-hoc analysis was done with a Bonferroni correction using paired sample and independent t-tests to investigate within and between subject interactions, respectively. Because each post-hoc analysis required different amounts of tests, the alpha level varied according to the number of t-tests performed for that analysis. Statistical analysis was performed with SPSS Statistics 21. All data are presented as mean ± standard deviation.

Results

Baseline Characteristics

Five participants completed the study in both training groups and four participants completed only one training group; a total of nine participants. There were no significant differences between groups for any baseline characteristics. BS 1RM significantly increased between sessions (1RM $Test_1$-139.2±23.0kg, 1RM $Test_2$-143±23.3kg, p=0.006) with no difference between training groups. Test-retest reliability between 1RM sessions was considered high (ICC=0.991). Baseline characteristics including the best 1RM achieved over two sessions is presented in Table 3.1.

Table 3.1 Baseline Characteristics

Group	TU (n=7)	TW (n=7)	Significance
Age(yr)	24±5	26±4	p=0.27
Height(m)	1.77±0.08	1.81±0.06	p=0.06
Mass(kg)	81.4±3.84	88.4±13.68	p=0.21
Sum-7(mm)	100.2±25.9	110.3±52.9	p=0.70
%Body Fat	16.33±5.07	18.64±10.22	p=0.66
Fat Free Mass(kg)	68.07±4.18	70.89±4.67	p=0.23
Fat Mass(kg)	13.36±4.46	17.54±13.28	p=0.51
1RM	143.21±25.1	143.86±22.78	p=0.96

TU-Unwrapped training group, TW- Knee wrapped training group

VJ Performance

The VJ did not pass Mauchly's test of sphericity (p=0.003) and the GG correction factor had to be applied to corresponding p-values for the ANOVA. The ANOVAs only revealed significant day*group interactions (p<0.001). However, the observed effect size for the day*group interaction was less than small (Partial Eta^2= 0.057). The absence of a three way interaction (day*group*set) did not allow for post-hoc analysis to determine what was driving the day*group interaction.

A total of twenty-five t-tests (twenty paired samples, five independent samples) were performed in post-hoc analysis for day*group interactions, reducing the alpha level from p<0.05 to p<0.002. As displayed in figure 3.4, significant interactions were observed such that the TU group had a significantly greater VJ than TW on days Train$_2$ (TU-60.3±6.1cm, TW-55.9±6.5cm, p<0.001) and Test$_3$ (TU-60.4±5.9cm, TW-56.2±4.9cm, p<0.001). However, when percent change of VJ [VJ%Δ=(Set$_2$-Set$_1$)/Set$_1$] was analyzed using repeated measures ANOVA, no day*group interactions were observed (p=0.504). With regards to pre to post-exercise changes in VJ, training groups (TU, TW) were not different on any BS testing or BS training day. Test-retest reliability for the VJ was considered high between Test$_1$:Test$_2$ (ICC=0.935) and between Train$_1$:Train$_2$ (ICC=0.955).

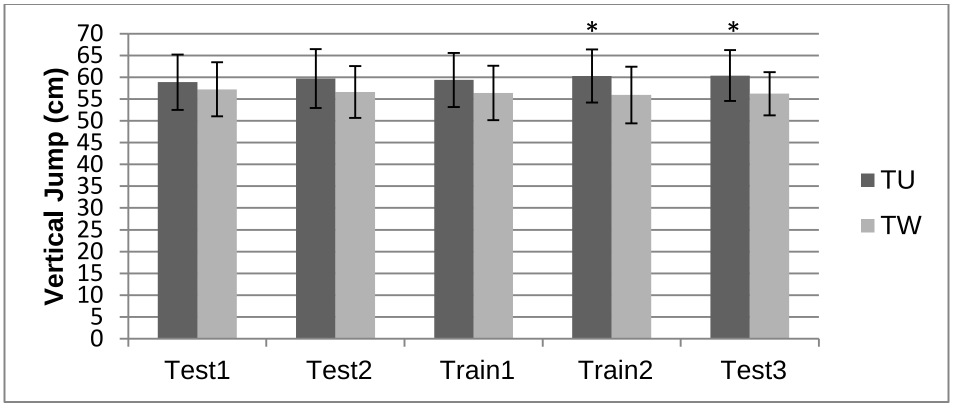

Figure 3.4: Mean VJ (±SD) grouped by day ($Test_1$, $Test_2$, $Train_1$, $Train_2$, $Test_3$) and training group (Training unwrapped=TU, Training with knee wraps=TW). * indicates a significant difference (p<0.001) between training groups.

<u>BS Testing</u>

Two BS performance characteristics failed to pass Mauchly's test of sphericity; EV (p=0.024) and PV (p=0.029). Thus, the GG correction factor was applied to both significant p-values of EV and PV for their respective ANOVAs. No three way interactions were observed in ANOVAs of BS performance characteristics with regards to BS Testing protocols. However, significant test day*condition interactions were observed in BS performance characteristics such as AV (p=0.049) and EV (p=0.018). Effect sizes were considered less than small for both AV (Partial Eta^2=0.037) and EV (Partial Eta^2=0.051). Table 3.3 displays the results of the ANOVAs that tested positive for day*condition interactions.

Table 3.2 Back Squat 3*2 (Test Day*Condition) ANOVAs

Back Squat Performance Variable	F	Significance	Partial Eta^2
Average Concentric Velocity	3.083	p=0.049	0.037
Average Eccentric Velocity	4.272	p=0.018	0.051

Post-hoc analysis of test day*condition interactions were examined with 24 paired samples t-tests, thus reducing the alpha level from p<0.05 to p<0.0021. Conditions for BS performance were significantly different (p<0.001) such that wearing KW significantly increased (p<0.001) AV during $Test_2$ and $Test_3$. In addition, wearing KW significantly decreased (p<001) EV on all three test days. Significant differences in AV (p≤0.001) between $Test_1$ and $Test_3$ and $Test_2$ and $Test_3$ were observed during the BS with and without KW. In addition, participants significantly increased (p<their AV on BS under both conditions on $Test_3$ compared to $Test_1$ and $Test_2$. EV was not significantly different between test days without KW. However, a significant increase (p<0.001) was observed between $Test_1$ and $Test_3$ for EV when BS was performed with KW. The results of test day*condition interactions are listed in Figure 3.5.

Test day*condition interactions were observed in AV (p=0.049) such that wearing KW improved AV during $Test_2$ (UW-0.40±0.06m/s, KW-0.44±0.09m/s, p<0.001) and $Test_3$ (UW: 0.44±0.05m/s, KW: 0.49±0.08m/s, p<0.001). Improvements to AV were observed in the UW BS condition such that $Test_3$ (0.44±0.05m/s) were considered significantly greater than $Test_1$ (0.41±0.07m/s, p<0.001) and $Test_2$ (0.40±0.05m/s, p=0.001). Improvements were also observed in the KW BS condition such that $Test_3$ (0.49±0.08m/s) was considered significantly greater than $Test_1$ (0.44±0.09m/s, p<0.001) and $Test_2$ (0.44±0.09m/s, p<0.001). Day*condition interactions were also observed in EV (p=0.018) such that wearing KW decreased EV during $Test_1$ (UW-0.33±0.10m/s, KW-0.22±0.08m/s, p<0.001), $Test_2$ (UW-0.33±0.08m/s, KW-0.25±0.08m/s, p<0.001), $Test_3$ (UW-0.35±0.09m/s, KW-0.28±0.08m/s, p<0.001). Improvements were observed in the KW BS condition such that EV increased significantly (p<0.001) from $Test_1$ (0.22±0.07m/s) to $Test_3$ (0.28±0.08m/s).

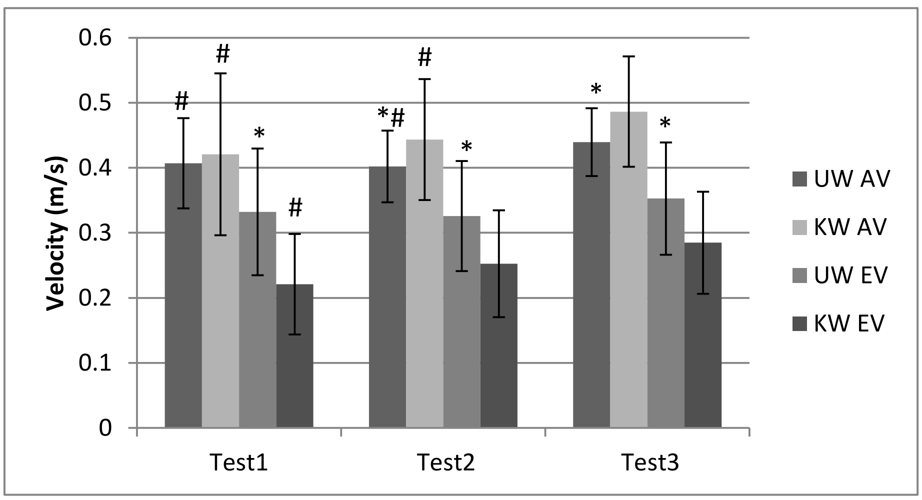

Figure 3.5: Mean (±SD) back squat average concentric velocity (AV) and average eccentric velocity (EV) grouped by day ($Test_1$, $Test_2$, and $Test_3$) and condition (Unwrapped=UW, Knee Wraps= KW). * indicates a significant difference (p<0.001) between BS conditions. # indicates a significant difference (p≤0.001) from $Test_3$.

Main effects for test day were observed for AP (p<0.001), AV (p<0.001), EV (p<0.001), PP (p<0.001), PF (p=0.007), and PV (p<0.001). All main effects were examined in using paired samples T-tests ($Test_1$:$Test_2$, $Test_2$:$Test_3$, $Test_1$:$Test_3$). Effect sizes (ranging from small to moderate) were greatest for AP (Partial Eta^2-0.253), AV (Partial Eta^2-0.247), and PV (Partial Eta^2-0.233). Small effect sizes were observed in EV (Partial Eta^2-0.145) and PP (Partial Eta^2-0.173), while effects size that were less than

small were observed in PF (Partial Eta^2-0.059). Tables 3.3 display the results of BS performance ANOVAs (main effect for test day).

Table 3.3 Back Squat 3*1 (Main Effect for Test Day) AVOVA Results

Back Squat Performance Variable	F	Significance	Partial Eta^2
Average Concentric Velocity	26.261	p<0.001	0.247
Eccentric Concentric Velocity	13.600	p<0.001	0.145
Peak Concentric Velocity	24.265	p<0.001	0.233
Peak Concentric Force	5.060	p=0.007	0.059
Average Concentric Power	27.065	p<0.001	0.253
Peak Concentric Power	16.794	p<0.001	0.173

To test for main effects of day, paired samples T-tests ($Test_1$:$Test_2$, $Test_2$:$Test_3$, $Test_1$:$Test_3$) were carried out on each BS performance characteristic measured by the TPA. Three comparisons between days resulted in the alpha level being reduced from p<0.05 to p<0.0167.   BS performance characteristics in $Test_3$ (AV-0.46±0.07m/s, EV-0.32±0.09m/s, PV-0.93±0.18m/s, AP-900±127W, PP-2174±483W, PF-2625±301N) were observed as significantly greater (p<0.01) than $Test_2$ (AV-0.42±0.08m/s, EV-0.29±0.09m/s, PV-0.85±0.20m/s, AP-823±148W, PP-1986±562W) as well as $Test_1$ (AV-0.41±0.10m/s, EV-0.28±0.10m/s, PV-0.82±0.21m/s, AP-805±185W, PP-1903±571W, PF-2570±325N). Thus, all BS performance characteristics measured by the TPA were significantly improved by $Test_3$ regardless of training group or condition. Main effects tor BS characteristics are displayed in Figures 3.6-8.

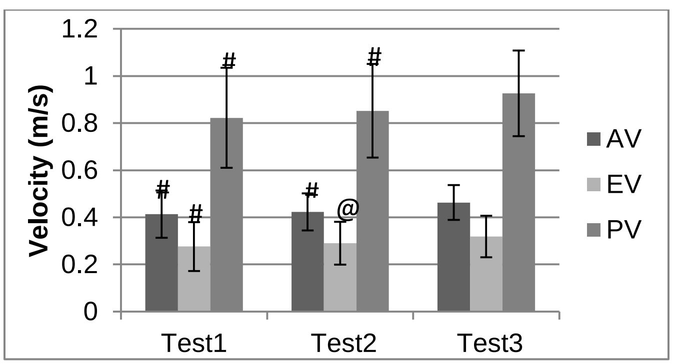

Figure 3.6: Mean (±SD) average concentric velocity (AV), average eccentric velocity (EV), and peak concentric velocity (PV) grouped by test day ($Test_1$, $Test_2$, and $Test_3$). # indicates a significant difference (p<0.001) from $Test_3$. @ indicates a significant difference (p=0.002) from $Test_3$.

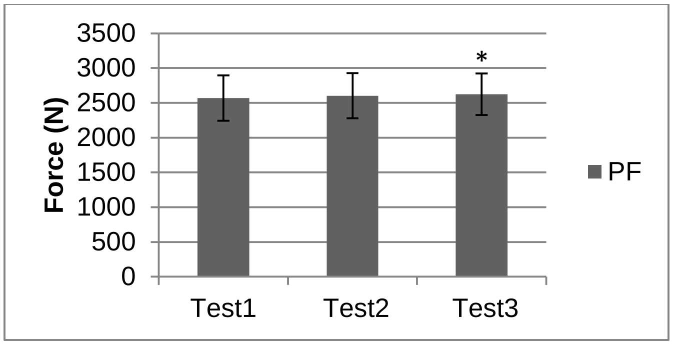

Figure 3.7: Mean (±SD) peak concentric force (PF) grouped by test day ($Test_1$, $Test_2$, and $Test_3$). * indicates a significant difference (p=0.003) from $Test_1$.

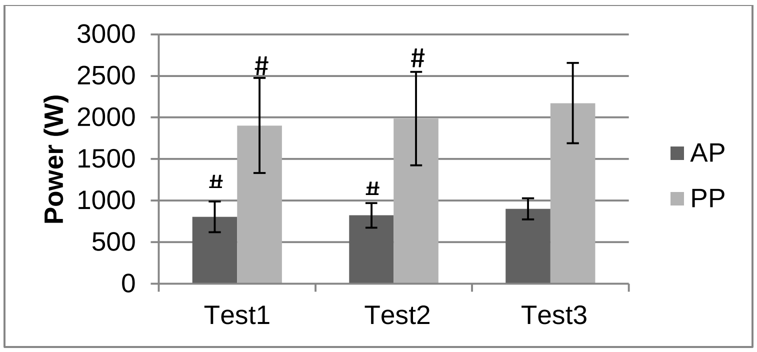

Figure 3.8: Mean (±SD) average concentric power (AP) and peak concentric power (PP) grouped by test day ($Test_1$, $Test_2$, and $Test_3$). # indicates a significant difference ($p<0.001$) from $Test_3$.

Test-retest reliability for the TPA during test days was considered moderate for velocity (AV ICC=0.805, EV ICC=0.757, PV ICC=0.856), high for force (PF ICC=0.938), and moderate for power (AP ICC=0.790, PP ICC=0.819).

BS Training

No three way interactions were observed in BS performance characteristics during BS Training protocols. In addition, main effects for training day were not observed for any BS performance characteristics. However, day*group interactions were detected with several BS performance characteristics (see Table 3.4). Although many of the BS performance characteristics are significant, the effect size for each is less than small (Partial $Eta^2<0.10$).

Table 3.4 Back Squat 2*2 (Training Day*Group) ANOVAs

Back Squat Performance Variable	F	Significance	Partial Eta^2
Average Concentric Velocity	5.057	p=0.025	0.021
Average Eccentric Velocity	4.595	p=0.033	0.019
Peak Concentric Velocity	5.320	p=0.022	0.022
Average Concentric Power	9.719	p=0.002	0.039
Peak Concentric Power	9.638	p=0.002	0.038

Post-hoc analysis was performed on all BS performance characteristic (except PF) using two independent t-tests to compare group differences and two paired samples t-tests to compare training days, effectively reducing the alpha level from $p<0.05$ to $p<0.0125$. Post-hoc analysis revealed significant group differences ($p<0.0125$) during both training days for AV [$Train_1$ (TU-0.37±0.06m/s, TW-0.46±0.07m/s, $p<0.001$); $Train_2$ (TU-0.38±0.05m/s, TW-0.45±0.09m/s, $p<0.001$)], AP [$Train_1$ (TU-697±97W, TW-907±147W, $p<0.001$); $Train_2$ (TU-725±96W, TW-892±144W, $p<0.001$)], and PP [$Train_1$ (TU-1715±391W, TW-1969±394W, $p<0.001$); $Train_2$ (TU-1783±395W, TW-1898±318W, $p=0.011$)]. PV was revealed to have a significant group difference ($p=0.001$) only during $Train_1$ (TU-0.77±16m/s, TW-0.84±0.15m/s). An interaction effect was observed for EV ($p=0.033$), but post-hoc analysis revealed no group differences during either training day. Post-hoc analysis regarding training day*group interactions are displayed in Figures 3.9 and 3.10.

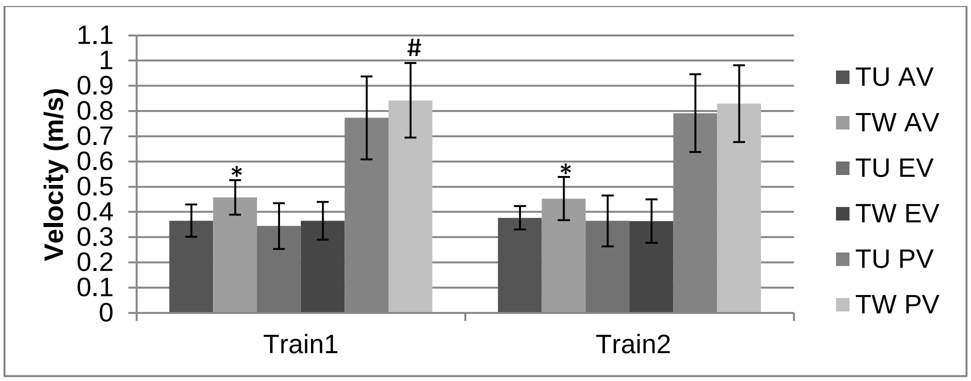

Figure 3.9: Mean (±SD) average concentric velocity (AV), average eccentric velocity (EV), and peak concentric velocity (PV) grouped by training day ($Train_1$, $Train_2$) and group (Training unwrapped=TU, Training with knee wraps=TW). * indicates a significant group difference ($p<0.001$). # indicates a significant group difference ($p=0.011$).

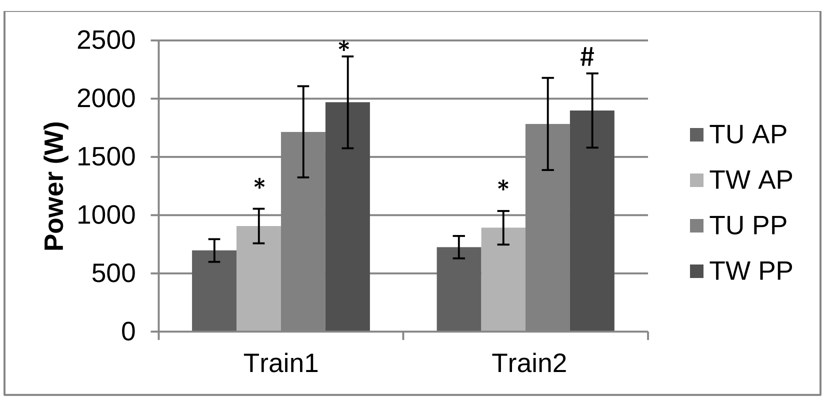

Figure 3.10: Mean (±SD) average concentric power (AP) and peak concentric power (PP) grouped by training day ($Train_1$, $Train_2$) and group (Training unwrapped=TU, Training with knee wraps=TW). # indicates a significant group difference ($p<0.001$) in mean AP. * indicates a significant group difference ($p<0.001$). # indicates a significant group difference ($p=0.011$) in mean PP during $Train_2$.

Test-retest reliability for the TPA during training days was moderate for velocity (AV ICC=0.858, EV ICC=0.747, PV ICC=0.860), high for force (PF ICC=0.945), and moderate for power (AP ICC=0.841, PP ICC=0.722).

Discussion

Unlike our previous research; which reported no benefits if using KW, this study observed multiple benefits of using KW as an ergogenic aid. When participants wore KWs during the last three sets of the BS testing protocol, concentric and eccentric velocity were significantly altered ($p<0.05$). Average concentric velocity significantly increased ($p<0.001$) during $Test_2$ (UW-0.40±0.06m/s, KW-0.44±0.09m/s) and $Test_3$ (UW: 0.44±0.05m/s, KW: 0.49±0.08m/s) while eccentric velocity significantly decreased ($p<0.001$) during $Test_1$ (UW-0.33±0.10m/s, KW-0.22±0.08m/s), $Test_2$ (UW-0.33±0.08m/s, KW-0.25±0.08m/s), $Test_3$ (UW-0.35±0.09m/s, KW-0.28±0.08m/s). More evidence is needed to support these day*condition interactions. Currently AP has a suggested trend ($p=0.055$) for a day*condition interaction, A small sample size and low number of repetitions performed during BS test protocols may have be responsible for the lack of significance between conditions.

Main effects for day were observed such that BS velocity (AV, EV, PV), power (AP, PP), and force (PF) significantly improved ($p<0.05$), regardless of condition or training group (see Figures 3.6-8). PP was the only recorded performance characteristic from this study that was also measured in a previous BS study using KW (2). PP is measured using a TPA in this study, but Lake and colleagues (2) used a force plate to measure PP. In addition, the study by Lake and colleagues (2) reported significant differences ($p<0.05$) according to BS condition. This study did not observe a significant difference in PP between BS conditions during BS testing protocols, thus was limited to express PP as the mean of both UW and KW conditions. Consequently, this disallowed the opportunity to compare the results of this BS test protocol to the one performed by Lake and colleagues (2). However during BS training protocols, significant group differences ($p<0.05$) were observed in PP during each training day (see Figure 3.10). Participants in this study performed the BS with lower PP both with and without KW compared to the Lake and colleagues (2). Reported PP means from this study had much smaller standard deviations, which should be viewed as a strength considering the small number of participants.

The lack of observed significant differences with regards to BS condition or training group and small effect size in significant observations could be explained by the small sample size. Few participants completed the study in at least one training group (n=9) and even fewer people completed the study in both groups (n=5). However, the interpretation of data was kept conservative as evident by the effect size cut-offs for Partial Eta^2 (Small-0.10, Moderate-0.25, Large-0.4) and post-hoc analysis requiring alpha levels to become more conservative (via Bonferonni correction) as t-tests used to analyze interaction effects increase in number. Included in Appendix IV is a separate analysis with each participant only completing the study one time (n=9).

A lack of observed significant interactions and smaller reported effect sizes could be attributed to the number of revolutions used in this study (seven revolutions) compared to previous studies had at least nine), or by the limiting the knee wrap orientation period and only allowing participants perform two repetitions of the BS. The study performed by Lake and colleagues (2) allowed for participants to practice using knee wraps for multiple repetitions, but the number by each participant was not specified.

Another significant observation was that participants improved their BS 1RM over two sessions ($1RM_1$-139.2±23.0kg, $1RM_2$-143±23.3kg, p=0.006). Future studies that base a designated training load on 1RM performance should perform the 1RM test twice in order to correctly asses BS 1RM. Previous literature has only tested the 1RM one time before participants underwent BS protocols with KW treatment (2, 3, 4).

Overall, observations suggest that the BS protocols used in this study could be recommended for improving BS performance characteristics in less than a two week time period; the time required to complete three BS testing protocols was eleven days. Training intensity and volume for BS testing and training protocols were based on recommendations from NSCA (25) and ACSM (30) for improving power. Test-retest reliability for using the TPA during BS testing and training protocols was moderate for velocity and power, but high for force. Future studies examining performance characteristics during BS exercise protocols should use heavier loading schemes (>80%1RM) and or greater volume (>18 repetitions) compared to protocols used in this study to further investigate differences in BS performance under UW and KW conditions.

With regards to VJ performance, using KW during BS testing (Set 4-6) and KW training protocols (6 sets of 3 repetitions at 80%1RM), did not significantly alter ($p<0.05$) VJ from pre to post-exercise. In addition, the BS testing protocol did not cause a significant difference ($p<0.05$) in VJ from pre to post-exercise. These observations suggests that BS testing and training protocols from this study can be used to evaluate and or improve BS performance without affecting VJ performance. Therefore, both protocols should be considered for use to improve BS performance characteristics without concern of causing decreases in athletic performance as measured by VJ.

CHAPTER IV:THE EFFECTS OF USING KNEE WRAPS ON BACK SQUAT, POST-EXERCISE PERFORMANCE, AND PERFORMANCE RECOVERY

Introduction

Our previous research observed that using KWs improved performance characteristics of the squat, agreeing with similar previous literature (1-6). However based on the results of our previous research, it is difficult to determine which BS performance characteristics benefit the most from the use of KW. Significant ($p<0.05$) day*condition effects were observed during single repetition protocols such that average concentric velocity was increased 10-11% and average eccentric velocity was decreased 10-33%. It is theorized that KW are the most helpful when transitioning from the eccentric to concentric phase (1-4), which occurred around the lowest portion of the lift (parallel depth). Significant ($p<0.05$) day*group interactions were also observed during multiple repetition protocols such that velocity (AV, PV) and power (AP, PP) characteristics were greater when performing the BS with KW compared to without KW. Lastly, significant ($p<0.05$) day*group interactions were observed during multiple repetition protocols such that EV was slower when performing the BS with KW compared to without.

Unfortunately neither BS protocol used in Chapter III was able to affect VJ performance to the extent of causing a significant ($p<0.05$) day*set interaction during any BS test or training day. A previous study used multiple repetition sets (>six repetitions) with moderate to high intensity training loads requiring participants to perform the BS to near or total failure causing up to a 19% decreases in post-exercise VJ (9). Another study used eccentric resisted back squat training as an exercise intervention, which resulted in a significant ($p<0.05$) decrease in VJ which lasted up to twenty-four hours post-exercise (22). Moir and colleagues (15) used BS protocols to affect VJ, but did not observe any significant changes to VJ. Lowery and colleagues (16) observed significant changes in VJ (pre to post-exercise) when BS protocols were performed with training intensities of 70% and 93% of1RM respectively. In addition, Evetovich and colleagues (20) observed a significant difference in VJ before (61.9 ± 12.3cm) and after (63.6 ± 11.6cm) a BS exercise protocol. This increase in VJ is also known as potentiation.

The purpose of this study was to determine if: a high intensity BS exercise protocol designed for strength gains can significantly alter post-ex VJ performance, if post-exercise VJ changes during the first

30 minutes of recovery from the BS exercise protocol with and without KW, and if performing BS protocol with or without KW can cause significant alterations in BS performance characteristics.

It was hypothesized that the BS exercise protocol designed for this study would cause a decrease in post-exercise compared to pre-exercise. It was also hypothesized that the recovery period (30 minutes) would be enough time to alleviate observed decreases in VJ performance. VJ recovery was hypothesized to be independent of BS condition, thus recovery time would not be affected by whether or not participants wore KW during BS protocols. Finally, it was hypothesized participants would improve BS velocity, force, and power characteristics when wearing KW.

Methods

Experimental Approach to the Problem

The BS protocols used in the previous study were not great enough in volume or intensity to induce fatigue as measured by a decline in VJ performance. Therefore, this study utilized a BS protocol that requires participants to train at a higher intensity (85%1RM) and volume scheme (five sets of five repetitions). In addition to increasing the volume requirements of the BS protocol, the VJ protocol was also increased in volume such that three post-exercise vertical jump tests were performed (0, 10, 20 minutes post-exercise) instead of one (0 min post-exercise) as was done in the previous study from Chapter III. Because the familiarization period from Chapter III was considered too short, the familiarization period for this study was extended such that participants were allowed to practice the BS training protocol with their expected training load (85%1RM) for sets of five (up to five sets). Once 1RM testing and familiarization was completed, participants performed the BS training protocol for this study once with KW and once without KW. The time of commitment required by participants was four visits to the laboratory over fifteen days. Our previous research study required seven visits to participate in one training group over eighteen days.

Population

Adult males (mean age 25±4 years) with at least 2 years resistance training experience, 1 year heavy resistance training experience, who participate in resistance training at least twice per week for the last 3 months participated in this study. All participants were free of lower body injuries for the last 2 years.

After receiving oral and written explanations of all procedures related to the study, participants gave their informed consent. All procedures and consent forms were approved by Institute Review Boards at Louisiana State University and Kent State University.

Procedures

This study used a counterbalanced design and each participant performed two BS training protocols with (KW) without knee wraps (UW) in a randomized order. After obtaining informed consent, participants filled out a health history questionnaire which screened for contraindications to exercise and gave a description of their resistance training history and current training loads used during high intensity BS workouts. After giving consent before initial testing, baseline characteristics for height, weight, and body composition were measured. Height was nearest centimeter (cm) via a stadiometer. Weight was measured to the nearest kilogram using a balance beam scale (Health O Meter, Chicago, IL). Body composition was measured using a 7-site skinfold test to estimate body density (23) and the Brozek equation was used to quantify% body fat (24).Participants performed the BS 1RM protocol on days one (1RM$_1$) and four (1RM$_2$) of the study. The highest 1RM achieved over two sessions was used as to calculate the designated training load for each participant. After completion of each 1RM session, participants will practice the familiarization protocol with or without KW on separate days in a randomized order. After both 1RM tests, participants performed two BS training protocols (KW- with KW, UW-without KW) that were separated by seven days (day eight, day fifteen). This model was more similar to the study by Lake and colleagues (2). However, this study will use a different approach in using two 1RM tests before performing BS training protocols. In addition, the BS training protocols will utilize sets with greater than one repetition and a load greater than 80%1RM. The timeline for this study is listed below in figure 4.1.

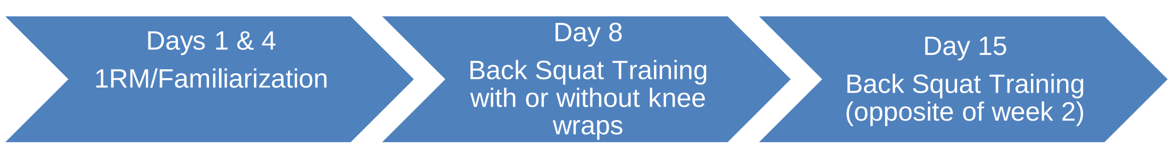

Figure 4.1 Timeline for Back Squat Training Sessions

KW Treatment: All aspects of the KW treatment described in Chapter II and demonstrated in Fig. 2.2 were used in all protocols requiring participants to perform the BS with KW. The experimenter, type of

KW (Titan Support Systems, Max RPM, 2m length), and technique (“X” pattern for seven revolutions and secured with slipknot) used to apply the KW treatment was consistent among all subjects.

Measures

BS Performance Evaluation: During all protocols, participants were assisted by two trained spotters and BS depth was performed to the standards of the NSCA guidelines (25). Participants performed the BS in a reinforced steel power rack that had safety pins set to catch the barbell if the lifter failed an attempt and/or descended below a parallel depth. To initiate the BS, participants stood up with a loaded barbell supporting the weight with the shoulders, trapezius, and hands. Participants would then walk at least two steps backwards and place their feet in the preferred squat stance. After optimal foot placement was achieved, participants descended to a parallel position; defined by the NSCA as the point where the top of the hip joint is on the same horizontal plane as the top of the knee joint (8) Participants would ascend with maximal force to achieve maximal power during the BS exercise. During working sets of BS Testing and BS Training protocols, participants attached the TPA to the waist band of their shorts. A previous study performed by Garnacho-Castano and colleagues (27) ensured the TPA is both valid and reliable when measuring BS performance characteristics. Figures 3.2 and 3.3 display the BS techniques and TPA used to measure BS performance characteristics.

VJ Performance: A VJ test established in Chapter II was used in this study to assess the ability of BS protocols to induce fatigue in participants. As displayed in Fig 2.3, participants performed a countermovement then jumped with maximal effort reaching towards the highest tab on a Vertec device using their dominant hand. VJ was recorded as the difference of the highest tab reached during VJ and the highest tab reached in standing position.

Exercise Protocols

BS 1RM/Familiarization Protocol: The primary purpose of this protocol was to determine the correct training load for BS training protocols. This was achieved with two 1RM tests that are separated by three days. Displayed below is the protocol’s timeline which took place after measuring baseline characteristics.

- (0 min.)- Sit quietly for 10 minutes
- (10 min.) Warm Up Set 1-50% estimated 1RM for 10 repetitions followed by 5 minutes rest

- (16 min.) Warm Up Set 2- 70% estimated 1RM for 5 repetitions followed by 5 minutes rest
- (22 min.) Warm Up Set 3- 80% estimated 1RM for 3 repetitions followed by 5 minutes rest
- (28 min.)Warm Up Set 4- 90% estimated 1RM for 1 repetition followed by 5 minutes rest
- (34-58 min) 1RM Test-5 attempts to achieve a 1RM with 5 minutes rest between attempts.
- After an extended period of rest (5-10 minutes), participants were weighed and then performed a familiarization protocol to practice squat with or without KW. The order of familiarization protocols (Day 1, 4) was randomized and simulated the order of BS training protocols (Day 8, 15). During familiarization protocols, participants were allowed to perform ≤5 sets of ≤5 repetitions at a load of ≤85% 1RM. The TPA will be used to evaluate BS performance. Sessions will be terminated when participants' maximal BS performance (AP, AV) does not improve between sets.

BS Training Protocol: Participants performed this protocol with and without KW on separate days in a randomized order. The BS exercise was performed to a parallel depth as described by a previous back squat study both with and without KW (2). The timeline for this protocol is displayed below.

- 0 min.)- Weigh in and rest quietly for 10 minutes
- (10 min.)- Pre-Ex VJ Test- 1 set of 5 vertical jumps with 20 seconds rest between jumps followed by 5 minutes rest.
- (16 min.)- BS Warm Up Set 1-50% 1RM for 10 repetitions followed by 5 minutes rest
- (22 min.)- BS Warm Up Set 2- 60% 1RM for 5 repetitions followed by 5 minutes rest
- (28-52 min.)- BS Sets 1-5- 85%1RM for 5 repetitions with 5 minutes rest between sets
- (53 min.)- Post-Ex VJ $Test_0$- 1 set of the 5 vertical jumps with 20 seconds rest between jumps. This took place immediately after the completion of the last set of BS.
- (63 min.) Post-Ex $VJTest_{10}$- 1 set of 5 vertical jumps with 20 seconds rest between jumps. This took place 10 minutes after the completion of the last set of BS.
- (83 min.) Post-Ex VJ $Test_{30}$- 1 set of 5 vertical jumps with 20 seconds rest between jumps. This took place 30 minutes after the completion of the last set of BS.

Statistics

VJ performance was analyzed using 2*4 repeated measures ANOVA for effects of BS training day (KW, UW) and set (Pre, $Post_0$, $Post_{10}$, $Post_{30}$). BS performance was analyzed using 2*5 repeated measures ANOVA for BS training day (KW, UW) and set (1-5). Significance for ANOVAs was set at alpha level $p<0.05$. Partial Eta^2 was used to interpret effect sizes of ANOVAs, defined as small (0.10), medium (0.25), and large (0.40). Post-hoc analysis was done with a Bonferroni correction using paired sample and independent t-tests to investigate within subject interactions and between subject

interactions, respectively. Because each post-hoc analysis required different amounts of tests, the alpha level will vary according to the number of t-tests are performed for that analysis. Test-retest reliability for the Vertec and the TPA were calculated using intraclass correlation coeffecients (ICC). Statistical analysis was performed with SPSS Statistics 21. All data are presented as mean ± standard deviation.

Results

Baseline characteristics

Since all participants in the study performed both BS training days, no pairwise comparisons were made between participants. Participants also saw no overall change in their BS 1RM between training days. The characteristics of participants are displayed in Table 4.1.

Table 4.1 Baseline Characteristics (n=12)

Age(yr)	25±4
Height(m)	1.79±0.06
Mass(kg)	86.6±13.3
Sum-7(mm)	99.3±30.3
%Body Fat	16.2±6.0
1RM(kg)	152.0±20.9

VJ Performance

With regards to VJ performance, there was a significant effect for day (F- 5.267, p=0.023, Partial Eta^2-0.022, and high test-retest reliability (ICC=0.901), but no day*set interaction (p=0.699). To examine the effect of BS training day on VJ performance, a paired sample t-test was used to compare the average performance of 20 VJ recorded over the two training days (Table 4.3). There was a significant difference (p=0.022) between BS training days. A greater mean VJ over 20 jumps was observed during the KW (60.4±6.0cm) BS training day compared to UW (59.9±5.6cm). The standardized error of measurement of the Vertec; ± 1 inch (2.54cm), is greater than significant difference observed between groups.

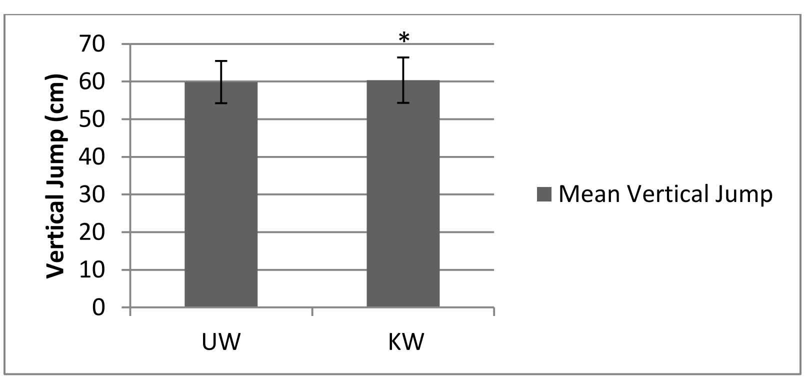

Figure 4.2: Mean Vertical Jump (±SD) grouped by day (UW-Unwrapped, KW-Wrapped). * indicates a significant difference (p=0.022) between days.

BS Perfomance

Day*set interactions were observed for AV (p=0.027), EV (p=0.015), PV (p=0.006), and AP (p=0.019) which are displayed below on table 4.3. The effect sizes for each observed interaction was considered less than small (AV- 0.036, EV-0.041, PV-0.047, and AP-0.039). In order to examine day*set interactions, post-hoc analyses of 25 t-tests were performed for each BS variable, lowering the alpha level from p<0.05 to p<0.002.

Table 4.3 Back Squat 2*5 (Day*Set) ANOVAs

Back Squat Performance Variable	F	Significance	Partial Eta^2
Average Concentric Velocity	2.780	p=0.027	0.036
Average Eccentric Velocity	3.159	p=0.015	0.041
Peak Concentric Velocity	3.660	p=0.006	0.047
Average Concentric Power	2.987	p=0.019	0.039

With regards to AV, each set was significantly greater (p<0.001) during the KW day (Set1: 0.40±0.09m/s, Set2: 0.40±0.09m/s, Set3: 0.40±0.10m/s, Set4: 0.38±0.10m/s, Set5: 0.38±0.11m/s) compared to the UW day (Set1: 0.35±0.09m/s, Set2: 0.32±0.08m/s, Set3:0.32±0.08m/s, Set4: 0.30±0.08m/s, Set5: 0.31±0.09m/s). During the UW training protocol, Set1 was considered significantly greater (p<0.001) than all other sets performed that day. However during the KW training protocol, Set4 was considered significantly less (p<0.001) than Set2 and Set3. These interactions are displayed in Figure 4.3.

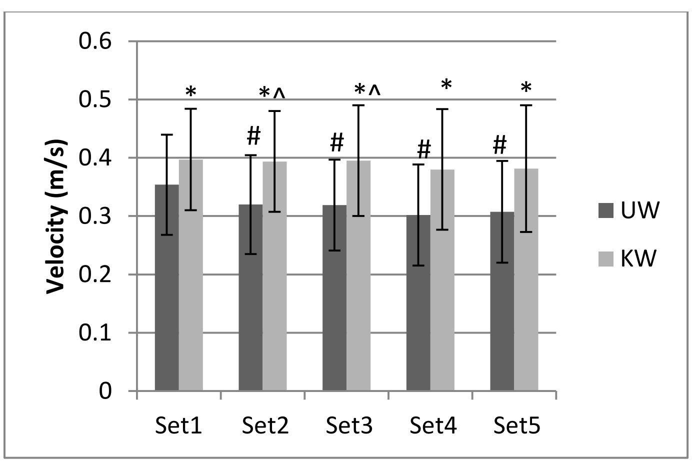

Figure 4.3: Mean (±SD) average concentric velocity (AV) grouped by training day (UW- Unwrapped, KW-Wrapped) and set (1-5). * indicates a significant difference (p<0.001) between days. # indicates a significant difference (p<0.001) from Set1. ^ indicates a significant difference (p<0.001) from Set4.

Post-hoc analyses revealed day*set interactions for EV such that during KW protocol was significantly less (p<0.001) than UW during the first two sets [Set1 (UW-0.40±0.09m/s, KW-0.32±0.12m/s); Set2 (UW-0.39±0.09m/s, KW-0.34±0.12m/s)]. In addition during the UW protocol, EV of Set4 (0.36±0.08m/s) was considered significantly less (p<0.001) than Set1, Set2, and Set3 (0.38±0.08m/s). These interactions are displayed below in Figure 4.4.

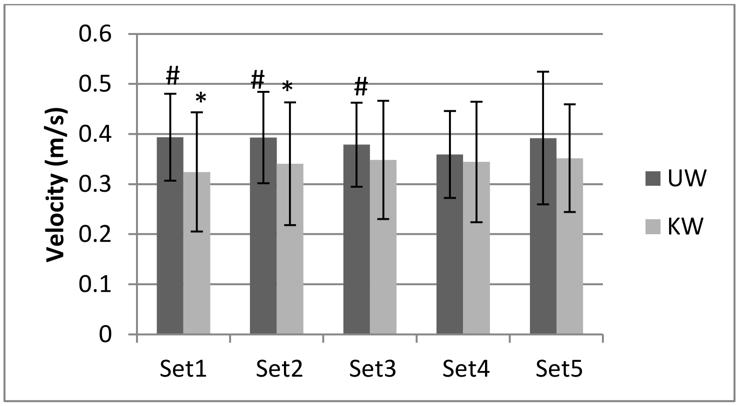

Figure 4.4: Mean (±SD) average eccentric velocity (EV) grouped by day (UW-Unwrapped, KW-Wrapped) and set (1-5). * indicates a significant difference (p<0.001) between days. # indicates a significant difference from Set4.

With regards to PV, day*set interactions were observed within the same day as well as between days. During the UW protocol, Set1 (0.77±0.19m/s) was significantly greater (p<0.001) than all proceeding sets (Set2-0.73±0.18m/s, Set3-0.73±0.19m/s, Set4-0.70±0.17m/s, Set5-0.67±0.22m/s). In contrast, sets during the KW protocols were not significantly different from each other. In addition, PV was significantly greater (p<0.001) during the KW protocol on Set4 (0.76±0.19m/s) and Set5 (0.77±0.19m/s). These interactions are displayed below in figure 4.5.

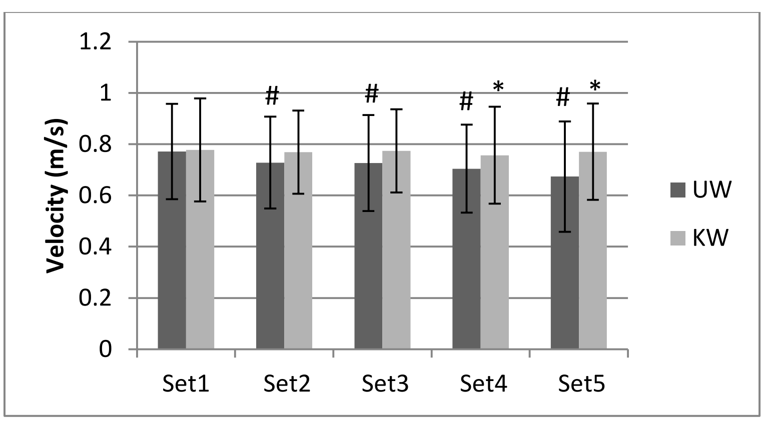

Figure 4.5: Mean (±SD) peak concentric velocity (PV) grouped by day (UW-Unwrapped, KW-Wrapped) and set (1-5). * indicates a significant difference (p<0.001) between days. # indicates a significant difference (p<0.001) from Set1.

Post-hoc analysis revealed day*set interactions for AP such that it was significantly greater (p<0.001) in the KW treatment (Set1: 833±177W, Set2: 827±171W, Set3: 830±185W, Set4: 798±207W, Set5: 803±220W) for all sets compared to the UW treatment (Set1: 743±178W, Set2: 671±168W, Set3: 670±162W, Set4: 630±149W, Set5: 645±183W). In addition during the UW protocol, Set1 was considered significantly greater (p<0.001) than all other sets performed that day.

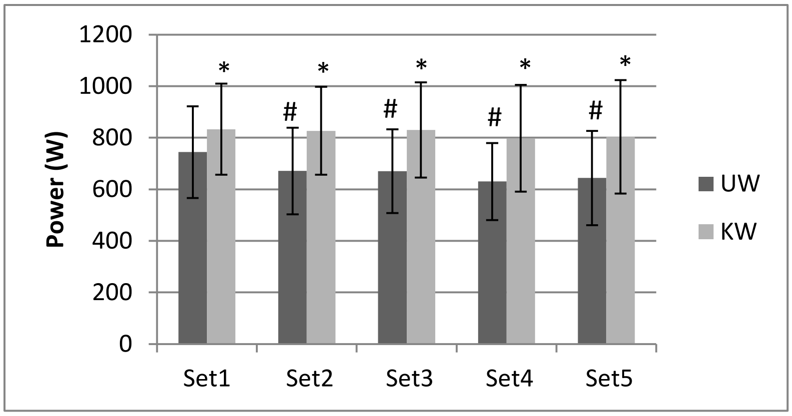

Figure 4.6: Mean (±SD) average concentric power (AP) grouped by day (UW-unwrapped, KW-wrapped) and set (1-5). * indicates a significant difference (p<0.001) between days. # indicates a significant difference (p<0.001) from Set1.

Significant effects (p<0.001) for KW treatment were observed for all BS performance characteristics as displayed below in Table 4.4. Effects sizes were greatest in AV (0.514) and AP (0.510), while all other characteristics had small effect sizes (EV-0.156, PV-0.122, PF-0.120, PP-0.105). Main effect for BS training day was examined with one paired sample t-tests for post-hoc analysis. The alpha level was not reduced from p<0.05 since only one t-test was performed per BS variable.

Table 4.4 Back Squat 2*1 (Main Effect for Day) ANOVAs

Back Squat Performance Variable	F	Significance	Partial Eta^2
Average Concentric Velocity	311.789	p<0.001	0.514
Average Eccentric Velocity	54.668	p<0.001	0.156
Peak Concentric Velocity	40.954	p<0.001	0.122
Peak Concentric Force	40.302	p<0.001	0.120
Average Concentric Power	306.804	p<0.001	0.510
Peak Concentric Power	34.426	p<0.001	0.105

Post-hoc analyses revealed main effects for day in all velocity characteristics such that participants performed the BS with significantly greater AV (UW-0.32±0.08m/s, KW-0.39±0.10m/s,

p<0.001), significantly lower EV (UW-0.38±0.10m/s, KW-0.34±0.12m/s, p<0.001), and significantly greater PV (UW-0.72±0.19m/s, KW-0.77±0.18m/s, p<0.001). Main effects for day with regards to velocity are displayed below in figure 4.7.

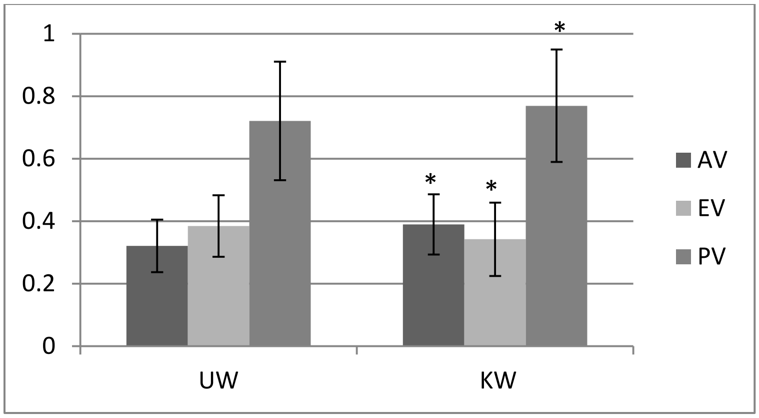

Figure 4.7: Mean (±SD) average concentric velocity (AV), average eccentric velocity (EV), and peak concentric velocity (PV) grouped by day (UW-Unwrapped, KW-Wrapped). * indicates a significant difference (p<0.001) between days.

Post-hoc analysis also revealed a main effect for day such that PF was significantly greater (p<0.001) during the KW protocol (2746±412N) compared UW protocol (2672±308N) (displayed in Figure 4.8). In addition, post-hoc analyses revealed main effects for day such that participants performed the BS with significantly greater (p<0.001) AP (UW-672±172W, KW-818±192W) and PP (UW-1760±524W, KW-1899±584W) (displayed in Figure 4.9).

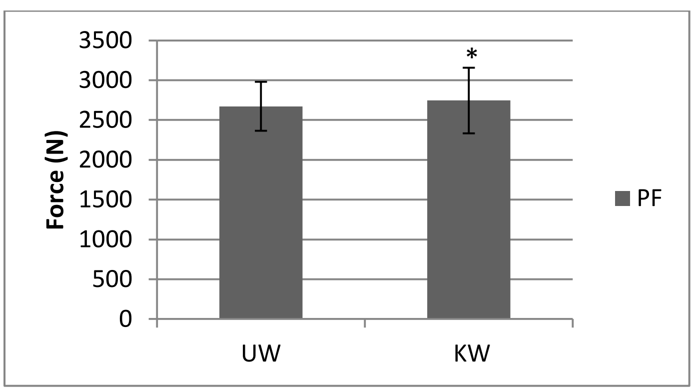

Figure 4.8: Mean (±SD) peak concentric force (PF) grouped by day (UW-Unwrapped, KW-Wrapped). * indicates a significant difference (p<0.001) between days.

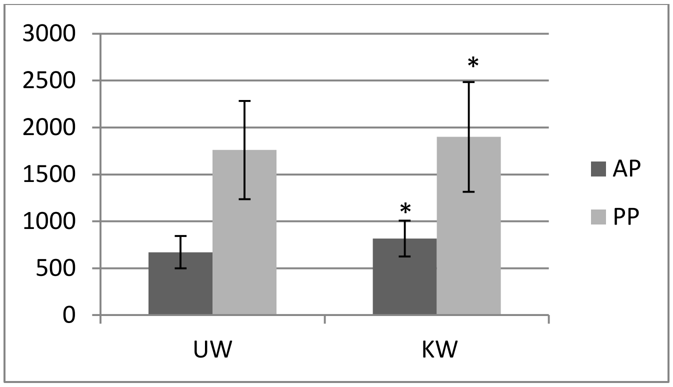

Figure 4.9: Mean (±SD) average concentric power (AP) and peak concentric power (PP) grouped by day (UW-Unwrapped, KW-Wrapped). * indicates a significant difference ($p<0.001$) between days.

The test-retest reliability of the TPA for measuring BS performance was moderate for velocity (AV ICC-0.832, EV ICC-0.718, PV ICC-0.848), high for force (PF ICC-0.917), and moderate for power (AP ICC-0.808, PP ICC-0.840).

Discussion

These data demonstrate that knee wrap treatment can be used to improve BS performance characteristics during protocols designed to improve strength in resistance-trained men. According to NSCA guidelines, exercise protocols designed to improve strength require a load ≥6RM which is about 85%1RM (25). Gomes and colleagues (4) had their athletes practice at intensities of up to 90%1RM, but did not measure BS performance characteristics (velocity, force, power). Although they did observed reductions in sEMG activity of the vastus lateralis; a major contributor to knee extension, it is difficult to determine the relationship between reductions in vastus lateralis activity and improvements in BS performance (4). The results of this study agree with previous literature relating to KW treatment (1-6) which observed improved BS performance characteristics.

Using the TPA as a measurement device allowed for the opportunity to observe multiple characteristics of BS performance (AV, EV, PV, PF, AP, and PP). Wearing KW caused the greatest changes to BS performance with greatest effect sizes in AV and AP. Two observations are worth noting with regards to BS performance. First, AV and AP during KW training days was significantly greater ($p<0.001$) for every set compared to UW. Second, wearing KW during BS prevented significant decreases ($p<0.001$) in AV, PV, and AV; which was observed in UW training protocols. .
there were significant decreases in AP and AV UW Set_1 and all other sets with regards to.

A previous study (27) reported high test-retest reliability when measuring BS velocity (AV, PV) and power (PV, PP) with a TPA AP, PV and PP. In addition, the same study suggested the TPA would be more valid and reliable for measuring BS performance characteristics at higher intensities where velocity and power measurements are expected to be considerably slower than BS performed with <85%1RM; the training load used in this study. In addition to increased error, PV and PP reportedly have greater bias (compared to AV and AP) when measuring BS performance and both of these will increase as PV and PP increase (27). Krcmar and colleagues (26) used the TPA as a measuring device for jump squat performance and quantified BS performance using AP, but no performance characteristics were reported in their results. Four (AV, PV, AP, PP) of six BS performance characteristics have been tested for validity and reliability in previous research (28). Therefore, significant interactions reported for EV and main effects for day for PF during the BS are difficult to interpret because validity and reliability of these measurements have not been established in peer reviewed publications.

Even though KW treatment during BS training significantly improved VJ: 1) the improvement was only observed as the mean VJ of 20 jumps with a difference was less than one cm, 2) there was no detected day*set interaction. Therefore, improvements observed for average VJ were less than one cm (0.5cm); smaller than the standard error of measurement of the Vertec (±1 inch (2.54cm)). Our previous research study had similar VJ performance results, not revealing a day*set interaction. However, a proposed benefit of protocols used in both studies is that each protocol could be used to improve strength as well as BS performance characteristics without impairing VJ performance. Future studies should also focus on recruiting athletes with VJ performance significantly greater than the population used in this study. According to the NSCA standards, the average VJ performance for recreationally trained male athletes is 60cm (25). Future studies should also try to recruit lifters with greater BS 1RM performance compared to recreationally fit and resistance trained populations. In theory, the suggested populations might be more susceptible to fatigue using the BS protocol from this study. Future studies should also consider making alterations to BS protocols (training loads, volume, and rest time) in order to cause significant changes in VJ performance.

CHAPTER V: CONCLUSIONS

The series of investigations in this dissertation examined the effects of knee wrap (KW) treatments across multiple studies. Observations within these studies suggest that using KWs: 1) did not improve VJ height when used during VJ and 2) significantly improves back squat (BS) force, velocity, and power.

One of the greatest strengths of this dissertation was the ability to use the same KW brand (Titan Support Systems), model (Max Revolutions), technique (figure eight), and investigator to apply KW treatments to all participants. As mentioned in the introduction, only two studies to date have both used the same wrap technique and reproduced the technique with a picture demonstration (1, 2). An alternative KW technique known as the "spiral" does exist and is mentioned in previous literature (4, 6). However, the technique is not demonstrated in the literature investigators cannot be sure how the KW treatment was applied to participants. While KWs were observed to be effective at improving BS performance, future studies could investigate additional ways to improve performance. Future studies should use KW that are matched length (2m) when not stretched and designed to produce more than seven revolutions; which is would be more than could be performed with the KW used in this dissertation (Max RPM by Titan Support Systems). In addition, future studies should also investigate the effects of different wrapping techniques. The "figure eight" wrap was used as demonstrated in previous studies (1, 2), but this wrap can be started below or above the knee and performed in a medial or lateral direction. Therefore, one KW technique can be applied multiple ways and future research should always describe a written and illustrated form of KW technique.

Another strength is that the same devices to measure VJ (Vertec) and BS performance (TPA) across all studies in this dissertation. The Vertec is the standard device used to measure VJ performance according to the NSCA (25). This instrument is both very direct in terms of measuring VJ (± 1in (2.54cm)) and has substantial applicability in the field since it is easy to use. Previous studies have used instruments such as jump mats, force plates, and video cameras; which are more favored by the biomechanics and strength and conditioning field. However, these items can be expensive and learning to use them may require extensive training time before being able to measure performance accurately and reliably. The TPA was used to measure performance characteristics of the BS and jump squat and in

recent studies (26, 27). Again, previous literature has suggested the use of force plates and motion sensor cameras as more accurate and reliable ways of measuring BS (2, 28) and jump squat (32) performance. Previous studies would use the TPA by attaching the unit to the end of a loaded barbell (26, 27). However, literature has discouraged measuring barbell kinematics and kinetics and suggested that measuring near the trunk and upper thigh would give more accurate readings of velocity and power (28, 32). Therefore, the studies in this dissertation attached the TPA to the waist band of participants shorts, positioned between the trunk and thigh. Lastly, the mass of the participant and loaded barbell were used by the TPA to measure BS performance; which is reported to be more accurate than measuring BS performance using only the mass of the loaded barbell.

The similarity of participants' VJ and BS performance was an additional strength of this dissertation. The average VJ was approximately 60cm for all three studies and the average BS 1RM was over 140Kg for the two BS studies. In addition, participants experienced similar effects on VJ performance as a result of the BS protocols used in these studies. BS performance was significantly improved by KW treatments in both BS studies, with the last study completed observing the greatest effects of KW treatment.

KWs are not the only ergogenic aid used to improve BS performance. The squat suit is also used to improve BS performance and should be incorporated with the use of KW in future studies. The effects of using KW and squat suits with respect to optimizing recovery are not clear since only two studies reported rest time between sets (2, 31) for the BS exercise (5 and 3 minutes respectively). The protocol performed by Blatnik and colleagues (31) required lifters to perform the BS with and without a squat suit on separate days with a randomized order and did not report an order effect. Blatnik and colleagues (31) observed significant increases ($p<0.05$) in peak concentric power (80%1RM: No Suit= 1566.56 ± 388.4W, Squat Suit= 1770.46 ± 483.2W; 90%1RM No Suit= 1493.16 ± 296.2W, Squat Suit= 1723.86 ± 449.5W) and peak concentric velocity (80%1RM: No Suit= 0.5486 ± 0.135m/s, Squat Suit= 0.6166 ± 0.113 m/s; 90%1RM: No Suit=0.4936 ± 0.117 m/s, Squat Suit= 0.5676 ± 0.119m/s; 100%1RM: No Suit= 0.4136 ± 0.127m/s, Squat Suit= 0.4626 ± 0.112 m/s) when a squat suit was used in training. Data from the study by Blatnik and colleagues (31) was collected in 2 training session (no suit, squat suit) utilizing a randomized order with a cross-over design. Each session used training loads of 80, 90, and 100%1RM in

a randomized order with 2 sets of single repetition sets per training load and 5 minutes rest between trials. In contrast, the study by Lake et al (2) had lifters squat with and without KW on the same day using a randomized order. The KW study by Lake and colleagues (2) used a similar training protocol to Blatnik and colleagues (31) with subtle differences. Only one training load (80%1RM) was used for the training protocol, single repetition sets were used with 3 minutes rest between attempts, and lifters performed 6 sets during the protocol; 3 with KW and without KW (2). Traditionally, both a squat suit and knee wraps are used in conjunction to balance out assistance in the hip and knee joint. Even though both Lake (2) and Blatnik (31) used acute effect models and collected valuable data on the kinematics and kinetics, neither study used the knee wraps and squat suit in conjunction. Additional research is needed to answer questions on using KW and squat suits as a training and performance aid. Only Godawa and colleagues (3) utilized both knee wraps and the squat suit together during training and 1RM testing and observed increased BS 1RM after 10 weeks of training.

The design flaws in each study are worth mentioning as well since future studies can make improvements to experimental design and procure better observations compared to the results of this dissertation. While all three studies had small sample sizes, the first two studies had small sample sizes and a combination of one time and crossover participants. This made data analysis extremely difficult since at times a combination of paired samples t-tests and independent t-tests had to be used during post-hoc analysis to identify interaction effects. If all participants were able to crossover in the first two studies, the results would be drastically different. Recruitment was a major issue during all three of these studies. The first study was hard to recruit for because most participants did not see the benefit of using KW to improve VJ performance but not BS. The KW used in all three studies was designed for heavy BS and was not comfortable to wear during the VJ. In fact, several subjects had a hard time initiating a countermovement were getting EV measurements of zero meters per second. The second study was hard to recruit for because it took a long time to complete and most participants did not want to participate in two 1RM sessions in the same week. While three weeks does not seem like a long time, potential recruits were full time students. Many of the recruits could not participate because of scheduling conflicts associated with school or work. Exercise protocols were scheduled for specific days and times and if a participant missed a session they would have to restart the study after a washout period of at least two

weeks. The last problem with recruitment was the difficulty in finding participants that were willing to give up their resistance training routines temporarily to complete any of the studies. There was the potential to recruit multiple powerlifters and bodybuilders in the last two studies, but scheduling conflicts and inability to comply with exercise protocol requirements deterred all but four recruits. Because of the difficulties with completing the first two studies, it was decided that all participants had to participate in both condition. Using a crossover design in the last study definitely helped with strengthening the observed effects of KW on BS performance. Located in Appendix IV are the results of the first two studies in this dissertation presented without the data of participants who performed the studies a second time.

Lastly, all three studies were lacking a control group and this would have helped the first two studies tremendously. In the first study, a control group would perform on VJ testing days and would be sedentary on training days. In the second study, a control group would perform the BS tests, and would be sedentary during the time in between VJ tests when BS training normally took place. Another idea for a possible third group in each study would be to use the KW as a blood flow restriction (BFR) device. BFR is a popular new way to use KW. The goal of BFR is to stimulate hypertrophy using intensities that are dramatically lower than traditional intensities prescribed by NSCA (25) and ACSM (30). Recent studies are promoting the use of KW for BFR during resistance training protocols (33, 34). The advantage of examining this protocol would be to observe the effects of a BS protocol with a much lower intensity, but matched for total work volume. Participants would have to perform several repetitions per set to match for work volume, since the intensity is only about 30%1RM (34). Traditionally this type of training requires an initial of set 30 repetitions, followed by three sets of 15 repetitions with each set being separated by 30 seconds rest.

While highlighting strengths and weaknesses of this dissertation, studies have demonstrated KWs can be used as a biomechanical ergogenic aid for the BS. However, not enough peer reviewed research exists in which readers can fully explain observed changes in BS performance characteristics. Investigators of future studies should examine BS and VJ performance characteristics with measurement tools used in this series of independent research studies (linear position transducer, Vertec) as well as more traditional measurement tools (force plate, video cameras). Results from future research would

help explain in which BS and VJ performance characteristics (force, velocity, power) are most affected by KW treatments.

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APPENDIX I: GENERAL EXAMS

THE EFFECTS OF RESISTANCE TRAINING LOAD, SET, AND REPETITION SCHEME ON POST-EXERCISE PERFORMANCE AND RECOVERY.

A General Exam

Submitted to the Graduate Faculty of the

Louisiana State University and

Agricultural and Mechanical College

In partial fulfillment of the

requirements for the degree of

Doctor of Philosophy

In

The Department of Kinesiology

by

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I. Intro: Metabolic/Performance Adaptations to RT
- Metabolism (Acute and Chronic)
  - Substrate Utilization/Storage
  - Metabolite Accumulation/Clearance
  - Inflammatory Markers
  - Hormones
- Performance
  - Acute Changes (Increased Motor Learning, Force, Velocity, Repetitions)
  - Chronic Changes (Muscle Hypertrophy, Fiber Type Shift)
- Conclusions

II. RT Variables and Programs
- Variables
  - Target Population
  - Exercise Selection/Order
  - Technique (Muscle Action)
  - Training Frequency
  - Load (Intensity)
  - Volume (Sets and Repetitions)
  - Rest Intervals
- Program Progression, Maintenance, and Periodization
  - ACSM
  - NSCA
- Applications to research
  - Periodization
  - Fitness
  - Sports
- Conclusions

III. Possible factors affecting post-exercise performance and recovery
- Relationship between metabolic markers and performance
- Optimum recovery timeline for performance based on exercise protocol
  - Between Sets
  - Between RT Sessions
- Accessory equipment
  - Elastic Bands
  - Assistive Lifting Apparel
- Conclusions

Preface

The purpose of this review is to examine the effects of program variables in resistance training and how they play a part in post-exercise performance and the time it takes to recover from a resistance training (RT) session. The stress caused by RT sessions can be strong enough to force metabolic and/or performance changes both acutely and chronically. Established organizations such as American College of Sports Medicine (ACSM) and National Strength and Conditioning Association (NSCA) both recommend using RT to improve fitness. However, RT prescriptions vary between these organizations (ACSM & NSCA). Along with determining the most important RT session variables for predicting performance and recovery time, this review will also examine different forms of measurement for evaluating performance and recovery.

The review will be broken into 3 sections. The first section will review metabolic and performance adaptations resulting from RT. RT can elicit varying acute and chronic effects depending on one's goal (training to optimize performance vs training to optimize training adaptations). The second section will discuss RT program variables as recommended by NCSA and ACSM and the concept of periodization being utilized in RT. These organizations target different populations (ACSM general population, NSCA athletes) and recommend different selections/order of exercise performed, technique, training load, volume, rest time, and frequency. The third section will address the significance of establishing relationships between metabolism and performance as affected by RT programs, RT variables most likely to affect recovery and post-exercise performance, and ergogenic equipment, such as elastic bands and assistive lifting apparel, used as RT accessories to facilitate recovery/enhance performance. Each of the topics in the last section will collectively be the main focus of the review.

Chapter I Introduction

When participating in an RT program, there are two types of adaptations that take place; metabolic and performance. Metabolism and performance can be affected both acutely during an RT session and chronically over the course of several RT sessions.

Metabolic Adaptations to RT

This section will examine how RT affects substrate utilization/storage and circulating levels of metabolic byproducts, pro/anti-inflammatory markers, and hormones.

<u>Substrate Utilization</u>

Substrate utilization is increased during exercise for the purpose of ATP resynthesis. Initially, muscles will use up ATP stores to release any actin/myosin cross bridges during the cross-bridge cycle. In addition, ATP is also required to operate calcium pumps in the sarcoplasmic reticulum, as well as sodium and potassium pumps for neural membranes and the sarcolemma (Baechle & Earle, 2008). Initially, anaerobic pathways such as the phosphagen and glycolytic systems will increase rates ATP production until ATP replenishments matches the rate of depletion. RT sessions are considered to be an intermittent activity, requiring bursts of high force or velocity movement that only last a few seconds followed by rest periods of up to several minutes. Power movements such as the clean and jerk (C&J), squat (SQ), push press (PP), bench press (BP), and deadlift (DL) utilize high force and/or high velocity contractions and require so much ATP that rest periods of several minutes are needed to fully replenish ATP stores (Baechle & Earle, 2008).

After initial resting ATP stores are used up, the phosphagen system starts contributing to ATP replenishment. This system consists of reactions from creatine kinase pathway (PCr + ADP ← creatine kinase(CK)→Cr + ATP) and the adenylate kinase pathway (ADP + ADP ←adenylate kinase(AK)→ATP + AMP) (Hardgreaves & Spriet, 2006). However, the CK pathway can only

work at max capacity for a short period as resting PCr concentrations are only about 4-6 times the amount of resting ATP stores (Brooks et al, 2005). While the AK reaction uses 2 ADP to form ATP, it also increases concentrations of AMP (Houston, 2006). Increased AMP levels stimulate the adenylate deaminase (AMPD) reaction and produces ammonia (NH3), which can leave the muscle cell resulting in a net loss total adenine nucleotides (TAN) available to resynthesize ATP (Houston, 2006).

The next reaction in line; glycolysis, increases its role in ATP replenishment as PCr stores become depleted and aerobic metabolism cannot meet ATP demands of work being performed (Kang, 2006). During intense exercise the demand of glucose as a substrate can increase and consequently stimulate hepatic glucose output (via glycogenolysis) and glucose uptake in the working muscle (via increased GLUT4 translocation) (Hardgreaves & Spriet, 2006). Measuring BG is the preferred method of detecting changes in glucose metabolism. It is difficult to determine the direct role of RT in glucose metabolism based on the available literature, due to the timing of blood glucose sampling in relation to RT protocols.

For example, studies by Kraemer and colleagues (1993) and Figuiera and colleagues (2013) observed a decrease in BG concentration following an RT session using multiple exercises. However, a study performed by French and colleagues (2007) observed dissimilar changes as a response to RT. BG increased significantly ($p<.05$) during a multiple set (6 sets * 10 repetitions) single exercise (back squat) RT protocol and was found be significantly higher ($p<.05$) post-exercise compared to pre-exercise (French et al, 2007). Vingren and colleagues (2008) also observed a significant increase ($p<.05$) in BG concentration starting mid-exercise and remained significantly higher ($p<.05$) in concentration compared to pre-exercise until 70 minutes post-exercise (Vingren et al, 2008).

A few RT studies that measured BG used alternate methods other than direct pre/post RT blood sampling such as oral glucose tolerance testing (OGTT), hyperinsulinemic/euglycemic clamp testing, and the 24 hour continual glucose monitoring system (CGMS). An acute effects study by Miller and colleagues (2007) observed improved glucose normalization for high intensity RT compared to low RT. The RT modality for the study was an isokinetic dynamometer with a high intensity (10setsx5reps @ 60deg/s) and low intensity protocol (4setsx15reps @ 180deg/s). Samples of BG and insulin were taken immediately after an OGTT administered post-exercise in 15 minute increments for the first hour (Miller et al, 2007). It was found that at 30 and 45 minutes post-exercise, the high intensity RT protocol resulted in significantly lower ($p<.05$) BG and insulin levels compared to low intensity RT. A follow up study by Luebbers and colleagues (2008) did not yield the same results. While both studies utilized RT protocols matched for work volume, the BG and insulin measurements performed by Luebbers and colleagues (2008) were performed the morning after the RT protocol. In addition, Luebbers did not use an OGTT, but instead a hyperinsuliemic/euglycemic clamp test to measure glucose and insulin activity. An earlier study performed by Holten and colleagues (2004) used the clamp test to compare diabetics and non-diabetics in a single leg training study. The results of this study showed that RT significantly improved ($p<.05$) glucose uptake in the trained leg of non-diabetics for stages 1 and 2 of the clamp test, but only stage 2 for diabetics (Holten et al, 2004). Another training study concerning the BG response of diabetics to RT utilized the CGMS technique for a 4 month training study (Cauza et al, 2005). After diabetics underwent 4 months of RT, a significant decrease ($p<.02$) in mean BG (over 24hr period) was observed. An acute effects study performed by Figueira and colleagues (2013) observed a significant drop ($p<.001$) in BG after an RT session using a CGMS. Because a combination of aerobic exercise and RT

were used in the same session, it is hard to determine the effects of RT alone in this study (Figueira et al, 2013). A training study by Poehlman and colleagues (2000) suggests improved insulin sensitivity after 6 months RT. This study is noteworthy because it compared an RT, aerobic training, and control group. The test to measure insulin sensitivity was a hyperinsulinemic-euglycemic clamp test. The test found that aerobically trained individuals had better insulin sensitivity per unit FFM, but the RT group gained FFM over the duration of the study (Poehlman et al, 2000). An increase FFM would imply that RT would over time provide for more control of blood glucose, since most hypertrophy occurs in fast twitch glycolytic (type II) fibers. This was also a significant training study because it looked at the effects of RT on women instead of men, and used the dual X-Ray absorption (DXA) methods to analyze body composition.

In conclusion, RT can have significant effects on substrate utilization, particularly glucose as reflected by BG and insulin concentrations. Holten and colleagues (2004) revealed via muscle biopsy increased expression of insulin receptors, glucose transporter (GLUT 4) receptors, protein kinase B, and glycogen synthase as a result of RT. Increasing the expressions of these receptors and enzymes also allows for greater flexibility in controlling BG. In addition, the ability for RT to acutely decrease BG may also correlate with decreases in muscle glycogen stores as reported by Nieman and colleagues (2004). A compensatory mechanism for transient decreases in these stores may result in chronic changes like increased storage capacity for substrates like ATP, PCr, and muscle glycogen (MacDougall et al, 1977).

<u>Anaerobic Metabolite Formation/Clearance</u>

The result of increasing the rate and duration of anaerobic pathways (specifically phosphagen and glycolytic) during RT sessions can also increase the rate of formation and

clearance of rate-limiting metabolites, cytokines, and hormones associated with anabolism/catabolism.

Pyruvate; formed during the glycolytic process, is converted to lactate via hydrogens donated by NADH (Hardgreaves & Spriet, 2006). Several studies have observed acute increases (pre to post exercise) in blood lactate due to RT. Table 1.1 provides a brief description of several studies measuring the effects of blood lactate during RT sessions. One of the strengths of Table 1.1 is that it points out weaknesses between the studies; i.e. the use of various RT modalities and timelines for measuring lactate. For instance, the bench press, a recognized common method of measuring upper body strength, was referenced by 4 of the studies in Table 1.1 (Kraemer et al, 1993; Abdessemed et al, 1999; Denton & Cronin, 2006; Sanchez-Medina & Gonzales-Badillo, 2011), while the squat, a common measure of lower body exercise, was referenced by 5 of the studies in Table 1.1 (Kraemer et al, 1999; French et al, 2007; Vingren et al, 2008; Sanchez-Medina & Gonzales-Badillo, 2011; Rogatzki et al, 2014). Since the exercises utilize different muscles as well as different workloads, one can be sure that the bench press findings transfer to the squat and vice versa.

Kraemer and colleagues (1993) measured blood lactate levels before, during, and after 6 different RT protocols composed of 8 different exercises with at least 3 sets per exercise, 5-10 repetitions per set, and 1 or 3 minutes rest. Results revealed that all 6 protocols significantly elevated ($p<.05$) lactate compared to pre-exercise at mid-exercise and immediately post-exercise for up to 15minutes, with most levels measuring between 4-7mmol/L (Kraemer et al, 1993). The most notable protocol (10RM load with 1 minute rest) in this study resulted in lactate levels that measured close to 10mmol/L up until 5 minutes post-exercise; the next measurement at 15 minutes post-exercise was 7 mmol/L (Kraemer et al, 1993). Two other studies performed in the

late 1990's observed very significant (p<.05) differences in pre and post-exercise lactate concentration with values nearing 15mmol/L (Kraemer et al, 1998; Kraemer et al, 1999).

Abdessemed and colleagues (1999) observed smaller yet still significant (p<.05) increases in lactate concentrations (highest post-exercise value 7mmol/L) when using the bench press exercise. Denton and Cronin (2006) also did a bench press study with similar findings regarding post-exercise lactate concentrations. The post-exercise lactate concentrations were between 4 and 7 mmol/L and regressed to pre-exercise values 30 minutes post-exercise (Denton & Cronin, 2006). A major variation in the studies is the difference in repetition volume in both studies. Abdessemed and colleagues (1999) used 10 sets of 6 repetitions with 1, 3, and 5 minutes rest. Denton and Cronin (2006) used 3 different protocols; one that alternated sets of 3 repetitions and repetitions to voluntary failure for 8 sets with 130 seconds rest, another using 4 sets of 6 repetitions with 302 seconds rest, and lastly a protocol using 8 sets of 3 with 130 seconds rest (Denton & Cronin, 2006). The first protocol mentioned resulted in the highest post-exercise lactate concentration (7mmol/L) (Denton & Cronin, 2006).

French and colleagues (2007) published observations from a squat study stating that 6 sets of 10 repetitions with 2 minutes rest could elevate blood lactate levels to 12mmol/L. Vingren and colleagues (2008) repeated this protocol, except this time females and males were recruited as subjects. Observations indicate that post-exercise lactate concentrations for males and females were approximately 15mmol/L and 12mmol/L respectively (Vingren et al, 2008). Izquierdo and colleagues (2009) published a lower body RT study on post-exercise lactate response using a different protocol (5 sets * 10 repetitions) than last 2 studies mentioned (French et al, 2007; Vingren et al, 2008). The results indicate in Table 1 that after 7 weeks of training when the leg press protocol used the same absolute load as the pre-training trial, lactate levels

were significantly lower ($p<.05$)than the pre-training trial (Izquierdo et al, 2009). However when matched for relative intensity, lactate levels were much higher than both the pre-training trial and post-training absolute load trial (Izquierdo et al, 2009). Sanchez-Medina and Gonzalez-Badillo (2011) observed significant ($p<.05$) elevations in lactate for squat and bench press when subjects had to lift in sets that were at or near repetition failure, sets involving greater than 6 repetitions. The highest lactate levels achieved for each lifting protocol were the 3x12@ 12RM for the squat (Lactate-12.5± 1.9mmol/L) and bench press (Lactate- 8.2 ± 1.3mmol/L) (Sanchez-Medina & Gonzalez-Badillo, 2011). The most recent study performed by Rogatzki and colleagues (2014) compared lactate responses of 3 different RT protocols {muscular endurance (ME), hypertrophy (HYP), strength (STR)} using the back squat exercise. While matched for total work, each protocol had different pre/post-exercise changes in lactate levels (ME-6.1mmol/L, HYP-4.9mmol/L, STR-3.9mmol/L) (Rogatzki et al, 2014).

Lactate can also be used as an aerobic fuel source by trained individuals. This done either by shuttling lactate to the liver for the Cori cycle, or dissociating back to pyruvate (while still in the muscle) which can then be converted to acetyl-CoA and used in the Kreb's cycle (Baechle & Earle, 2008; Hardgreaves & Spriet, 2006). A recent RT study by Wirtz and colleagues (2014) observed slight reductions in blood lactate concentration during working sets of an RT protocol; indicating lactate may be used as a fuel source during RT. The protocol used 3 sets of 10 repetitions with 3 minutes rest and compared unilateral and bilateral arm and leg curl exercises. Observed post-exercise blood lactate concentrations were approximately 4 mmol/L and 7mmol/L via arm and leg curl exercises during a single RT session (Wirtz et al, 2014).

Increased monocarboxylase transporter (MCT) expression is an adaptation that is also associated with chronic RT (Juel, et al, 2004). MCT1 seems to play a role in the uptake of lactate

and is found in slow oxidative muscle, while MCT4 is found more in fast twitch skeletal muscle fibers and may be related to release of lactate into the bloodstream (Hardgreaves & Spriet, 2006). One study observed increases in MCT1 expression for diabetics and healthy control subjects as a result of RT (Juel et al., 2004). However, while the expression of MCT4 increased in healthy subjects, it did not increase in Type 2 diabetics (Juel et al., 2004). The observations of Juel and colleagues (2004) are significant because muscle biopsies suggest type 2 diabetics had significantly less MCT1 but not MCT4 content when compared to healthy control patients. The factor theorized to increase in MCT is a localized mechanical stimulus as a result of muscle contraction (Juel et al., 2004).

Besides lactate, ammonia (NH3) is produced during prolonged anaerobic exercise via catabolism of adenine nucleotides, specifically the AMP deaminase pathway (AMP + H20 $\rightarrow$ IMP + NH3) (Houston, 2006). The purpose of this pathway is to keep AMP concentrations low, which is formed by the adenylate kinase reaction (ADP + ADP $\rightarrow$ ATP + AMP). Ammonia becomes ammonium (NH4) after accepting a hydrogen atom from the cytoplasm and is simple enough in structure to cross the blood brain barrier, so elevated levels can cause central nervous system fatigue (Hardgreaves & Spriet, 2006). There are a few pathways in which the body can eliminate ammonia to prevent toxicity, but require additional energy to drive the reaction or only increase in activity during rest. When ammonia is produced in skeletal muscle, it can combine with glutamate and ATP to form glutamine then sent to the liver and degraded back to ammonia and glutamate. The liver will then synthesize urea from ammonia and aspartate and shuttle the urea to the kidneys to be excreted as urine (Houston, 2006). The liver can also rid the body of ammonia by combining with it with bicarbonate and 2ATP to form carbamoyl phosphate which enters the urea cycle (Houston, 2006). One more pathway; the purine nucleotide cycle,

combines NH3, IMP, and aspartate to form adenylosuccinate, which can then be degraded to AMP, H20, and fumarate a TCA cycle intermediate (Houston, 2006). It should also be noted that IMP can lose its phosphate group and gain the ability to leave the cell as inosine or hypoxanithine (Stathis et al, 1999).

Along with blood lactate, Table 1.1 also references studies which measured ammonia production during RT sessions. With relatively few studies measuring blood ammonia levels during RT sessions (5 studies in table 1.1), it becomes clear that future research should focus on establishing relationships between RT and blood ammonia production. The studies discussed below will pertain to what has been established with regards to RT and its effects on blood ammonia production (Kraemer et al, 1993; Leveritt et al, 2000; Izquierdo et al, 2009; Sanchez-Medina & Gonzales-Badillo, 2011; Rogatzki et al, 2014).

Kraemer and colleagues (1993) observed significantly elevated ($p<.05$) blood ammonia; compared to pre-exercise, at mid-exercise, immediately post, and 5 minutes post-exercise for a hypertrophy protocol using 1 minute rest periods with a 10RM load (Kraemer et al, 1993). Similar results were observed for a hypertrophy protocol using the same rest period and a 5RM load, but only immediately post and 5 minutes post-exercise (Kraemer et al, 1993). Peak values for ammonia concentration were approximately 300 and 200 μmol/L respectively (Kraemer et al, 1993). Leveritt and colleagues (2000) performed post-RT blood samples for ammonia. Elevated levels of ammonia (>100μmol/L) were detected in blood samples taken immediately after RT sessions that took place 8 and 32 hours post-exercise via a 50min cycle ergometry @ 70-110% critical power (Leveritt et al, 2000). Almost a decade later, Izquierdo and colleagues (2009) collected post-exercise ammonia samples during 3 different leg press trials (as described earlier) and observed results similar to the post-exercise lactate findings (see table 1). The REL trial had

the highest post-exercise ammonia ratings (120 µmol/L), followed by PRE (100 µmol/L), with ABS having the lowest post-exercise ammonia (40 µmol/L) (Izquierdo et al, 2009). Sanchez-Medina and Gonzalez-Badillo (2011) modeled an acute effects RT model and observed the highest ammonia response in SQ 3x12@ 12RM (Ammonia-125 ± 34 µmol/L) and BP (Ammonia-111 ± 20µmol/L) protocols. Post-exercise blood ammonia was also significantly elevated (>75µmol/L, $p<.05$) compared to pre-exercise for 2 other protocols (3x8 @ 8RM, 3x10 @ 10RM) used for SQ and BP (Sanchez-Medina & Gonzalez-Badillo, 2011). Rogatzki and colleagues (2014) published the most recent RT study related to post-exercise ammonia levels. Comparing 3 different SQ protocols, observations concluded the muscular endurance (ME) protocol resulted in the highest pre/post-exercise difference in blood ammonia (79.8µmol/L), followed by hypertrophy (HYP) (45.3µmol/L), then strength (STR) (31.7µmol/L).

In conclusion, several research studies have observed changes in blood lactate and ammonia concentrations during RT protocols, usually expressed as an increase in concentration. At least one study observed a correlation between lactate and ammonia that was moderate ($r=.59$) yet still significant ($p<.01$) (Rogatzki et al, 2014).

Appearance of Pro-Inflammatory/Anti-Inflammatory Markers

Along with metabolites such as lactate and ammonia, markers of inflammation (also known as cytokines) can increase as a result of RT. Listed in Table 1.2 are studies that examined the effects of RT on inflammatory markers. Some of the studies mentioned in Table 1.2 were featured in a literature review by Mariana Calle and Maria Hernandez (2010) which contained 8 acute effect studies, and 4 long term training effect studies. Callie & Fernandez (2010) made an extensive list of cytokines measured during RT protocols (IL-1ra, IL-1β, IL-2, IL-4, IL-5, IL-6, IL-8, IL-10, IL-12, IL-13, IL-15, TNF-α, sTNF-αR1). These cytokines can be measured either

through blood sampling or muscle biopsy (mRNA expression) and have both pro-inflammatory and anti-imflammatory effects. Cytokines are produced by many sources including but not limited to macrophages, epithelial cells, monocytes, neutrophils, hepatocytes, T cells, mast cells, myocytes, fibroblasts, natural killer cells, and keratinocytes (Calle & Fernandez, 2010).

Acutely, RT can increase cytokines that are pro-inflammatory (IL-6) and anti-inflammatory (IL-10) (Izquierdo et al, 2009; Nieman et al, 2004). However, long term adaptations to RT blunt the post-exercise inflammatory response when training with the same absolute load and volume used pre-training (Izquierdo et al, 2009). According to 2 studies (Martins et al, 2010; Henagan et al, 2012), chronic RT can also decrease circulating baseline levels of C-reactive protein (CRP) and expression of melanocortin receptors (MCR 1, MCR 3), which are also markers of inflammation. This reduction in CRP is thought have a protective effect on the cardiovascular system and is seen as beneficial to at risk populations such as the elderly and diabetics. A study performed by Buell and colleagues (2008) that measured CRP in chronically resistance trained college football players, however, did not have the same results. This study observed elevated levels (>3mg/L) of CRP in 15 out of the 70 players (Buell et al, 2009). Since participating football players performed approximately 100-350 minutes of RT per week and over 100 minutes of running per week, it was suggested that these findings could suggest that the protective effects of RT against cardiovascular disease and metabolic syndromes can be cancelled by other health risks such as high blood pressure, obesity, elevated cholesterol/triglycerides, and insulin resistance, factors that were also prevalent amongst these athletes. Unfortunately the flaw with this study is that the results only deal with baseline blood markers and the immediate effects of the football players' RT sessions were not measured via post exercise blood sampling. A later study by Peake and colleagues (2006) observed increased

IL-6 and expression of receptor site 1 of TNF-α (sTNF-αR1) after an RT session involving two different single arm elbow flexion protocols (see Table 1.2).

Of all the cytokines measured in studies listed in Table 1.2, IL-6 appears to be the cytokine of greatest interest. An important feature of IL-6 is that it is the only cytokine that is produced within skeletal muscle and released into systemic circulation. The systemic circulation of IL-6 can also stimulate the production of other anti-inflammatory cytokines such as IL-10 and IL-1ra (Steensburg et al, 2003) while inhibiting the production of pro-inflammatory cytokines such as TNF-α (Fiers, 1991). Some studies have observed increased glucose infusion rate and glucose/fatty acid oxidation in as well as decreased circulating plasma insulin, suggesting enhanced insulin sensitivity in conjunction with increased circulating IL-6 (Petersen et al, 2004; Carey et al, 2006). Most recently, an RT study suggested IL-6 has a stronger correlation with muscle hypertrophy compared to anabolic hormones such as testosterone and growth hormone (Mitchell et al, 2013).

In conclusion, increases in cytokine levels have been observed in studies from immediately after an RT session to over several hours post exercise (Izquierdo et al, 2009; Nieman et al, 2004), or in some cases several days (Smith et al, 2000). It appears that studies using a high repetition volume RT protocol (with moderate to heavy load) had a much greater inflammatory effect compared to high intensity RT with low to moderate volume. However, it should also be noted that exercise protocols emphasizing eccentric movements (which is not limited to RT but also downhill treadmill running and eccentric cycling) can also elicit muscle damage and increase expression of cytokines (Paulsen et al, 2012). A recent literature review (Paulsen et al, 2012) suggests categorizing RT sessions as measured by muscle damage. Muscle damage should be determined by performing a slow (30-60degress/second) concentric movement

that utilizes full ROM and includes measurements of peak torque, angle at which peak torque was achieved, and total work performed. Recovery from the initial RT session should be determined by the length of time it takes to achieve 100% force production in the form of daily measurements of performance. Protocols which reduce muscle force production by ≤20% and allow full recovery ≤48 hours after initial exercise bout are considered mildly damaging to muscle. Protocols that result in moderate damage reduce muscle force production by 20-50% and allow full recovery 2-7 days after initial exercise bout. Lastly, protocols resulting in severe damage will reduce muscle force production >50% and require >7 days for full recovery.

Anabolic/Catabolic Hormone Response

Along with the production of cytokines, RT can have a powerful effect on increasing hormone production; specifically testosterone (T), growth hormone (GH), insulin like growth factor (IGF-1), and cortisol (C).   T is the most recognized and studied anabolic hormone with properties stimulating GH and increasing protein synthesis (Baechle & Earle, 2008). These hormones can remain elevated in the blood stream up to 60 minutes after an RT session.   In addition, androgen receptors will remain sensitive to anabolic hormones for up to 48 hours. In theory increased androgen sensitivity helps to prevent prolonged production of hormones; which can be metabolically taxing. This however is highly dependent on substrate (CHO and protein) intake pre and post exercise and training status (up to 2 years consecutive training to maximize yield) (Baechle & Earle, 2008). RT sessions utilizing complex multi-joint movements such as squat, deadlift, and power clean with loads of high relative intensity (85-95%1RM), moderate to high load and repetition volume (>3 sets, >10 rep sets) and short rest time between sets (<120s) are all possible factors contributing to production of T, GH, and C levels according to *Essentials of Strength and Conditioning* (Baechle & Earle, 2008).

Although several studies are available documenting the effects of RT on circulating hormone levels, only the 8 studies listed on Table 1.3 will be discussed thoroughly. The reason for limiting the discussion on hormones is very little research has focused on the relationship between performance, recovery, and hormone levels. The most frequently measured hormones of studies listed in Table 1.3 are T (8 studies), GH (6 studies), and C (7 studies). IGF-1 is measured as well, but only in 4 studies (Kraemer et al, 1998; Kraemer et al, 1999; Izquierdo et al, 2006; Mitchell et al, 2014). It's hard to compare results of the studies in Table 1.3 since most of them did not use the same exercise protocol, modality, or timeline for blood sampling.

Izquierdo and colleagues (2009) observed increases in both free and total T concentration when subjects performed 5 sets of 10 on the leg press before (Pre) and after a 7 week RT intervention using a load of the same relative intensity (Rel), but not when repeated with pre training 10RM (Abs). These increases in testosterone occurred mid exercise, immediately post exercise, and 15 minutes post exercise. At 45 minutes post exercise, testosterone levels had decreased to levels significantly different from 0 minutes post exercise for trials Pre and Rel. The same study also observed an increase in growth hormone from baseline to pre-ex, pre-ex to mid-ex, and post-ex at 0 and 15 minutes post exercise.

Cortisol levels have been shown to increase when rest time is short and volume is high. Observations by Izquierdo and colleagues (2009) suggest that cortisol levels become significantly elevated above baseline levels ($p<.05$) about 15 minutes post exercise and stay elevated 45 minutes post exercise. The only trial that did not see a significant rise in elevation in cortisol levels was the Abs trial; which is interesting because that same exercise protocol still caused elevation in testosterone (total and free) mid and post exercise. One could suggest based on the findings that as little as 7 weeks of RT; particularly when implementing periodization, can

provide a protective effect against catabolic hormones such as cortisol and previously mentioned inflammatory markers. It's significant to note that overtraining can cause unexpected increases in cortisol for otherwise normal training volumes.

Schumann and colleagues (2013) did a much more in depth study that also involved the previous author Mikel Izquierdo and took samples of the same hormones (T, GH) while using a much more intense leg press protocol (3x10 40%1RM, 1x3 75%1RM, 3x3 90% 1RM, 1x10 75%1RM, 2x10 80-85%1RM, 1x10 75% 1RM). In addition to RT, an endurance (E) training session was performed either before (E+S) or after RT (S+E) during each loading trial. The RT acclimation period that was much longer (24 weeks) than the study done by Izquierdo and colleagues. Both training groups experienced significant increases in baseline T levels ($p < .05$), but not in GH. Observations during exercise trials suggest that GH only increases significantly ($p<.05$) during E, but not S, regardless of order (S+E, E+S). Observations for cortisol samples were similar to GH responses during exercise (increased during E, but not S) with no group differences during recovery (24, 48 hours post-ex).

Mitchell et al (2013) observed significantly lower ($p<.05$) post-exercise area under the curve (AUC) (0, 15, 30, 60min) response in T, GH, IGF-1 with a suggested trend of lowered AUC response for C ($p=.142$) after 16 weeks of RT. In addition the same study also observed significantly lower ($p<.05$) resting concentrations of the same hormones (T, GH, IGF-1, C). The decrease in resting hormone concentrations and post-ex AUC response could be explained by an increase in androgen receptors over the 16 week training period. However, the increase in androgen receptors was not enough to achieve statistical significance ($p=.186$). Interestingly as reported in Table 1.3, the androgen receptor increase did correlate well with changes in muscle cross sectional area (CSA).

The last study covered in Table 1.3 was covered by French et al (2007). This study stands apart from the rest because it studied not only an anabolic hormone (T), but also the catecholamines epinephrine (E), norepinephrine (NE), and dopamine (DA). The methodology for blood sampling was unique to this study, as it used the same timeline for an RT protocol and a control protocol where no exercise was performed. As noted in Table 1.3, T was found to increase significantly ($p<.05$) over time during the RT protocol (compared to control) as well as catecholamines.

In conclusion, T and catecholamines may be the most beneficial homomones to measure with regards to improving performance. T can also be important in acutely improving performance by increasing release of calcium and neurotransmitters when bound to cell membrane receptors (Baechle & Earle, 2008). Catecholamines are beneficial to performance by way on increasing muscle force production, muscle contraction rate, energy availability, blood flow/pressure, and metabolic enzyme activity (Baechle & Earle, 2008).

Performance Adaptations to RT

Training adaptations such as increased resting substrate concentrations (ATP, PCr, glycogen), anaerobic enzyme concentrations (AMPD, CPK, LDH, PFK), and in some cases fiber type shifting (Type IIx→IIa) can increase the rate and (if training is consistent over months and years) duration of anaerobic pathways compared to untrained subjects. As a result, the trained lifter is able to selectively recruit fast twitch fibers with light to moderate loads (therefore bypassing the size principle), reduce time needed to produce maximal force in moderate to heavy loads (rate of force development or RFD), and increase mechanical efficiency (Baechle & Earle, 2008). The next section will examine how strength and power performance are affected acutely by RT sessions and how chronic adaptations to RT can affect strength and power performance.

Acute effects of RT sessions that affect performance

Depending on the desired goal of the session, RT can decrease performance if measured pre to post exercise; especially for sessions designed to maximize hypertrophy, endurance, and in some cases strength gains. For instance Sanchez-Medina and Gonzalez-Badillo (2011) observed decreases in vertical jump during RT sessions requiring 3 sets of squat. The same study also observed decreases in mean propulsive velocity after both squat and bench press protocols and some of the protocols revealed significant ($p<.05$) differences between the squat and bench press when matched for repetitions scheme. Most workouts that lead to decreases in performance require short rest time (≤3minutes), moderate to high intensity (≥70%1RM), and moderate to high volume (≥3 sets* ≥6 reps). It should also be noted that training intensity and volume may be related, since protocols with higher training intensities tend to result in few total repetitions being achieved if training load remains constant.

For the purposes of this review stretching studies will be referenced because the eccentric component to stretching is similar to the eccentric phase of a weight lifting movement. Dynamic movements such as knee flexion (Winchester et al, 2009), sprinting (Winchester et al, 2008; Nelson et al, 2005), and countermovement jump (Cornwell et al, 2002) all experienced decreases in performance. However, stretching studies have also observed increased rate of force development and peak force on isometric movements like the squat (Bazett-Jones et al, 2005). The acute effects of stretching on performance are not clear due to observations of increased and decreased performance, different exercise modalities yielded different results. Stretching the muscle can cause potentiation; a reflexive increase in the force-velocity characteristics of a muscle (Baechle & Earle, 2008). Some studies observed an increase in performance for events such as the weight throw (Judge et al, 2010) and back squat (Wallace et al, 2006) as a result of

potentiation. In addition, chronic stretching has resulted in increased strength for knee extension/flexion and leg press (Kokkonen et al., 2010) as well as standing toe raise (Nelson, et al 2012).

Lastly, feedback training; providing information about lifter performance during an RT session, has resulted in increased peak power in the power snatch (Winchester et al, 2009) and power clean (Winchester et al, 2005). So depending on how it is used in conjunction with a performance test, resistance training can be used to increase power and speed. Acutely, these increases would most likely be attributed to feedback (if multiple attempts are allowed) or potentiation. Instances where both might be useful for acutely improving performance would be events such as shotput, Olympic weightlifting, and powerlifting.

Chronic RT adaptations that affect performance

As outlined by Crewther et al (2006), elevated anabolic hormones caused by RT sessions can increase rates of protein turnover resulting in net protein accretion. If RT sessions are repeated over time, individuals will experience increased muscle cross sectional area (CSA) as a result of what is known as the repeated bout effect (Crewther et al, 2006).

A study by Brechue and Abe (2002) attempted to establish relationships between fat free mass, muscle thickness, and lifting performance (as measured by 1 repetition max (1RM) squat (SQ), bench press (BP), and deadlift (DL) in world class powerlifters with at least 9 years of experience. Ultrasound measurements of 13 different muscle groups (revealed that subscapular thickness was the most significant ($p<.01$) predictor of all three lifts (SQ- $r=.91$, BP- $r=.85$, DL $r=.90$) (Brechue & Abe, 2002). In addition fat free mass also was a significant ($p<.001$) predictor of all three lifts (SQ- $r=.94$, BP- $r= .88$, DL- $r=.86$) (Brechue & Abe, 2002). This study is novel in that researchers examined drug tested competitive powerlifters and anyone who tested

positive for steroids would have been excluded from the study. However, the lack of a control group or less experienced group of lifters matched for mass did not allow researchers the opportunity to see if the same relationships would have existed in other populations.

Andrew Fry (2004) has suggested that muscular hypertrophy is optimized at intensities of 80- 95% of one repetition max, although hypertrophy can occur at training intensities greater than 40% one repetition max. In addition relative intensity may only account for 35% of the total hypertrophy response (Fry, 2004). In other words other factors besides training intensity can lead to muscular hypertrophy such as rest time, exercise selection, and training volume (sets*reps). In addition, other chronic training factors can affect RT performance besides hypertrophy. For instance, chronic RT can also alter muscle fiber type expression. The most common finding is a shift from type IIx to type IIa (Fry et al, 2003). Type IIa is more fatigue resistant than type IIx fibers. The relationship between fiber type shifting and the difference in strength levels between trained and untrained lifters has been explored, but not explained clearly (Fry et al, 2003). Fry et al (2003) sampled muscle biopsies from trained powerlifters and untrained controls in order to examine fiber-type distribution (I, IIa, IIx) and CSA. Results indicated that trained powerlifters had significantly ($p<.05$) less type IIx CSA as well as significantly ($p<.05$) elevated type IIa CSA (based on percent) compared to controls. The same study also observed significantly ($p<.05$) higher vertical jump height, peak vertical jump power, isokinetic squat force output, and isokinetic squat power output for powerlifters compared to controls.

Untrained lifters can activate only about 70% of working muscle (Adams et al, 1993). While undergoing training, several changes occur in the neuromuscular junction and central nervous system such as increased synchronization of motor units, increased frequency of motor

unit firing patterns (Gabriel et al., 2006), decreased demand of stimulation in the motor cortex (Kazennikov et al., 2007) for the same absolute workload, changes in descending pathways (Caroll et al., 2002), increased end plate perimeter length, area of the neuromuscular junction, dispersion of acetylcholine receptors (Deschenes et al, 2000), increased reflex potentiation (Aagard et al, 2002; Roth et al., 2003), increased force production for the same workload (Izquierdo et al, 2009), increased maximum voluntary contraction (Izquierdo et al, 2009), and increased strength of stabilizer muscles (Rutherford & Jones, 1986). Neuromuscular (NM) adaptations occur before of changes in body mass/composition. Fitts and Posner (1967) explain NM adaptations with the three stage model (cognitive, associative, autonomous stage). Consider an individual who is untrained or of novice experience, his skill level of resistance training would be best described as the cognitive stage, because basic movements would require much more concentration compared to a more experienced lifter, and their force production would be limited by the amount of motor units (and muscle mass) they are able to recruit during the movement. The motor cortex contributes to learning new movements by inhibiting muscle activity that would result in interfering with the new movement (Kazennikov et al., 2007). Using bench press as an example, the three stage model (Fitts & Posner, 1967) of learning can explain this concept through the first two stages. The first few weeks of resistance training would be associated with the cognitive stage. During this time, the person is expected to make many errors associated with the movement. Bellar and colleagues (2011) used a bench press program that allowed individuals to learn the bench press movement for the first three weeks of training. This period of learning allowed the lifters to undergo motor unit changes associated with resistance training (Bellar et al., 2011).

Coordination of the muscles involved with the movement (Rutheford & Jones, 1986) will be discussed first. A factor that may contribute to improved coordination is the reorganization of corticospinal pathways (Caroll et al., 2002). Reorganization of these pathways would allow for better firing of the motor neurons that innervate with muscles used for the lift. Chronic training results in less transcranial stimulation being required for a given workload (Caroll et al., 2002). Another form of adaptation that may occur is the alteration of the firing rate of motor neurons (Gabriel et al., 2006). A firing rate known as doublets is associated with the activation of fast twitch muscle fibers. According to Gabriel and colleagues (2006) the use of resistance training increases the frequency of doublet firing, which would lead to more explosive movements. Increases in motor unit firing rate, coupled with reduced motor cortex stimulation leads to more efficient lifts and this helps the lifter transition from cognitive to the associative stage, and eventually the autonomous stage (Fitts & Posner, 1967).

Conclusion

In conclusion, a single RT session can have an effect on several metabolic factors such as changes in lactate, ammonia, cytokines, and hormones. Although it is not clear how these mechanisms are related to each other, one can speculate that the combination of metabolic and mechanical damage to muscle from RT can cause increases in cytokine and anabolic hormone expression in order to stimulate repairs to muscle involved in RT. Repeating RT sessions over time can cause chronic changes in both resting and post-exercise concentrations of the same makers. In terms of performance, most RT sessions are designed such that performance decreases pre to post-exercise. However, some RT sessions can also be used to increase performance for events that require high force or power output. Chronic RT should result in increased performance, whether it be from changes muscle mass (hypertrophy) or neuronal

adaptations (motor learning). How RT programs are manipulated to elicit specific training goals rwill be the topic of discussion in the next chapter.

Table 1.1 RT Studies Measuring Anaerobic Metabolites

Author/Year	Subjects	Movement	Group- Protocol	Metabolites	Samples	Results
Kraemer et al (1993)	8 trained males	Bench Press Leg Extension Shoulder Press Sit Ups Seated Rows Lat Pulldown Arm Curls Leg Press	Strength 3sets*5reps @5RM, 3min rest 3sets*5reps @5RM, 1min rest 3sets*5reps @10RM, 3min rest Hypertrophy 3sets*10reps @10RM, 3min rest 3sets*10reps@10RM, 1min rest 3sets*5reps@5RM, 1min rest	Lactate Ammonia	Blood Pre-ex Mid-ex (after 4 exercises) Post-ex (0, 5, 15min) Recovery (24, 48hours post-ex)	Lactate levels were significantly ($p<.05$) higher than pre-exercise levels at mid-ex and post-ex for all time points. Recovery measurements were similar to pre-ex levels. Strength (5RM/1min rest) had highest lactate readings mid-ex (7.0mmol/L) and 0min post-ex (6.0mmol/L). Hypertrophy (10RM/1min rest) had highest lactate readings mid-ex, 0 min post-ex, and 5min post-ex (9.0-11.0mmol/L). Ammonia levels significantly ($p<.05$) elevated only for hypertrophy sessions. 10RM/1 min rest session observed significantly ($p<.05$) higher levels compared to pre-ex at mid-ex (250µmol/L), 0min post-ex (300µmol/L), and 5min post-ex (225µmol/L). 5RM/1min rest session observed significantly ($p<.05$) higher levels compared to pre-ex at 0 and 5 min post-ex (approx. 210 µmol/L).
Leveritt et al (2000)	8 trained males	Leg extension	Con- RT testing (8/32h) Exp- 50min cycling then RT (8/32h) Isokenetic-5sets*5reps, 1set*3reps Isometric-3sets*5s Isotonic-2sets*10reps	Lactate Ammonia	Blood Immediately post RT @ 8h and 32h post-exercise	Con-Lactate concentration elevated ($p<.05$) post-RT @ 8h (compared to pre-RT). Exp-Lactate elevated ($p<.05$) post-RT @ 8h and 32h (compared to pre-RT). Ammonia elevated ($p<.05$) post-RT @ 8h (compared to Con) and 32h (compared to pre-RT and Con).
Abdessemed et al (1999)	10 untrained male	Bench Press	10sets*6reps @ 70%1RM 1, 3, 5 min rest	Lactate	Blood Post Set 1-10	Lactate levels highest with 1 minute rest set 4-10 (4-7.5mmol/L respectively) and significantly different ($p<.05$) than other rest periods (3min, 5 min).

Kraemer et al (1999)	17 males	Squat	Squat – 4 sets*10reps @10RM, 90s rest. Pre-Training (Wk0) Post-Training (Wk10) Y- Subject 30 years or younger O- Subjects 62 years or older	Lactate	Blood Pre, Post-ex(0, 5, 15, 30)	All Post-ex lactate values significantly higher ($p<.05$) than pre-ex for Y and O. Lactate values significantly different ($p<.05$) between groups (Y and O) pre/post-training. Y group had significantly lower ($p<.05$) lactate levels post-training compared to pre training.
Denton and Cronin (2006)	10 trained males	Bench Press	CONT- 4sets*6reps @ 6RM, 5min rest ISRV- 8sets*3reps @ 6RM, 2min rest ISRR-alternate 4sets*3reps, 4 sets*failure, 2min rest @ 6RM	Lactate	Blood Pre-Ex Post-Ex (0, 5, 15, 30min)	ISRR had highest lactate readings (Post-Ex 0min- 6.5mmol/L, 5min- 6.0mmol/L, 15min- 3.5mmol/L). All conditions increased lactate (P0) and returned to baseline values within 30min (<2.0mmol/L).
Gentil et al (2006)	12 trained males	Leg Extension	10RM- 10reps SL- 1 super slow rep (30s eccentric, 30s concentric) VO- 1 20s rep to cause vascular occlusion followed by 5 reps. FI- 6 reps with 5s Isometric contraction @ full extension	Lactate	Blood T0- Pre T3- 3min Post	VO and FI had highest response for single set of exercise (T0-1.0 mmol/L, T3- 4.0 mmol/L). These protocols elicited significantly different T3 blood lactate values ($p<.05$) compared to SL.
French et al (2007)	10 trained males	Squat	RT- 6sets*10reps @ 80%1RM C- Control	Lactate	Blood Pre-Ex(-60, -30, -15, -10, -5, 0min) Ex (5, 8, 11, 14, 17, 20min) Post-Ex (25, 30min)	During RT trial, lactate was significantly elevated ($p<.05$) starting at 8 min (set 2) (5.56±2.11mmol/L) and remained elevated during (peak value 20min or set 6 at 12.04±2.12mmol/L) and post exercise (25min-11.89±1.77mmol/L) compared to pre-ex (-60min-1.07±.26mmol/L , 0min-2.05±1.0) and control trial at same time points (approx. 1mmol/L).
Vingren et al (2008)	8 males 7 females	Squat	6sets*10reps @ 80%1RM, 2min rest	Lactate	Blood Pre-ex Mid-ex (after 3 sets) Post-ex (0, 5,	Mid-ex and all post-ex lactate levels significantly ($p<.05$) higher than pre-ex for both males and females. Males' highest lactate reading 0min post-ex (15.3±4.1mmol/L). Females' highest

					15, 30, 70min)	lactate reading 0 min post-ex (11.9±1.7mmol/L).
Izquierdo et al (2009)	12 physically active males	Leg Press	5sets*10reps @ 10RM Pre- pre training 10RM REL- post training 10RM. ABS- post training using same load as Pre	Lactate Ammonia	Blood Pre-ex, Mid-ex (1st, 3rd set), Post-ex (0, 3, 5, 10, 15, 30min). Post-ex only peak value reported	Lactate and ammonia levels were highest mid-ex (1st and 3rd set) and post-ex during REL trial. Lactate- Pre-10 mmol/L, REL-12 mmol/L, ABS-8 mmol/L Ammonia- Pre-100µmol/L, REL-120µmol/L, ABS- 40µmol/L
Sanchez-Medina & Gonzalez-Badillo (2011)	18 physically active males	SQ, BP	3sets*2-12reps @ 4, 6, 8, 12RM	Lactate Ammonia	Blood Post-Ex	Lactate and Ammonia levels were higher in SQ vs BP (p<05). SQ- Highest values (Lactate-12.5mmol/L, Ammonia-125µmol/L). BP- Highest values (Lactate-8.2mmol/L, Ammonia-111µmol/L)
Wirtz et al (2014)	10 trained males	Leg Extension Arm Curl	3sets*10reps 1vs2 limb conditions	Lactate	Blood Resting, Pre/Post Set (1-3), Post-Ex (2, 4, 6min)	Lactate increased every 2min post set (p<.01). Lactate levels were highest in 2 limb vs 1 limb, and leg extension vs arm curl. Highest values (2arm- 4.0mmol/mol, 1arm- 4.5mmol/mol; 2leg- 7.0mmol/mol, 4.5mmol/mol). Significant decrease (p<.05) detected in post-ex lactate @ 6min all conditions.
Rogatzki et al (2014)	16 college age males	Squat	ST- 5sets*5reps @ 85%1RM, 180s rest HYP-3sets*10reps @ 70%1RM, 120s rest ME-2sets*20reps @ 53%1RM, 45s rest	Lactate Ammonia	Blood Pre/Post-Ex (5min) change	Lactate- ME (6.1±2.9mM) significantly different (p<.05) than ST (3.9±2.1 mM) Ammonia- ME (79.8±45.4 µM) significantly different (p<.05) than HYP (45.3±34.5 µM) and STR (31.7±52.3 µM) *Moderate correlation (r=.59) between Lactate and Ammonium was determined significant (p<.01)

Table 1.2 RT Studies Measuring Inflammatory Markers

Author/Year	Subjects	Training/Acute	Group-Protocol	Cytokines	Samples	Results
Smith et al (2000)	6 untrained males	Acute	Eccentric bench press and leg curl 4sets*12reps @ 100%1RM, 2 min rest.	IL-1β, IL-6, IL-10, TNF-α	Blood Pre-ex, Post-ex (1, 5, 6, 12h), Recovery (1-6days)	IL-1β reduced 6h, 1 day, and 5 days post-exercise. IL-6 elevated 12h, 1 day, and 3 days post-exercise. IL-10 elevated 2, 3, 4, 5, and 6 days post-exercise.
Peake et al (2006)	10 untrained males	Acute	Submax- 10sets*60reps @ 10%1RM elbow flexor of one arm Max- 10sets*3 reps @ 100%1RM elbow flexor of opposite arm	IL-1ra,IL-6, IL-10, TNF-α, sTNF-αR1, CRP	Blood Pre-ex Post-ex (1, 3 hours), Recovery (1-4days)	IL-6 elevated only for Submax session post-ex (3 hours). sTNF-αR1 was elevated post-ex (1, 3 hours, 1 day).
Buell et al (2009)	70 elite college football lineman	Acute	A survey was used to quantify duration (min/week) of RT and Run. DI-353 min/week RT, 267 min/week Run DII-374 min/week RT, 126 min/week Run DIII-146 min/week Run, 105 min/week Run	CRP	Resting Blood 12h fast	15 had significantly ($p<.05$) elevated CRP levels (>3.0mg/L) Study does not indicate which groups had players with elevated CRP. DI had significantly more ($p<.001$) run time than DII & DIII. DIII had significantly less ($p<.001$) RT time than DI & DII.
Stewart et al (2007)	60 Subjects men and women n=29(age<30), n=31(age>60)	Training (12weeks)	Con-Active RT- Inactive do 12 weeks RT 2 sets*(70-80%1RM, failure) 8 exercises	IL-1β, IL-6, TNF-α, and CRP	Resting Blood at Pre (0wks), Post RT (12wks)	No change Pre to Post in IL-1β and IL-6 for both groups. Higher TNF-α levels for age<30 regardless of group. RT had no effect
Phillips et al (2010)	14 untrained males	Acute	Con- Rest Low Intensity- 2sets*12reps, 1 set to failure @ 65%1RM, 2 min rest High Intensity-2sets*8reps, 1 set to failure @ 85%1RM, 2 min rest. 8 exercises	IL-6	Blood Pre Post-ex (0min, 6hour)	IL-6 elevated for both protocols compared to Con (0min post-ex). Low intensity session had greater load volume than high intensity, possibly explaining difference in IL-6 levels between sessions.

Henagan et al (2012)	Con-13 females, 6 males RT- 10 women, 11 men	Training (12weeks)	Con-None RT- Periodization Program Training cycles include adaptation, hypertrophy, power, circuit, power, and strength all lasting 1-3 weeks. Movements- bench press, push-ups, bent over rows, seated rows, squat, dead lift, walking lunges, and crunches.	CRP, MCRI, MCR3, IL-1β, IL-6, IL-10	Resting Blood Pre (0wks), Post-RT (12wks)	MCRI – Increase Pre to Post ($p<.0001$) RT group only MCR3- Decrease Pre to Post ($p=.0307$) RT group only. CRP- Decrease Pre to Post ($p=.0472$) Highest RT group (n=9) (Pre-2.97mg/L, Post-1.37mg/L) IL-10- Decrease Pre to Post ($p<.0001$) in both groups.
Nieman et al (2004)	30 strength trained males	Acute	4sets*10reps (40-60%1RM) 10 exercises	IL-1β, IL-ra, IL-2, IL-4 IL-5, IL-6, IL-8, IL-10, IL-12, IL-15	Blood & Muscle Pre, Post-Ex (0min)	Muscle- Increase Pre to Post in IL-1β, IL-6, IL-8, TNF-α. Plasma- Increase Pre to Post in IL-1ra, IL-6, IL-8, and IL-10
Izquierdo et al (2009)	12 physically active males	Both (Training= 7weeks)	Leg Press 5sets*10reps Pre- pre training 10RM REL- New 10RM after 7 weeks RT. ABS- Pre 10RM after 7 weeks RT.	IL-1β, IL-ra, IL-6, IL-10	Blood samples Pre-ex, Mid-ex, Post-ex (0, 15, 45min.)	IL-1β significantly higher ($p<.05$) for ABS and REL trials compared to Pre for all time points. IL-ra significantly elevated ($p<.05$) Post-ex (0min) for ABS and REL only. IL-6 significantly elevated ($p<.05$) post-ex (45min) for Pre and REL only. IL-10 significantly elevated ($p<.05$) only in REL at mid-ex and post-ex (0, 15, 45 min).
Mitchell et al (2013)	23 young healthy adult males	Both (Training 16 weeks)	No Groups 4sets*8reps (leg press, leg extension, leg curl, calf press) 2 minutes rest	IL-6, CRP, TNF-α	Blood- Post-ex AUC (0, 15, 30, 60min), Reting Wk0, Wk16	Significant correlation ($p<.05$) between IL-6 AUC and increased CSA (Mean-r=.48, Type II-r=.42, Type I-r=.51) CRP significantly increased ($p<.05$) resting levels at Wk16.

Table 1.3 RT Studies Measuring Hormones

Author/Year	Subjects	Acute/Training	Group- Protocol	Hormones	Samples	Results
Kraemer et al (1998)	9 trained males	Acute	S- Supplement P- Placebo 4sets*10reps (squat,bent over row, bench press, military press) 2 minutes rest. Performed 3 consecutive days	T,GH,IGF-1, C, Insulin	Blood- Pre-ex, Post-ex (0, 15, 30, 45, 60 min).	T- Significant (p<.05) difference between groups on Day 2 (45, 60min) and Day 3 (30min), indicating higher T levels for P group. Both groups experienced significant (p<.05) increase in T concentration pre to post-exercise all 3 days. GH- Significant (p<.05) difference between groups on Day 1 (0, 15, 30min), indicating higher GH levels for S group. Both groups had significant (p<.05) elevations in post-ex GH (0, 15, 30, 45min) C- Day 1 observed significant (p<.05) elevations in post-ex C (0, 15, 30 mi) for both groups. Post-ex C for S group stayed elevated significantly (p<.05) entire 60 min and was significantly (p<.05) different from placebo group at 45min. Days 2 and 3 observed diminished post-ex C response for both groups and was significantly (p<.05) different from Day 1 (0, 15, 30, 45, 60min post-ex). IGF-1- Significant (p<.05) pre-ex differences between groups on Day 2 and Day 3. Insulin- Significant (p<.05) elevations post-ex (30, 45, 60min) in insulin for S group only all 3 days. Differences between groups were significant (p<.05) at same time points all 3 days.
Fry et al, (1998)	17 trained	Both (2 weeks	Squat- 10 reps @	T, C, GH	Blood- Pre-ex (-	T- Significant (p<.05) difference between

	males	training)	70%1RM, 1min rest. Repeat until exhaustion. OT- Overtrain (1rep*10sets @100%1RM, 2min rest every day for 2 weeks) Con- Control		15min, 0min) Post-ex (5min) Test 1-Day 1 Test 2- Day 7 Test 3- Day 14	pre/post-ex for both groups all test days. Pre/post-ex T levels for Con group are significantly ($p<.05$) greater during Test 3 compared to Test 1. OT had significantly ($p<.05$ post-ex T levels during Test 3 compared to Test 1. C- Post-ex C levels significantly ($p<.05$) lower for Con group during Test 3 compared to Test 1. No group differences GH- Post-ex GH levels significantly ($p<.05$) higher compared to pre-ex for both groups all test days. No group differences
Kraemer et al, (1999)	17 males	Both (10 weeks training)	Y- $\leq$30 years O- $\geq$62 years Squat – 4 sets*10reps @10RM, 90s rest.	T, C, GH, IGF-1, IGFBP-3, ACTH	Blood (Squat)- Pre, Post -ex(0, 5, 15, 30) (Resting)- Wk 0, 3, 6, 10	T- Resting concentrations were higher in Y group compared to O, which was significant ($p<.05$) at Wk 3, 6. Post-ex levels were elevated T for both groups pre/post training. Training elevated post-ex response significantly in O group (5, 30min, $p<.05$). Significant ($p<.05$) post-ex differences in free T pre/post training between Y and O. C- Resting concentration significantly lower ($p<.05$) at Wk 3, 10 for O group but not Y. Post-ex levels significantly elevated ($p<.05$) both groups pretraining. Significant ($p<.05$) group difference in post-ex C levels, Y group having lower levels 0 and 5 min post-ex. GH- No differences in resting concentration between groups. Post-ex GH levels significantly elevated ($p<.05$) in Y group pre and post training. Only significant ($p<.05$) between group difference occurred pretraining 30min post-ex.

						ACTH- No differences in resting concentrations between groups. Significant (p<.05) elevations for both groups post-ex (Y-0, 5, 15min; O-0, 5min) with no between group difference. Post training post-ex ACTH levels were significantly (p<.05) reduced for both groups (Y-0, 5, 15mi; O-0min) but no between group differences. Resting IGF-1 and IGFBP-3 were significantly higher (p<.05) in Y compared to O.
Izquierdo et al (2009)	12 physically active males	Both (Training 7weeks)	5sets*10reps (Leg Press) Pre- pre training 10RM REL- New 10RM after 7 weeks RT. ABS- Pre 10RM after 7 weeks RT.	T, GH, C	Blood- Pre-Ex, Mid-Ex, Post-Ex (0, 15, 45min.)	T increased Free T (p<.05) at Mid-Ex and Post-LP (0min) for all protocols. Pre and REL stayed elevated (p<.05) Post-Ex (15min). GH-Increased (p<.05) Post-Ex (0, 15, 45) for Pre and REL. Cortisol increased (p<.05) Post-Ex (15, 45min) for Pre and REL.
Schuman et al (2013, 2014)	29 physically active males	Both (Training 24 weeks)	S- 11 sets of leg press E- 30 min cycling. S+E or E+S	T, GH, C, TSH	Blood- Basal, Pre-Ex, Mid-Ex, Post-Ex, Rec (24, 48h)	T increased (p<.05) Mid to Post-Ex for the S+E group. Both groups had decreased (p<.05) levels during Rec (24, 48h). Basal levels increased with training. Group differences during Rec at Week 0 of training GH increased (p<.001) with E but not S (both groups). No recovery measurements. C increased (p<.05) Mid to Post-Ex in the S+E group. TSH decreased (p<.05) in both groups during Rec (24, 48h).

Mitchell et al (2013)	23 young healthy adult males	Both (Training 16 weeks)	No Groups 4sets*8reps (leg press, leg extension, leg curl, calf press) 2 minutes rest	T, GH, IGF-1, C, Androgen Receptor (AR)	Blood- Post-ex AUC (0, 15, 30, 60min), Resting Muscle- 1, 5h (Wk0, Wk 16)	Significant decrease (p<.01) in all resting hormone concentrations (Wk0 compared to Wk16). Significant decreases (p<.05) in post-ex AUC (0, 15, 30, 60min) response for T, GH, IGF-1. Significant correlations (p<.05) between AR Fold Change and increase in CSA (Mean-r=.60, Type II- r=.60, Type I-r=.47)
Izquierdo et al (2006)	42 physically active males	Training (16 weeks)	RF- Train to failure during RT sessions NRF- No failure during RT C- Control	T, IGF-1, C	Blood (Resting)- Week 0(T0), 6 (T1), 11 (T2), 16 (T3)	T increased (p<.05) at T2 for NRF group only. IGF-1decreased (p<.05) at T2 and T3 for RF group only C- Decreased (p<.05) at T1 and T2 for NRF group only.
French et al (2007)	10 trained males	Acute (2 trials 7d apart)	RT- Squat 6x10 @ 80%1RM, 2min rest C- Control	E, NE, DA, T	Blood Pre-Ex(-60, -30, -15, -10, -5, 0min) Ex (5, 8, 11, 14, 17, 20min) Post-Ex (25, 30min)	E- Significant increase (270% compared to C, p<.05) starting pre-ex (-5min) and continued to increase significantly during exercise (512% compared to C, p<.05). NE- Significant increase (255% compared to C, p<.05) starting pre-ex (-5min) and continued to increase significantly during exercise (271% compared to C, p<.05). DA- Significant increase (164% compared to C, p<.05) starting pre-ex (-60min) and continued to increase significantly during exercise (38% compared to C, p<.05). T- Significantly elevated (compared to C, p<.05) at 17min (set 5) and 30min (+5 post-ex).

Chapter II Resistance Training Variables and Programming

Introduction

The purpose of this chapter is to identify and discuss different RT variables (exercise selection/order, training frequency, load, volume, technique, and rest time used to achieve desired fitness outcomes (strength, hypertrophy, power, and endurance). In addition, the process of periodization; manipulating RT variables over the course of a training program to optimize performance and recovery for long term progression, will be explained and reviewed.

RT program variables and periodization schemes will be based on the recommendations by the American College of Sports Medicine (ACSM) and National Strength and Conditioning Association (NSCA). Since each organization targets different populations a careful examination of each organization's recommendations and how they are applied to RT research will be reviewed.

The ACSM RT Position Stand (Ratamess et al, 2009) categorized their levels of recommendations [(A)-Rich body of randomized control trial studies with a rich body of data, (B)-Limited body of randomized control trial data, (C)-Nonrandomized trials, observational studies, (D)-Panel Consensus Judgment] based on the research (280 sources) available to support claims. This method of grading adds great validity to the recommendations of ACSM research and clearly shows which areas of RT research have been established and which ones need more research before recommendations can be fully supported.

The NSCA recommendations from Essentials of Strength and Conditioning (Baechle & Earle, 2008) cite 118 sources (including peer reviewed journals) for RT variables, 25 for periodization, and 144 sources on how age and sex related differences can affect RT prescription. However unlike the ACSM, they do not grade the recommendations but merely cite the available

research to support their claims. Even though this lack of grading may be considered a weakness, the NSCA makes up for this by listing several exercises, programs, and tests that can be performed to evaluate the efficacy of RT programs based on training demands.

Target Population

ACSM

Recommendations are provided by the following primary sources; Guidelines for Testing Exercise and Prescription 8th Edition (Thompson et al, 2010) and Progression Models for Resistance Training in Healthy Adults (Ratamess et al, 2009).The ACSM Guidelines and RT Position Stand has been updated since 2005 and 2002 respectively. ACSM targets clinical populations as well as healthy active adults with their recommendations. According to ACSM, the goal of RT is to improve health, increase functional/muscular fitness, and delay the onset of or treat conditions such as non-insulin dependent diabetes, chronic inflammatory diseases, osteoporosis, and obesity (Ratamess et al, 2009; Thompson et al, 2010).

NSCA

Recommendations are provided by the Essentials of Strength and Conditioning Research 3rd Edition (Baechle & Earle, 2008). The NSCA targets populations participating in athletic events (football, basketball, track and field, etc.) and RT related sports (weightlifting, powerlifting). Their RT recommendations also account for differences in gender, age, experience, and primary fitness goals.

Exercise Selection/Order

Before comparing ACSM and NSCA recommendations on exercise order and selection, a recent literature review performed by Simao et al, (2012) will be examined. A few studies from this review article are referenced in Table 2.1 and focus exclusively on how exercise selection

and order acutely affects performance as measured by repetitions completed per set during a given exercise. All of the studies mentioned in Table 2.1 assign exercise order either smallest to largest muscle groups (S2) or largest to smallest muscle groups (S1). Most of the studies in table 2.1 measure the effects of upper body exercises such as bench press, shoulder press, and triceps extension (Simao et al, 2005; Monteiro et al, 2005; Simao et al, 2007; Silva et al, 2009). Only 2 of the studies in Table 2.1 examined the effects of exercise order on lower body exercises such as leg press, squat, leg extension, and leg curl (Spreuwenberg et al, 2006; Simao et al, 2007). Of the studies examined, a trend emerges suggesting that the exercises performed first in a workout result in more repetitions completed regardless or intensity or exercise selection. For example Simao et al (2007) displayed increased repetitions performed in the bench press when it was performed first with fewer repetitions being performed for the bicep curls and triceps extensions while the opposite was true when triceps extension and biceps curls were performed before the bench press. The same study also observed increased repetitions performed in the leg press when it was performed before leg extension and leg curls and vice versa (Simao et al, 2007). In conclusion the literature review performed by Simao et al (2012) suggests that exercise movements of the highest priority should be placed in the initial portion of an RT session so as to optimize performance (defined as completing more repetitions to failure when compared to movements placed in the latter portion of a workout).

<u>ACSM</u>

According to ACSM Guidelines (Thompson et al, 2010), sessions should include 8-10 exercises per one full session whole-body or two split sessions of upper and lower body. Also training opposing muscle groups is also recommended to prevent muscle imbalance (Thompson et al, 2010). Complex multi-joint movements are preferred over single-joint movements for

training. Exercises such as squat and bench press should be implemented in strength and hypertrophy programs, while programs designed to increase power recommend using movements such as the snatch and clean and jerk (Ratamess et al, 2009). All of these movements require complex neural responses (Chilibeck et al, 1998), allow a person to lift greater loads compared to single-joint exercises (Stone et al, 1998), and require rapid force production (Grahamer et al, 1992) especially at heavier (>70%1RM) loads.

<u>NSCA</u>

According to NSCA, when selecting movements for a resistance training program considerations one should include primary fitness goals, availability of equipment/time, technique experience, and specificity of movement (Baechelle & Earle, 2008). Movements should be ordered from most to least complex (multi-joint→single joint) when goals of strength, hypertrophy, or power are demanded. The multi-joint movements recommended for strength as a primary fitness goal include the squat, leg press, bench press, good morning, and deadlift (Baechelle & Earle, 2008). Other multi-joint movements such as the push-press, power clean, and snatch are recommended when training for power. NSCA also recommends that these multi-joint power movements be performed first during the workout, due to the high demands of energy and concentration required to properly execute repetitions (Fleck & Kraemer, 1987; Stone & Bryant, 1987). Alternating upper and lower body exercises or push/pull movements is recommended for reducing fatigue (Fleck & Kraemer, 1987; Pauletto, 1986). To hasten fatigue it is recommended to perform movements in compound sets (2 movements for similar muscle groups) or supersets (2 movements for opposing muscle groups) (Baechle & Earle, 2006) (Stone & Bryant, 1987).

Technique/Muscle Action

ACSM

ACSM guidelines suggest RT movements should include both an eccentric and concentric phase through a full range of motion with normal breathing (Thompson et al., 2010). The ACSM RT Position Stand makes more in depth suggestions on muscle action according to training goals. For example, recommendations for strength and hypertrophy sessions are to utilize a combination of concentric, eccentric, and isometric contractions during training. Recommendations for novice lifters trying to improve strength, hypertrophy, or endurance include using slow to moderate contraction velocities. This will most likely avoid injuries associated with lack of stability during high velocity contractions. Advanced lifters should try to achieve maximal velocities for all training loads in order to improve strength, power, and endurance (Ratamess et al., 2009). The ACSM Guidelines (Thompson et al, 2010) and RT Position Stand (Ratamess et al, 2009) both lack recommendations on technique for individual lifts. The Health Fitness Instructors Handbook (Howley & Franks, 2003) provides instruction for proper technique for movements such as leg press, bench press, leg curl, lat pull down, arm curl, and overhead press. However, technique instructions for exercises such as the squat, power clean, and deadlift could not be found amongst the available literature endorsed by ACSM.

NSCA

Recommendations on exercise technique and muscle action are discussed more in terms of how they relate to specificity of activity (sport specificity). Movements relating to low velocity strength testing should be practiced with control and go through a full range of motion, while movements relating to high power or high velocity require the lifter to accelerate through the full ROM of a movement (Baechle & Earle, 2008). In addition to the guidelines of proper muscle action, *Essentials of Strength and Conditioning* dedicates an entire chapter to technique

with a step by step description of RT movements such as the squat, deadlift, bench press, push press, power clean, and snatch etc. (Baechle & Earle, 2008).

Training Frequency

ACSM

For all primary training goals (strength, power, hypertrophy, endurance), novice lifters should perform RT 2-3 days per week with at least 48 hours between sessions (Thompson et al, 2010; Ratamess et al, 2009). Intermediate lifters may perform as much as 3-4 sessions per week and advanced lifters 4-6 sessions a week with respect to all training goals (Ratamess et al, 2009). The ACSM RT Position Stand recommends novice lifters limit their training to 2-3 days per week for all fitness goals (strength, hypertrophy, power, endurance). In addition, training frequency for novice lifters received an A level rating. Less is known about the frequency of training for intermediate and advanced lifters with respect to all fitness categories. With regards to intermediate lifters training for strength and hypertrophy, the ACSM gives a B rating for training frequency meaning more randomized control research is needed to support recommendations (Ratamess et al, 2009). Little to no research supports recommendations on strength and hypertrophy RT frequency for advanced lifters or power and local muscular endurance RT frequency for both intermediate and advanced lifters, resulting in C's for all each respective fitness category (Ratamess et al, 2009).

NSCA

The number of sessions a person trains per week is dependent on training status (or sport season), intensity, and type of movements used. People who participate in low frequency training (1-3sessions/week) include untrained/novice lifters as well as athletes who are in season or immediately post-season. Intermediate/advanced lifters and athletes who are in offseason or

preseason are to participate in more than 3 RT sessions per week, in some cases as many as 6 or 7 sessions per week (DeRenne et al, 1996; Stone et al, 1982; Tan, 1999). The table below (2.2) summarizes training frequency recommendations for non-athletes and comes directly from *Essentials of Strength and Conditioning 3rd Edition* (Baechle & Earle, 2008). Athletes' training frequencies are generally higher in the off season (4-6 RT sessions per week) and lower in season (1-3 sessions per week) (Baechle & Earle, 2008).

Table 2.2 Training Frequency Example

Training Status	Experience	Sessions (week)
Beginner	< 2 months	2-3
Intermediate	2-6 months	3-4
Advanced	>1 year	4-7

Load (Intensity)

ACSM

While the ACSM guidelines (Thompson et al, 2010) give a very brief description for prescribed training loads (60-80%1RM), the ACSM RT Position Stand (Ratamess et al, 2009) goes into detail about specific training intensities for training goals of strength, hypertrophy, power, and endurance. Recommendations for strength sessions received an A level rating and suggest novice lifters should train with loads 60-70%1RM, progressing to 70-80%1RM loads for intermediate lifters, and advanced lifters should cycle loads of 80-100%1RM (Ratamess et al, 2009). Recommendations for hypertrophy sessions also received an A level rating suggest novice and intermediate lifters may use loads similar to strength training (60-70%, 70-85%1RM respectively), while advanced lifters may require heavier loads up to 100%1RM. However, the majority training loads should be 67-85%1RM for advance lifters training for hypertrophy. To enhance power, ACSM recommends training with light to moderate loads [upper body (30-60%1RM), lower body (0-60%1RM)] to increase force production at fast velocities, while advanced lifters may need additional training with heavy loads (85-100%1RM) to increase

maximal force output at low velocities (Ratamess et al, 2009). The ACSM RT Position Stand gave the first recommendation on training loads for power listed above an A level rating, while the recommendations for advanced lifters had less research to support it resulting in a B level rating (Ratamess et al, 2009). The most recent edition of the ACSM RT Position Stand (Ratamess et al, 2009) does not provide specific recommendations on endurance training loads for novice to intermediate lifters. Instead novice and intermediate lifters were instructed to lift with light training loads while advanced lifters were instructed to use light, moderate, and heavy loads in a periodized manner. Nevertheless the recommendations received an A level rating, and recommendations for advanced lifters received a C level rating. However, an earlier edition of the ACSM RT Position stand (2002) does cite specific training loads for novice and intermediate lifters (50-70%RM) as well as advance lifters (30-80%1RM).

NSCA

All recommendations for load intensity were derived from *Essentials of Strength and Conditioning 3rd Edition* (Baechle & Earle, 2008) and cited at least 20 references with respect to all training goals combined. For programs demanding strength gains, training load should be >85%1RM (Stone et al, 1982; Fleck & Kraemer, 2003). Programs designed for power training require loads to be 75-90%1RM for complex multi-joint movements (Garhammer, 2007) (Kraemer et al, 1992) (Newton et al, 1994), while single joint movements may require as little as 30% 1RM (Garhammer, 1993). If hypertrophy is the training goal, loads should be 67-85%1RM. Endurance programs should utilize light training loads (<67%1RM) (Baechle & Earle, 2008).

*Volume (Sets*Repetitions)*

ACSM

The overall goal of RT is to involve all major muscle groups for 2-4 sets per session for 8-12 repetitions per set according to ACSM Guidelines (Thompson et al., 2010). ACSM's RT Position Stand is more specific with respect to experience level and training goals (Ratamess et al, 2009). Novice and intermediate lifters training for strength and hypertrophy should use 1-3 sets with 8-12 repetitions per set. Advanced lifters training for strength and hypertrophy should progress towards 1-12 repetition sets for 3-6 sets. Recommendations on improving endurance for novice to intermediate lifters include using moderate to high repetition (10-15 reps) sets , while advance lifters should use (10-25reps or more) sets. Power sessions for novice and intermediate lifters on should include 3-6 repetition sets; not achieving failure, for 1-3 sets. Volume recommendations for RT sessions focused on strength, power, and hypertrophy received A's, indicating that enough sources were available to be fully supported by ACSM (Ratamess et al, 2009). Endurance training volume recommendations also received an A rating, but these recommendations were limited to novice and intermediate lifters whereas training volume recommendations for advanced lifters received a C (Ratamess et al, 2009).

NSCA

According to *Essentials of Strength & Conditioning* (Baechle & Earle, 2008), volume can be identified as load volume (load*repetitions*sets) or repetition volume (repetitions*sets). A table, with over 10 different citations, prescribing sets and desired repetitions per set outlines volume recommendations is also provided. Strength and power RT sessions should have low to moderate repetition sets (1-5 reps) for 2-6 sets if training for strength (Fleck & Kraemer, 1987; Tan, 1999) or 3-5 sets if training for power (Garhammer, 2007; Hickson et al, 1980; Stone et al, 1982; Stone & O'bryant, 1987). Volume for strength and power RT sessions are low compared to hypertrophy and endurance workouts, since failure occurs in fewer repetitions due to heavier

training loads associated with such RT sessions. Hypertrophy RT sessions use moderate repetition sets (6-12 reps) for 3-6 sets (Dudley et al, 1991;Fleck & Kraemer, 1987; Hedrick, 1995; Ostrowski et al, 1997;Tesch, 1992), while endurance RT sessions use high repetition sets (>12 reps) for 2-3 sets (Kraemer & Koziris, 1982).

Rest Intervals

ACSM

As recommended by the ACSM Guidelines (Thompson et al, 2010), 2-3 minutes rest between sets is sufficient for optimal recovery between sets. However, the ACSM RT Position Stand (Ratamess et al, 2009) gets more specific in terms of prescribing rest time between sets based on fitness goals. Strength and power sessions have similar rest time recommendations of 2-3 minutes between sets, even though both have different ratings (Ratamess et al, 2009). The rest time recommendations for strength are based on at least 10 sources and received a B rating, while recommendations for power were not based on any sources and received a D rating (Ratamess, et al 2009). Rest time recommendation for hypertrophy and endurance sessions is 1-2 minutes, and receives a C rating due to very few studies being cited to support the recommendations (3 and 2 sources respectively, Ratamess et al, 2009). Rest time recommendations of 1-2 minutes for hypertrophy sessions are limited to novice and intermediate lifters, while advanced lifters require additional rest time (2-3 minutes) to recover from high repetition sets with heavier training loads (Ratamess et al, 2009). Also, 1-2 minute rest time recommendations for endurance sessions are limited to high repetition (15-20) sets, whereas moderate repetition (10-15) sets or circuit training programs may require 1 minute or less for recovery between sets (Ratamess et al, 2009).

NSCA

The NCSA provides numerous references for at least 3 of the categories of fitness training goals (strength, power, and hypertrophy) in the *Essentials of Strength and Conditioning* (Baechle & Earle, 2008). NSCA recommends that strength and power sessions have similar rest times and 14 references are cited as support. Rest time recommendations for hypertrophy and endurance sessions are based on 6 sources and 3 sources respectively. Again, even though NSCA does not grade the recommendations in the same fashion as ACSM, they use more references to support claims on rest time recommendations.

The Essentials of Strength and Conditioning (Baechle & Earle, 2008) contains both a table with 8 cited sources and several passages with multiple cited sources regarding appropriate rest times. An RT session designed for strength and power should use long rest periods (3-5 minutes) (Epley, 1985; Lombardi, 1989; Spasov, 1989; Stone & O'Bryant, 1987; Weiss, 1991). Moderate rest periods (30-90 seconds) are recommended for hypertrophy sessions (Hedrick, 1985; Kraemer & Koziris, 1992; Kraemer et al, 1987; Larson & Potteiger, 1987; Tesch, 1982; Tesch, 1992). Very short rest periods (≤30 seconds) are recommended for endurance sessions (Baechle & Earle, 2006; Gettman & Pollock, 1981; Harman & Frykman, 1992; Richardson, 1993).

Progression, Maintenance, and Periodization

<u>ACSM</u>

Overload can be achieved through increased training load, repetitions, sets, or frequency. The ACSM RT position stand gives examples of this by increasing the aforementioned training variables as a lifter acquires more experience; for example an intermediate lifter might use a heavier training load or higher volume compared to a novice, but less than an advanced lifter (Ratamess et al, 2009). The rule of thumb on progression is to increase load or volume no less

than 2.5%, but not more than 5% for succeeding RT sessions (Fleck and Kraemer, 1997). If the goal of training is maintenance, a frequency of 1 day per week may be all that is required as long as load and volume are held constant (Thompson et al., 2010).

Periodization, also known as variation in training, is recommended for continual progression in RT. ACSM does not explain periodization with much depth (compared to NSCA). However, brief summaries are given on three different models (classical, reverse, undulating) (Ratamess et al, 2009). Classical (or linear) periodization programs start with high volume/low intensity and gradually increases intensity while decreasing volume as the lifter progresses through the program. Reverse periodization is the opposite of classical periodization because its design increases volume through the duration of the program while reducing intensity of the training load. This approach to RT is recommended for increasing local muscular endurance, but not strength when compared to classical periodization (Ebben et al, 2004; Rhea et al, 2004). Undulating periodization involves changing training protocols either weekly or daily by adjusting volume and/or intensity (Baker et al, 1994; Rhea et al, 2002; Kraemer et al, 2002; Marx et al, 2001).

The only available source to provide a detailed description on periodization programming comes from the *Health Fitness Instructor's Handbook* (Howley & Franks, 2003). The traditional (linear) model is divided into 4 phases (general preparation, hypertrophy, strength, peaking), each phase lasting 6-8 weeks. Each phase is identified by Howley & Franks (2003) as amesocycle and the combination of all phases makes up what is known as a macrocycle. Upon completing a macrocycle, a period of active rest lasting 1-3 weeks is recommended to ensure full recovery from the macrocycle. After the active rest period is completed, the macrocycle is repeated with the same set/repetition schemes, but training loads altered to accommodate for

changes in strength derived from the previous training cycle. Undulating periodization cycles are also mentioned by Howley & Franks (2003) and its description is similar to the one outlined in the ACSM RT Position Stand (Ratamess et al, 2009); daily fluctuations in training volume and intensity to account for changes in strength. An example for both linear and undulating periodization given by Howley & Franks (2003) is displayed in the tables below.

Table 2.3 Example of Linear Periodization Macrocycle (Howley & Franks, 2003)

	Phase 1 General Prep	Phase 2 Hypertrophy	Phase 3 Strength	Phase 4 Peaking
Training Load	12-15RM	8-12RM	6-8RM	4-6RM
Sets	1-2	2	2-3	3
Rest	1-2 min	1 min	1-2 min	2-3 min

Table 2.4 Undulating Periodization 1Week Example (Howley & Franks, 2003)

	Monday	Wednesday	Friday
Training Load	8-10RM	4-6RM	13-15RM
Sets	2	3	1
Rest	2 min	3 min	1 min

NSCA

In regards to overload and progression, the NSCA uses the 2-for-2 rule to determine if progression is warranted (Baechle & Earle, 2008). This means the lifter must complete 2 or more repetitions over the desired repetition goal on the last working set for at least 2 consecutive training sessions (Baechle & Earle, 2006). In terms of absolute load increases, it is recommended that less trained individuals limit increases to 2.5-5 pounds for upper body, 5-10 pounds for lower body movements. More trained individuals can make larger load increases for progression (e.g. 5-10 pounds or possibly more) for upper body progressions, and 10-15 pounds or more for lower body lifts. In terms of relative intensity, the NSCA recommends that load increases stay within the range of 2.5-10% (Baechle & Earle, 2008). NSCA recommendation for maintenance of strength will be explained later in this section as it pertains to a specific phase regarding periodized RT programs.

Recommendations by the NSCA for periodization have far more depth compared to ACSM in terms of explanation and application. Periodization was proposed by Leo Matveyev (1966) as a better way to construct programs for sports training. The program structure of periodization is modeled to optimize the General Adaptation Syndrome (GAS) response curve (Seyle, 1956). This curve consists of the alarm, super compensation, and maintenance phases. The alarm phase is identified as the stress response to stimuli brought on by training, observed as a transient decrease in performance. The super compensation phase occurs when noticeable performance gains are observed. The maintenance phase is identified as the phase where performance gains are no longer made, such as during a sports season for athletes (Baechle & Earle, 2008).

The traditional model of periodization (linear periodization) takes place for an extended period of time, and is also known as a macro cycle. A macro cycle is broken into different phases {preparatory, transition, competition, and second transition (active rest)} consisting of mesocycles (lasting several weeks/months) and/or microcycles (lasting 1-2 weeks). These phases allow for manipulation of RT variables to achieve specific short term fitness goals that build towards a primary long term goal. The purpose of the preparatory phase is to condition the muscles with high volume moderate intensity RT sessions gradually shifting towards high intensity low to moderate volume RT sessions. During the preparatory phase the athlete goes through 3 meso cycles of training; hypertrophy/endurance, basic strength, and strength/power. Hypertrophy/endurance sessions require training loads with low to moderate intensities (50-75% 1RM) and high volume (10-20 reps * 3-6 sets) and a mesocycle can last up to 6 weeks (Fleck & Kraemer, 2004). The basic strength phase uses significantly greater training loads (80-90%1RM) with slightly less volume (4-8 reps * 3-5 sets) than the hypertrophy endurance phase.

Following the preparatory phase, the first transition (Stone et al, 1981) takes place and indicates a break between high volume and high intensity training (Chargina et al, 1986; Chargina et al, 1987). Here, the RT sessions are designed to maintain strength and power and use training loads similar to the basic strength (75-95% 1RM), but volume (2-5 reps * 3-5 sets) is reduced. Following the first transition, the competition phase is the last mesocycle in which RT session are programmed and occurs during the competition season of the athlete. Competition RT sessions are designed to peak or maintain strength and power acquired from the previous mesocycles. Peaking strength and power gains would require the heaviest training loads (>93%1RM) and lowest volume (1-3 reps * 2-3 sets). A competition RT cycle allows an individual to peak for about 3 weeks before overtraining becomes a problem (Bompa, 1983; Chargina et al, 1987). Maintaining strength and power gains requires lighter training loads (80-85%1RM) and more volume (6-8 reps * 2-3 sets) when compared to peaking. Post-season, athletes go through a second transition also known as the active rest phase involving little to no RT. Below is a table summarizing the NSCA recommendations for prescribed load and repetition volume (for core lifts only) according to phase in the periodization cycle (Baechle & Earle, 2008).

Table 2.5 Example of Linear Periodization Macrocycle (Baechle & Earle, 2008)

Phase	Preparation		First Transition	Competition	
Goal	Hypertrophy/Endurance	Basic Strength	Strength/Power	Peaking	Maintenance
%1RM	50-75	80-90	75-95	≥93	80-85
Sets	3-6	3-5	3-5	1-3	2-3
Reps	10-20	4-8	2-5	1-3	6-8

While linear models gradually increase intensity and reduce repetition volume over the course of a macro cycle, another form of periodization; undulating periodization, has also been used for RT programs (Baker et al, 1994; Fleck & Kraemer, 2004). Undulating periodization has more frequent (weekly/daily) fluctuations in training intensity and repetition volume during a

training cycle. These fluctuations are thought to reduce the accumulation of neural fatigue, which has been observed in linear models (Komi, 1986). A one week example of undulating periodization from *Essentials of Strength & Conditioning* (Baechle & Earle, 2008) is shown below.

Table 2.6 Undulation Periodization 1 Week Example (Baechle & Earle, 2008)

	Tuesday	Thursday	Saturday
Training Load	6RM	10RM	3RM
Sets	4	3	5

Controversy exists over which model (linear or undulating) is more effective for achieving gains in specific fitness goals (strength, hypertrophy, power, and endurance) since at least one study has found no difference between the two (Baker et al, 1994), but other studies favor the undulating model (Kraemer, 1997; Stone et al, 1997). Finally, periodization models should not be limited to the examples displayed in previous tables (2.4, 2.6) since individuals might have different training demands/schedules and the whole point of undulating periodization is to allow more flexibility in RT programming compared to linear periodization.

Research Applications

Periodization

A previous review (Fleck, 1999) and more recent meta-analysis (Rhea & Alderman, 2004) have concluded periodized RT programs are superior to non periodized programs.   The majority of periodization studies used in the review by Stephen J Fleck (1999) are displayed in Table 2.7. Many of the studies observed gains in strength for the squat, bench press, leg press, and hang clean; favoring periodized training over non periodized training. Some of the studies outlined in the table also observed favorable gains in power as measured by vertical jump and cycling; and therefore favored periodized training for power compared to non periodized training (Stone et al, 1982; O'Bryant et al, 1988; Kraemer, 1997). In addition a few studies observed

increased endurance as measured by reps to exhaustion in the bench press (Kraemer, 1997**)** and squat (McGee et al, 1992; Kraemer, 1997); suggesting that periodized training could enhance muscular endurance better than non periodized training. The majority of the studies reviewed in Table 2.7 required subjects to train at the same frequency; 3 times per week, with the exception of Willoughby (1992) and Kraemer (1997) in which subjects trained 2 and 4 times per week respectively. A problem that emerges when comparing studies from Table 2.7 is that each study follows lifters for a different amount of time for the duration of training. In some cases studies are less than 12 weeks (Stone et al, 1982; Stowers et al, 1983; O'Bryant et al, 1988; McGee et al, 1992), while other studies are 12-16 weeks in duration (Willoughby, 1992; Willoughby, 1993; Baker et al, 1994; Kraemer, 1997). Only one training study lasted longer than 16 weeks, and that was a 24 week study conducted by Kraemer (1997). Another problem with comparing all the programs in table 2.7 is that they all used different combinations and numbers of exercises for the duration of the study. Some studies used only the tested lifts such as squat and bench press (Willoughby, 1992; Willoughby, 1993). Most studies used 6-10 exercises during their programs (Stone et al, 1982; Stowers et al, 1983; O'Bryant et al, 1988; McGee et al, 1992; Kraemer, 1997), but a few used more than 10 exercises (Baker et al, 1994; Kraemer, 1997).

During linear periodization, some mesocycles requiring high intensity training loads and high repetition volume can put a lifter at risk for overtraining. Undulating periodization allows for more recovery by varying training load set and repetition schemes each RT session, which should facilitate the recovery process (Fry & Kraemer, 1997). More research favors the undulating periodization model compared to the linear periodization model (Rhea et al, 2002; Kramer et al, 2000; Marx et al, 2001). Rhea & Alderman (2004) established some important conclusions about using periodization for RT programs in their literature review. First,

periodized RT programs have greater effects compared to non periodized programs; effect sizes were 1.28 and 1.03 respectively. Second, periodized RT programs appear to have a greater effect on younger adults (<55years) compared to older adults (>55years); effect sizes were 1.34 and 0.85 respectively (Rhea & Alderman, 2004). Third, optimal length of a training cycle has not been determined since no effect size differences were seen in programs that ranged from 1-8, 9-20, and 20-40 weeks (Rhea & Alderman, 2004). Therefore, additional research is needed to compare linear and undulating periodization models; preferably with programs lasting longer than 6 months, to answer questions about the long term effects of different forms of periodization on sports performance and physical fitness and how they affect post exercise performance and recovery (Rhea & Alderman, 2004).

Sports & Fitness

According to the ACSM Position Stand (Ratamess et al, 2009), RT can also be used to improve performance in soccer (Poulmedis et al, 1988), in baseball (Lachowetz et al, 1998), shotput (Chu, 1950), and tennis (Kraemer et al, 2000). ACSM suggest that RT programs improve sport specific movements such as vertical jump and sprinting ability. Recommendations to improve both movements received B's, which means there is some randomized control trial data, but more studies are needed to fully endorse recommendations (Ratamess et al, 2009). Multiple sources suggest improving vertical jump performance should utilize programs with multiple-joint movements practiced at a fast repetition velocity, with loads and volume being implemented in a periodized fashion (Adams et al, 1992; Garhammer & Gregor, 1992; Hakkinen & Komi, 1985; Hakkinen & Komi, 1985; Hoffman et al, 2004; Kraemer, 1997; Tricoli et al, 2005). ACSM also claims sprinting ability can be increased if ballistic and resistance movements are used in combination with training (Delecluse, 1997; Hoffman et al, 1990;

Hoffman et al, 2004). In contrast, the *Essentials of Strength & Conditioning* gives several examples of RT program templates, with regards to sports specificity (Baechle & Earle, 2008). Sleivert and Taingahue (2004) demonstrated that traditional and split squat performance have moderate ($r=-0.64-.68$) yet significant ($p<.001$) correlations with short distance sprint times. Another study by McGuigan and Winchester (2008) found a strong correlation ($r=.54$) between squat 1RM and vertical jump performance.

There is no reason why RT for fitness and sport should be different in regards to prescribing movement selection, training load, volume, and frequency. Strength training recommendations for exercise selection, muscle action, training load, volume, and frequency (novice lifters only) have A-level recommendations. Hypertrophy training recommendations for exercise selection, training load, volume, muscle action, and frequency (for novice lifters only) also receive A-level recommendations. Power training recommendations for training load (for novice and intermediate lifters), volume, and frequency (novice lifters only) have A-level recommendations. Endurance training recommendations for exercise selection, training load (for novice and intermediate lifters), and frequency (for novice lifters only) receive A-level recommendations. In a review authored by Warren B. Young (2006), he outlined an important concept with regards to applying RT to sports performance. Although RT is beneficial for increasing strength, hypertrophy, power, endurance, neuromuscular activation, and intramuscular coordination; the gains elicited from RT must be transferred to sport specific activity in a way that enhances intermuscular coordination. Otherwise, problems such as decreased or inhibited performance can arise due to increased activation of antagonist muscles, musculotendinous stiffness, or lack of sport specific training time due to increase time dedicated to RT.

Conclusions

The table below summarizes NSCA recommendations for RT programs according to fitness training goals, based on several tables derived from Essentials of Strength and Conditioning (Baechle & Earle, 2008).

Table 2.8 NSCA General Recommendations for RT

	Intensity (1RM)	Sets	Reps	Rest
Strength	>85%	2-6	≤6	2-5 min
Hypertrophy	67-85%	3-6	6-12	30-90 sec
Power	75-90%	3-5	1-5	2-5 min
Endurance	<67%	2-3	≥12	≤ 30sec

In regards to RT training variables and the validity of recommendations, rest intervals for all fitness categories (strength, hypertrophy, power, endurance) have no more than a B in terms of quality of research. Also, the NSCA has a completely different set of recommendations for rest intervals with regards to all fitness categories. However, the NSCA targets a different population (athletes, competitive lifters) compared to the ACSM (general population, healthy active adults) which would explain the difference. The table below provides comparison between the two.

Table 2.9 Rest Time Comparison (ACSM v NSCA)

	ACSM	NSCA
Strength	2-3min	2-5min
Hypertrophy	1-2min (novice, intermediate) 2-3min (advanced)	30-90sec
Power	2-3min	2-5min
Endurance	1-2min (>15reps) ≤1min (10-15 reps)	≤30sec

Training frequency seems to be another RT variable requiring additional research with respect to intermediate and advanced lifters. However, the ACSM (Ratamess et al, 2009) and

NSCA (Baechle & Earle, 2008) agree on their recommended training frequencies (Intermediate: 3-4 days per week, Advanced: >4 sessions per week).

Despite the popularity of periodization in training, its effects are not as well known for novice (<6 months experience) lifters or for programs lasting longer than 6 months. Some studies have observed similar effects between linear and undulating RT programs and other studies finding non-periodized RT to be just as effective as periodized RT (Ratamess et al, 2009).

Rest time between sets, training frequency, and periodization model seem to be the 3 variables that require additional research as soon as possible. Modeling RT studies with these factors as dependent variables would provide much needed information on how to maximize recovery between sets and RT session as well as maximize performance. Performance would be important in terms of 1) successfully completing required volume within a given RT session and subsequent training RT sessions and 2) optimizing performance for those who compete in athletic events that are required to produce large amounts of force and/or power (ex: competitive lifting, football, track & field, volleyball, baseball, basketball, etc).

Table 2.1 Acute effects of exercise order on repetitions completed in an RT session.

Author	Load	Order	Exercise	Set 1	Set 2	Set 3	Set 4	Mean	Total
Simao et al, 2005	10RM	S1: Large to small muscle groups	Bench Press S1	9.9	9.7	8.5		*	
		S2: Small to large muscle groups	Bench Press S2	8.3	6.9	6.7			
			Lat Pull Down S1	10	9.5	7.8		*	
			Lat Pull Down S2	9.8	8.3	7.1			
			Shoulder Press S1	9.4	8.1	5.6			
			Shoulder Press S2	9.8	8.6	7.1			
			Biceps Curl S1	10	9	6.5*		*	
			Biceps Curl S2	10	10	9.6			
			Triceps Extension S1	9.3	7.9	7.8		*	
			Triceps Extension S2	9.5	9.9	9.5			
Monteiro et al, 2005	10RM	S1: Large to small muscle groups	Bench Press S1	9.9	9.9*	9.1*		9.6*	
		S2: Small to large muscle groups	Bench Press S2	9.5	8.6	8.0		8.7	
			Shoulder Press S1	8.9	8.8	8.5		8.7*	
			Shoulder Press S2	9.9	9.6	9.3		9.7	
			Triceps Extension S1	9.3	9.7	9.3*		9.4	
			Triceps Extension S2	9.9	9.9	9.9		9.9	
Spreuwenberg	85%1RM	S1: Squat at	Squat S1	8.0*	6.2	5.6	5.0		

et al, 2006		beginning of session							
		S2: Squat at end of session	Squat S2	5.4	5.0	4.7	4.5		
Simao et al, 2007	80%1RM	S1: Large to small muscle groups	Bench Press S1	10.2*	8.2	6.7		8.4*	
		S2: Small to large muscle groups	Bench Press S2	6.7	6.0	5.3		6.0	
			Shoulder Press S1	9.4	7.9	7.3		8.2*	
			Shoulder Press S2	7.9	6.7	5.7		6.8	
			Triceps Extension S1	8.8*	8.5	8.4		8.6*	
			Triceps Extension S2	12.4	10.3	9.6		10.8	
			Leg Press S1	23.9*	20.3*	19.3*		21.1*	
			Leg Press S2	20	16.3	16.2		17.5	
			Leg Extension S1	9.4*	9.9*	9.8		9.7*	
			Leg Extension S2	12.7	13.0	12.0		12.5	
			Leg Curl S1	15.7*	14.3*	13.4*		14.5*	
			Leg Curl S2	18.4	16.6	16.1		17.0	
Silva et al, 2009	10RM	S1: Large to small muscle groups	Bench Press S1 Younger Women						27.8*
		S2: Small to large muscle groups	Bench Press S2 Younger Women						20.4
			Shoulder Press S1 Younger Women						27.5
			Shoulder Press S2						28.8

			Younger Women						
			Triceps Extension S1 Younger Women						23.9*
			Triceps Extension S2 Younger Women						29.9
			Bench Press S1 Older Women						26.8*
			Bench Press S2 Older Women						21.0
			Shoulder Press S1 Older Women						26.4
			Shoulder Press S2 Older Women						27.3
			Triceps Extension S1 Older Women						27.2
			Triceps Extension S2 Older Women						27.7

*Denotes significant difference between S1 and S2

Table 2.7 Examples of Studies using Periodization in Resistance Training

Author	Length of Study	Training Frequency (per week)	Group	Sets*Reps	Intensity	Number of Exercises	Tests	% Increase
Stone et al, 1981	6 weeks	3	Non Periodized	3*6	N/A	6	Squat Vertical Jump	N/A* N/A*
		3	Periodized	5*10 (3wk) 5*5 (1wk) 3*3 (1wk) 3*2 (1wk)	NA	6	Squat Vertical Jump	N/A*,# N/A*,#
Stowers et al, 1983	7 weeks	3	Non Periodized	1*10	10RM	8	Bench Press Squat Vertical Jump	7* 14* 0
		3	Non Periodized	3*10	10RM	8	Bench Press Squat Vertical Jump	9* 20* 1*
		3	Periodized	5*10 (2wk) 3*5 (3wk) 2*3 (2wk)	10RM	8	Bench Press Squat Vertical Jump	9* 27*,# 10*
O'Bryant et al, 1988	11 weeks	3	Non Periodized	3*6	81-91%1RM	9	Squat Cycle Power	32* 6*
			Periodized	5*10 (4wk) 3*5, 1*10 (4wk) 3*2, 1*10 (3wk)	70-117%1RM	9	Squat Cycle Power	38*,# 17*,#
McGee et al, 1992	7 weeks	3	Non Periodized	1*8-12	8-12RM	7	Cycle to exhaustion Squat reps to exhuaustion	12 46
			Non Periodized	3*10	10RM	7	Cycle to exhaustion Squat reps to exhaustion	15* 71*
			Periodized	3*10 (2wk) 3*5 (3wk) 3*3(2wk)	10RM 5RM 3RM	7	Cycle to exhaustion Squat reps to exhaustion	29* 74*
Willoughby et al, 1992	12 weeks	2	Non Periodized	3*10	10RM	2	Bench Press Squat	8* 13*

			Non Periodized	3*6-8	6-8RM	2	Bench Press Squat	17*,$ 26*,$
			Periodized	5*8-10 (4wk) 4*5-7 (4wk) 3*3-5 (4wk)	8-10RM 5-7RM 3-5RM	2	Bench Press Squat	28*,# 48*,#
Willoughby et al, 1993	16 weeks	3	Non Periodized	5*10	79%1RM	2	Bench Press Squat	8* 14*
			Non Periodized	6*8	83%1RM	2	Bench Press Squat	10* 22*,^
			Periodized	5*10 (4wk) 4*8 (4wk) 3*6 (4wk) 3*4 (4wk)	79%1RM 83%1RM 88%1RM 92%1RM	2	Bench Press Squat	23*,# 34*,#
Baker et al, 1994	12 weeks	3	Non Periodized	5*6 core exercise 5*8 all others	6RM 8RM	17	Bench Press Squat Vertical Jump	12* 26* 9*
			Periodized (Linear)	5*10 core exercise 3*10 all others (4wk) 5*5 core exercise 3*8 all others (4wk) 3*3, 1*10 core exercise 3*6 all others (3wk) 3*3 core exercise 3*6 all others (1wk)	10RM 10RM 5RM 8RM 3, 10RM 6RM 3RM 6RM	17	Bench Press Squat Vertical Jump	11* 18* 4*
			Periodized (Undulating)	5*10 core exercise 3*10 all others (2wk) 5*6 core exercise 3*8 all others (2wk) 5*4 core exercise 3*6 all others (2wk) 5*6 core exercise 3*8 all others (2wk) 4*3 core exercise 3*6 all others (2wk)	10RM 10RM 6RM 10RM 4RM 6RM 6RM 8RM 3RM 6RM	17	Bench Press Squat Vertical Jump	16* 28* 10*
Kraemer et al, 1997	14 weeks	3	Non Periodized	1*8-10 forced reps	8-10RM	9	Bench Press Hang Clean Vertical Jump Wingate Power	3* 4* 3* 0
		3	Periodized	2-3*8-10 (3wk) 3-4*6 (2wk)	50% 1RM 70-85%1RM	12	Bench Press Hang Clean	11*,# 19*,#

				3-5*1-4 (2wk) Repeat all weeks	85-95%1RM		Vertical Jump Wingate Power	17*,# 14*,#
	24 weeks	3	Non Periodized	1*8-10 forced reps	8-10RM	20	Bench Press reps 80%1RM Leg Press reps 85%1RM Bench Press Leg Press Wingate Power	37* 22* 13* 6* 5*
		4	Periodized	Strength session 2-4*12-15, 8-10, 3-5 Hypertrophy session 2-4*8-10	12-15RM, 8-10RM, 3-5RM 8-10RM	21	Bench Press reps 80%1RM Leg Press reps 85%1RM Bench Press Leg Press Wingate Power	56*,# 41*,# 29*,# 20*,# 55*,#

* Significant difference pre to posttraining
\# Significant difference from non periodized group(s)
$ Significant difference from 3*10 group
^ Significant difference from 5*10 group

Chapter III Possible factors affecting post-exercise performance and recovery.

Introduction

The first purpose of this section is to examine relationships between measured metabolic markers and physical performance. Chapter 1 examined the effects of RT on metabolism and physical performance separately, but this chapter will determine if there is any relationship between changes in metabolism and physical performance as a result of RT.

The second purpose of this section is to examine recovery time between sets of RT exercises during a session and the optimal time it takes to fully recover from an RT session before another should take place. Briefly covered in chapter 2 under the sections of rest time and training frequency, this chapter will explore factors that have an effect on recovery.

The last purpose of this section is to examine emerging fields of research such as the use of accessory equipment in conjunction with RT such as elastic bands and assistive lifting apparel. The use of either accessory in RT would allow lifters additional options to add variation to their training programs; similar to how periodization is applied to RT programs.

Relationship between metabolic markers and performance

Initially, working muscle will hydrolyze ATP (via ATPase activity) and use up any available ATP stores which activates the PCr pathways due to the appearance of ADP and Pi (Houston, 2006). Sustaining high intensity activity for more than 10-15s will activate glycolysis and other pathways such as adenylate kinase (AK) and AMP deaminase (AMPD) in order to maintain the concentration of ATP (Houston, 2006). AK and AMPD work synergistically since AK reaction results in the formation of ATP and AMP, while AMPD will eliminate AMP to form ammonia (NH3) and IMP in order to shift AK to the right (Houston, 2006). Since the AMPD reaction is irreversible, IMP can only be converted back to AMP if it undergoes the

pathways of the purine nucleotide cycle (Houston, 2006). The enzymes required for this reaction (adenylosuccinate synthase, adenylosuccinate lysase) are not highly active during exercise, so regeneration of AMP must occur during rest (Houston, 2006). AMPD's product ammonia can leave the cell since it is not bound to phosphorus and cross the blood brain barrier leading to fatigue of the central nervous system (Hargreaves & Spriet, 2006). Another devastating consequence of AMPD is that continued activity of this pathway can lead to losses of total adenine nucleotides (combination of ATP, ADP, AMP) of up to 50% which can reduce force and power output (Houston, 2006). Reducing total adenine nucleotides would be harmful because the interaction of myosin and actin during cross-bridge cycling would be limited by the amount of ATP available (Hargreaves & Spriet, 2006). The next section will review studies establishing correlations between pre/post-exercise blood samples and performance.

Sanchez-Medina and Gonzalez-Badillo (2011) observed elevations in post-exercise blood lactate concentration as well as ammonia. Post-exercise lactate and ammonia levels also correlated well with percent loss of height in counter movement jump (CMJ) (L-R=.97, A-R2=.86), percent loss of mean propulsive velocity (MPV) over 3 sets for SQ (L- R= .97, A-R2= .85) and BP(L- R=.95, A- R2=.89), and percent loss of MPV with load of expected V of 1m/s for SQ(L- R=.93, A- R2=.9) and BP(L- R=.97, R2=.95). This study also observed different metabolic and performance responses between SQ and BP protocols that were matched for relative load intensity and repetition volume. Observations indicate a significant difference ($p<.05$) in percent loss of MPV over 3 sets and percent loss of MPV for loads with expected V of 1m/s between SQ and BP when working at RM for protocols using 3 sets of 12RM, 10RM, 8RM, 6RM, and 4RM. Blood lactate concentrations between post-exercise SQ and BP protocols matched for repetition volume were found to be significantly different ($p<.05$). However,

despite the significant difference ($p<.05$) between pre and post-exercise ammonia blood concentrations for SQ (12RM, 10RM, 8RM) and BP (12RM, 10RM, 8RM, 6RM) protocols, no differences were detected between SQ and BP protocols for post-exercise blood ammonia concentrations. In this literature review, only 2 other studies attempted to establish relationships between ammonia production and performance during RT protocols (Leveritt et al, 2000) (Izquierdo et al, 2009). Unfortunately, the strength testing protocol used in this study was not enough to elicit a change in performance at 32 hours post-exercise (50 minute cycle ergometer protocol) despite a significant increase ($p<.01$) in blood ammonia (Leveritt et al, 2000). The RT protocols observed by Izquierdo and colleagues (2009) observed decreases in both isometric strength and dynamic power in conjunction with increases in blood ammonia concentration. Unfortunately, no correlations were established to determine a relationship between these changes in performance and metabolite concentration (Izquierdo et al, 2009).

An earlier study observed significantly decreased ($p<.05$) power output in sets for a bench press protocol (6 sets * 10 repetitions @ 70%1RM) using 1 minute rest, but not 3 and 5 minutes rest (Abdessemed et al, 1999). The lactate levels for the protocol with 1 minute rest started becoming significantly higher ($p<.05$) at set 3 and continued to remain significantly different than other protocols (3, 5min rest) for every set all the way to set 10 (Abdessemed et al, 1999). Though not established with correlations, the study also observed significantly increased ($p<.05$) blood lactate in conjunction with decreased mean power per set in the 1 minute rest protocol (Abdessemed et al, 1999). Denton and Cronin's (2006) bench press study observed similar effects on lactate production with dissimilar effects on power output. The protocol with the highest post-exercise lactate readings also had the significantly greater ($p<.05$) eccentric and concentric output of force and power compared to the other protocols (Denton & Cronin, 2006).

However, this protocol also observed decreased number repetitions needed to achieve failure each subsequent set (7 reps initial set, 4 reps last set), despite alternating with sets of 3 with a load based on 6RM (Denton & Cronin, 2006).

The next study discussed will focus on other metabolites commonly measured such as blood lactate, testosterone, and catecholamines. French and colleagues (2007) used the squat exercise to alter metabolite concentrations and physical performance. After performing 6 sets of 10 reps (3min rest), isometric strength declined significantly over time ($p<.05$) from 4000N to around 3500N and dynamic strength decreased ($p<.05$) to below 2500N in the squat exercise. Along with decreases in strength, significant increases ($p<.05$) were noted in epinephrine (2pmol/mol), norepinephrine (10nmol/mol), dopamine (1pmol/mol), testosterone (25nmol/mol), blood glucose (6mmol/mol), and blood lactate (12mmol/mol). In addition to measuring the aforementioned metabolites, this study classified lifters in post-hoc analysis according to their force output abilities (maintainers vs reducers), and used a randomized control trial for each lifter in which to compare measured blood metabolites (French et al, 2007). Post-hoc analysis revealed a significant difference between force maintainers and reducers for area under the curve (AUC) of isometric force production ($p=.001$), epinephrine production ($p=.005$), and norepinephrine production ($p=.026$) (French et al, 2007). These observations imply that the force maintainers were able to produce higher levels of catecholamines during the exercise protocol compared to force reducers. When comparing the control trial to the RT trial, observations indicate the following. First, catecholamines became elevated during the exercise protocol even before the exercise trial began which implies that anticipation of exercise alone can significantly elevate catecholamines compared to rest. Second, concentrations of blood glucose, lactate, and testosterone for RT trials became significantly different ($p<.05$) than control

trials at different time points (Glucose- set 5, Lactate- set 2, Testosterone-Set 5) (French et al, 2007). Methods used by French and colleagues (2007) are novel and further research is needed comparing metabolic stress and physical performance for other RT protocols.

The next study to be examined is different from the previous studies because it utilizes 3 RT trials and is built into a 7 week training study. Izquierdo and colleagues (2009) compared the effects of 3 leg press protocols matched for volume (5 sets * 10 repetitions); pre-intervention (PRE), post-intervention absolute load (ABS), and post-intervention relative load (REL). The ABS protocol yielded significantly lower ($p<.05$) post-exercise blood concentrations of lactate, IL-6, IL-10, cortisol, and growth hormone when compared to PRE and REL levels (Izquierdo et al, 2009). Another significant observation was the effect of ABS protocol on post-exercise isometric strength and power when compared to PRE and REL (Izquierdo et al, 2009). The PRE protocol elicited significant ($p<.05$) reductions in isometric strength (23.4±11.7%) and power (58.4±14.5%), while the REL protocol elicited significant ($p<.05$) reductions in isometric strength (34.2±15.8%) and power (62.3±14.4%). The ABS protocol also elicited significant ($p<.05$) reductions in isometric strength (11.4%) and power (20.3%), but the post-training values for each were significantly ($p<.05$) greater than the PRE and REL protocols. Because the ABS protocol utilized the same training load as the PRE protocol, one could argue there was not enough training stimulus to elevate post-exercise lactate, cortisol, ammonia, or IL-6 to levels similar to PRE and REL leg press trials (Izquierdo et al 2009). In other words, a trained lifter will require heavier training loads and/or greater repetition volume during an RT trial to elicit similar decrements in performance and elevations in stress markers compared to an untrained person; which can be achieved by training with intensities that are relative to repetition max.

In conclusion high intensity and/or high volume RT generally results in elevated levels of lactate, ammonia, cytokines, catecholamines, and hormones such as testosterone, cortisol, and growth hormone immediately post exercise. Consequently, a decrease in performance such as decreased isometric/dynamic force, velocity, and ability to complete repetitions may be observed in exercises like the SQ, BP, LP, and CMJ in conjunction with elevated stress markers such as catecholamines, ammonia, and/or lactate (Abdessemed et al, 1999; Denton & Cronin, 2006; French et al, 2007; Izquierdo et al, 2009; Sanchez-Medina & Gonzales-Badillo, 2011). Some authors have also observed transient increases in hormones (C, T, GH) and cytokines (IL-6, IL-10), but relationships have not been established between all these aforementioned metabolites and performance (French et al, 2007; Izquierdo et al, 2009). Therefore, one can only speculate the relationship between metabolites, hormones, cytokines, and physical performance decrements. In addition, more information is needed to correlate the rate of decline in metabolic stress factors and rate of increase in performance.

Optimal recovery timeline for performance based on exercise protocol

Prescribing the appropriate recovery period between RT sets (rest interval) and sessions (training frequency) is critical since each fitness goal demands different recovery timelines. Recommended rest interval times for optimal recovery is subject to debate and is considered an underserved area of RT with respect to all fitness goals, especially in people who have more than 6 months RT experience (Ratamess et al, 2009).

<u>Recovery Between Sets</u>

Almost 30 years ago, Hakkinen & Komi (1986) established fatigue induced by RT can reduce the force and rate of force development of muscle contraction in 21 strength trained males. Peak force as measured during isometric leg extension began at 4108±1050N and

significantly decreased ($p<.001$) to 3279±897N following a fatigue protocol which involving maintenance of 60% max voluntary isometric contraction until failure (average time 35.7±8.2s). After 3 minutes of recovery, peak isometric force and rate of force production significantly increased ($p<.001$).

In a follow up study using 33 subjects, (Hakkinen & Myllyla (1990) went a step further by categorizing subjects by training type (Endurance-9, Strength- 9, Power-6, Control-9). As expected power and strength athletes had significantly more ($p<.05$) body mass (77.2±6.8Kg and 78.9±5.6Kg respectively) and the endurance group had significantly less ($p<.05$) body fat (10.8±2.3). The endurance group had the longest time to failure at approximately 70 seconds, whereas all other groups achieve failure approximately 30 seconds. Unfortunately, peak isometric force was reported as relative intensity so absolute force is unclear. All groups had a significantly lower peak isometric force ($p<.05$-.001) after the fatigue protocol (Endurance-92.9±7.1%, Strength-65.7±7.0%, Power-64.3±8.0%, Control-75.4±8.2%). After 3 minutes of recovery, force productions significantly increased for strength (80.5±7.7%, $p<.01$) and power (84.5±7.0%, $p<.05$) groups, but not for endurance (93.4±8.9%) or control (89.0±6.0%). Rate of force production also decreased significantly ($p<.05$-.001) for all groups following the fatigue protocol. The recovery period of 3 minutes allowed for significant recovery of performance for only the strength ($p<.01$) and control ($p<.05$) groups.

A common problem in the RT protocols investigating recovery time is to reduce training loads during working sets if subjects fail to complete the necessary repetitions with the initial training load. It would appear that such protocols are more concerned with inducing fatigue over a set time rather than optimizing performance. For example, Kraemer and colleagues (1999) used a load reduction technique for a protocol involving 4 sets of 10 repetitions on the back squat

with only 90 seconds rest. The reason for this technique as was to ensure each set was performed at 10 repetition max (10RM) (Kraemer, 1999).

Similar studies seen in Table 3.1, show that studying the effects of maintaining set/repetitions schemes and rest times between sets while utilizing load reduction techniques is a very recent and uncommon line of research (French et al,2007; Vingren et al, 2008; Izquierdo et al, 2009). While the studies mentioned in this table use the same rest time between sets (2 minutes), one study (Izquierdo et al, 2009) has a different set/rep protocol and exercise modality compared to the other two (French et al, 2007; Vingren et al, 2008). In addition while all three studies mention the initial training load used, only the study by Vingren et al (2008) mentions the absolute training loads used in each subsequent set. The other studies (French et al, 2007; Izquierdo et al, 2009) express training loads for subsequent sets as a percent change (%Δ) from the initial training set.

French and colleagues (2007) used a squat protocol consisting of 6 sets of 10 repetitions with 2 minutes rest and mean initial load of 122Kg. Divided into two groups based on isometric force output between sets (maintainers and reducers), force maintainers had greater load reductions compared to force reducers after 6 sets (Table 3.1). Another squat study performed by Vingren and colleagues (2008) used the same set, repetition, and rest time scheme as well as accounting for load reductions by stating the absolute load used by men and women in each set (Table 3.1). The leg press study by Izquierdo and colleagues (2009) compared load reductions before (PRE) and after (REL) a 7 week training intervention and observed 2 notable findings. First, the initial load used during the REL trial (198.9±33.9Kg) was significantly different ($p<.05$) than the load used for the PRE trial (160.2±26Kg). Second, load reductions (based on %Δ) were significantly different ($p<.05$) in the 2^{nd}, 4^{th} and 5^{th} sets of leg press (Table 3.1).

A literature review by de Salles and colleagues (2009) outlined 5 RT studies (see Table 3.2) that observed another form of decreased performance in the form of reduced repetitions for subsequent sets when training load and rest time are held constant (Kraemer, 1997; Richmond & Goddard, 2004; Willardson & Burkett, 2005; Willardson & Burkett, 2006; Willardson & Burkett 2006). While all of the studies examine the effects of rest time on upper body exercise (via bench press), only 3 of the studies examine the effects of lower body exercise in the form of leg press (Kraemer, 1997) and squat (Willardson & Burkett, 2005; Willardson & Burkett 2006).

The first study in table 3.2 (Kraemer, 1997) compared 3 set bench press and leg press protocols utilizing 1 and 3 minutes rest for a load consistent with 10RM. Observations showed declines in repetitions performed in sets 2 and 3 for the 1 minute rest protocol, but not 3 minutes rest (Kraemer, 1997). When a different training load (75%1RM) and 3 rest time intervals (1, 3, 5 minutes) were used for a bench press protocol, Richmond and Godard (2004) noticed a decrease in repetitions performed for every rest time used. The protocol with 1 minute rest experience the largest decrease in repetitions over 2 sets, followed by 3 minutes rest, and finally 5 minutes rest (Richmond & Godard, 2004). Willardson and Burkett (2005, 2006) published findings on multiple RT studies observing declines in repetitions performed for the squat and bench press at multiple training loads (8RM, 15RM, 50%1RM, 80%1RM) and rest times varying from 30seconds up to 5 minutes. RT protocols with multiple sets (up to 5) demanding repetition failure; even at low intensity training loads (50%1RM, 15RM), resulted in reductions of repetitions performed for each subsequent set. In addition, the greatest reduction in repetitions performed during subsequent sets occurred with bench press compared to squat when matched for training load and rest time (Willardson & Burkett, 2005; Willardson & Burkett 2006).

Only one study didn't reduce load or observed decreased repetitions per set (Abdessemed et al, 1999). Instead subjects were excluded from subsequent sets when they were unable to complete a full set of repetitions. In addition, Abdessemed et al (1999) revealed multiple interesting observations. First, all three bench press protocol lacked compliance by all 10 subjects; only 4 subjects of 10 finished this protocol with 1 minute rest while 8 finished the protocol with 3 and 5 minutes rest (Abdessemed et al, 1999). Second, the protocol with 1 minute rest also had significantly lower ($p<.05$) values of mean power per set compared to the protocols with more rest time in sets 4 and 7-10 (Abdessemed et al, 1999). Third, the last 3 repetitions of 6 repetitions performed in a set had significantly lower power output for the 1 minute rest protocol, starting with set 4 and for all other sets (Abdessemed et al, 1999). This study shows that allowing more rest time between sets was beneficial to maintaining performance for some but not all lifters. Unfortunately, no information was provided to explain why some subjects but all subjects benefited from added rest time.

Therefore it is apparent from the literature rest time between sets is an important factor in maintaining performance due to the inability of most lifters to finish their respective RT protocol with the initial prescribed load. The first example of decreased performance would be load reductions for each working set, despite adhering to the established sets and repetitions required for each RT protocol. Another example of decreased performance would be inability to complete the same number of repetitions for subsequent sets if both training load and rest time are held constant. The last examples of decreased performance would be observed reductions in velocity (and power) for dynamic repetitions and reduced force output for isometric contractions.

<u>Day to Day Recovery</u>

According to the ACSM guidelines (Thompson et al, 2010), a minimum time period of 48 hours is needed for recovery when training the same muscle group. RT sessions designed to promote strength and hypertrophy gains require more recovery time between sessions, sometimes up to 72 hours (Baechle & Earle, 2008). High frequency (4-6 sessions per week) RT programs require adjustments to intensity/volume (AKA periodization) to ensure optimal force production for each repetition and minimize the number of failed repetitions during a session. Another variation known as split training or working different muscle groups on different days can be implemented to prevent overtraining (Ratamess et al, 2009; Baechle & Earle, 2008). For example, a lifter may participate in 4 RT sessions per week but only target similar muscle groups twice per week. While this information is good for maximizing training goals, information about maintaining day to day performance still requires addition research.

Muscle damage is thought to be a major factor in the reduction of performance on successive days. Recently the idea of monitoring serum creatine kinase (CK) activity has become a readily accepted method of grading muscle damage; specifically isoform MM, as a result or RT instead of directly measuring performance decrements (Koch et al, 2012). For example post-exercise elevations in serum CK concentration can last for as many as 24 (Kraemer et al, 1993), 72 (Machado & Willardson, 2010), or 96 hours (Brancaccio et al, 2008**)** following a single RT session. Elevated CK levels are theorized to be caused by eccentric muscle damage, formation of free radicals within the sarcolemma, and/or increased intracellular levels of calcium (Friden & Lieber, 2001; Su et al, 2010; Sonobe et al, 2008; Zhang et al, 2008). Other factors that may elevate CK concentration include exercising muscles less adapted to fatigue; such as upper body muscles, and RT studies with short rest time intervals (<60 seconds) (Mayhew et al, 2005; Machado & Willardson, 2010; Chen et al, 2011; Jamurtas et al, 2005, Saka et al, 2009; Machado

et al, 2013**)**. However, training for as little as 5-6 weeks will cause individuals to adapt to low rest interval training programs; as observed in an RT study by Buresh and colleagues (2009). Aside from training adaptations being able to cause resistance to rises in CK levels, the interpersonal variability of post-exercise CK activity makes establishing relationships between between CK activity and performance (such as muscular strength) quite difficult (Koch et al, 2014). While serum CK concentrations are indirect indicators of muscle damage, no studies have correlated have correlated these levels to performance decrements. Therefore, just measuring muscle damage indicators does not give a clear picture of how many days it takes for performance to fully recover. The amount of time to recover increases when the volume of work increases per session, but no study has determined the relationship between the two or how other factors such as rest time between sets, training load used, and repetitions per set come into play. In conclusion, the amount of days it takes to optimize performance for subsequent sessions has yet to be determined.

Accessory Equipment

Elastic Bands

An alternative to increasing free weight resistance is to add elastic bands to a loaded barbell for additional overload. The body responds to elastic band tension (EBT) by increasing force production for the duration of the concentric phase until lock out is achieved as a reaction to the phenomena known as accommodating resistance. EBT can increase both strength and power with the same training load (Wallace et al, 2006; Joy et al, 2013), as opposed to utilizing different FW loads to optimize increases in strength and power. One could argue that observations from Frost and colleagues (2008) suggest using modalities such as pneumatic resistance would be better than using free weights at all. However, most RT facilities utilize FW

resistance because of their reduced cost compared to pneumatic resistance machines. Also, it's much easier to supplement EBT with FW training as opposed to replacing FW equipment with machines which have the potential to take up more space and are susceptible to malfunction. Recently, a JSCR publication stated that 39.3% of powerlifters surveyed in Great Britain (n=28) use elastic bands in training (Swinton et al, 2009).

The most recent studies examining the effects of EBT are displayed in Table 3.3 and observed their effects on the squat (Wallace et al, 2006; Rhea et al, 2009; Isratel et al, 2010; Joy et al, 2013) and bench press (Bellar et al, 2011; Joy et al, 2013) compared to FW assistance alone. Squat studies by Wallace et al (2006) and Isratel et al (2010) focus on the acute training effects of EBT usage and used college age males and females (only Wallace et al, 2006) as participants. In contrast, Rhea et al (2009) and Joy et al (2013) focus on chronic training effects and use NCAA athletes as participants. Bellar and colleagues (2011) also performed a training study, but only studied the bench press exercise and recruited untrained college age males as subjects. Before going into detail about the studies listed in Table 3.3, note that only 2 studies (Wallace et al, 2006; Bellar et al, 2011) reported rest times between sets for RT protocols which were also not the same. Additionally, none of the studies utilized the same training load or set/repetition scheme.

Wallace and colleagues (2006) did an acute effects study with elastic bands and the SQ exercise under three conditions (FW only, FW with 20%EBT, FW with 35%EBT) at two intensities (60%1RM, 85%1RM). Each training intensity was performed on a different day and the load repetition scheme for each day was 2 sets of 3 repetitions with 3 minutes per condition with 5 minutes rest between conditions; resulting in a total of 6 sets of 3 repetitions (Wallace et al, 2006). No significant differences in power and force production were observed when EBT

was used as 20% and 35% of the 60%1RM load (Wallace et al, 2006). However when 85%1RM was used as the training load; significant increases ($p<.05$) in force and power production were achieved in the SQ using EBT compared to free weights alone. Training with 35% EBT increased force production by 16% compared to free weight and training with 20% EBT increased power by 24% (Wallace et al, 2006). Isratel and colleagues (2009) observed similar effects (increased force, velocity, and power) along with increased EMG activity in the vastus lateralis; specifically the initial eccentric phase and latter concentric phase of squat. However, training load and set repetitions scheme used for this study was markedly different and rest time between sets was not declared. Each condition was performed for 1 set of 5 repetitions; training load for the first set was just a 20 Kg bar plus enough EBT to produce 100Kg of force and the second set was loaded with enough free weight to match the force output of the previous set (Isratel et al, 2009).

One of the first training studies that focused on elastic band usage in RT was performed by Rhea and colleagues (2009). For 12 weeks, 48 NCAA (Div I) athletes participated in a daily undulating periodization program. The load, set, and repetitions schemes along with rest time between sets for this training study were not reported to exact specification; so much is left to interpretation (Rhea et al, 2009). What is known about this study is that loads were prescribed between 75-85%1RM and roughly 4 sets were used per exercise. Athletes were divided into three groups which trained the squat exercise slow (heavy load, velocity=.2-.4m/s), fast (light load, velocity=.6-.8m/s), or FACC (light load with bands, velocity=.6-.8m/s). Testing squat 1RM and vertical jump power before and after the training program, observation indicate the FACC group improved their squat 1RM by 9.44% (ES-1.10) and vertical jump power by 17.8% (ES-1.06) (Rhea et al, 2009). The slow group improved squat 1RM by 9.59% (ES-1.08), but

vertical jump power increased by less than 5% (ES-.28) (Rhea et al, 2009). Furthermore, the fast group made an almost negligible increase of 3.2% in squat 1RM (ES-.38) and increased vertical jump power by 11% (ES-.80) (Rhea et al, 2009). These observations imply that training with elastic bands for squat can not only increase 1RM to a greater extent than just training with heavy loads, but also improve vertical jump power more than just training at high velocities with lighter loads without elastic bands.

Another training study by Bellar and colleagues (2011) observed greater increases in bench press 1RM by supplementing EBT with free weights in the bench press exercise. Subjects were untrained, which made them more susceptible to neural adaptations than resistance trained individuals. Initially a bench press orientation phase was used for the first 3 weeks of the study (Bellar et al 2011). After the initial learning phase, subjects were assigned to BP with 15%EBT (BAND) or with FW only (STAND) for 3 weeks. All subjects trained under both conditions before finishing the training study, makings this study the only training study to use a cross-over design. During each of the 3 weeks phases of training, the bench press protocol was the same (5 sets*5 reps @ 85%1RM with 90 seconds rest). The learned adaptation of constant acceleration through the duration of the concentric phase could explain the significant difference ($p<.05$) between training conditions for increased BP 1RM regardless of order (BAND 9.95 ± 3.7 kg, STAND 7.56 ± 2.8 kg) (Bellar et al., 2011).

Most recently, a training study conducted by Joy and colleagues (2013) observed the effects of utilizing elastic bands in a periodized RT program for basketball players. This training study utilized elastic bands at 30%1RM as resistance for the squat and bench press exercise. Despite only using EBT in RT once a week, moderate to large effect sizes for SQ 1RM, BP 1RM, VJ power, and lean mass were observed after only 5 weeks of training. Most importantly a

significant ($p<.05$) interaction effect (group*time) was noticed for rate of power development in the vertical jump, which favored the group who used EBT (Joy et al, 2013). Training load, set, and repetition schemes are declared in this study (40-60%1RM, 3*3-5 repetitions), but rest times are not declared for RT sessions that involved EBT usage (Joy et al, 2013).

In conclusion, training with elastic bands is beneficial to improving strength and power performance not only acutely (Wallace et al, 2006; Isratel et al, 2009), but also chronically (Rhea et al, 2009; Bellar et al, 2011; Joy et al, 2013). It is suggested that training with EBT allows the lifter to have greater ability to maintain set performance and recovery. This ability to maintain performance could stem from the elastic nature of the bands themselves, as loads used per sets are heavier at the top portions of a lift and deload as a lifter descends to the bottom portion of the lift (Isratel et al, 2009). A possible training adaptation could be that lifters anticipate the increase in load as they ascend and consequently increase force production to overcome the sticking point and heaviest phases of the lift (Bellar et al, 2011; Isratel et al, 2009). Unfortunately, none of the EBT studies measured performance, recovery between sets, or recovery from RT session utilizing EBT. Also none of the studies used elastic bands in RT with the same methods. Therefore, benefits from EBT may not stem from the above mentioned neurological factors but may be due to other factors such as reduced production of metabolic stress markers such as lactate, ammonia, catecholamines, and cytokines.

Assistive Lifting Apparel

The last underserved area that will be discussed is a topic that is very new to RT research, but has been utilized in RT training and strength competitions for several decades. The area of research being referred to is the use of assistive lifting apparel during RT. Assistive lifting apparel (ALA), such as knee wraps, squat/deadlift suits, and bench press shirts are devices that

preload the muscle via compression and have the capacity to store elastic energy. This elastic energy assists the lifter transition from eccentric to concentric phase (propulsive phase) with increased force, velocity, and power output resulting in more efficient concentric movements (Blatnik et al, 2012; Lake et al, 2012; Silver et al, 2009). ALA can significantly increase a lifter's 1RM compared to lifting raw as established by the IPF World Championships; compare scores from equipped (ALA) and Classic (RAW) competitions (IPF website- http://www.powerlifting-ipf.com/46.html). In addition, current records from International Powerlifting Federation (IPF- http://www.powerlifting-ipf.com/44.html) and USA Powerlifting (USAPL- http://www.usapowerlifting.com/records/american-records/) as well as results from competitions show a clear advantage to wearing ALA in competition, with significantly greater successful attempts in SQ, BP, DL, and total score (absolute and wilks). ALA has been available for decades (Titan Support Systems, Inzer Advance Designs) and its popularity amongst competitive lifters has generated limited research studies about the benefits of usage in training. Training with ALA could be advantageous for maximizing between sets performance and reduce recovery time by providing external assistance during high intensity protocols.

Recent studies using ALA during RT sessions required lifters to use loads ≥80%1RM (Blatnik et al, 2012; Godawa et al, 2012; Lake et al, 2012; Silver et al, 2009) while using full ROM for SQ, BP, or DL (see Table 3.4). The effects of using ALA with respect to optimizing recovery are not clear since only 2 of the studies listed in Table 3.4 reported rest time between sets (Blatnik et al, 2012; Lake et al, 2012) for the squat exercise (5 and 3 minutes respectively). The protocol performed by Blatnik et al (2012) was the only study to require lifters to perform with and without ALA on separate days with a randomized order and did not report an order

effect. In contrast, the study by Lake et al (2012) had lifters squat with and without ALA on the same day using a randomized order.

A training study by Godawa and colleagues (2012) examined the effects ALA for squat, bench press, and deadlift. Observations after 10 weeks of training with ALA suggested a trend for increased gains in 1RM for the squat (ALA-33lb, RAW-5lb, $p<.10$) and total (ALA-66lb, RAW-23lb, $p=.15$) (Godawa et al, 2012). Unfortunately, the study did not use a cross over design, so each group only received one treatment. In addition, the study did not do a 1RM test on the ALA group under raw conditions before or after they started training in equipment. However, both groups (ALA, Raw) did use the same relative load, set, and repetition schemes when training for the duration of the 10 week training study. The next paragraph will discuss studies which examine the immediate performance effects of ALA usage on a lifter's 1RM, force production, bar path efficiency, and velocity (when compared to lifting raw).

Lake and colleagues (2012) also observed significantly decreased ($p<.037$) horizontal displacement during the lowering phase and increased power ($p<.05$) during the lifting phase when knee wraps were used. Another squat study performed by Blatnik and colleagues (2012) observed significant increases ($p<.05$) in peak concentric power (80%1RM, 90%1RM), velocity (80%1RM, 90%1RM, 100%1RM), and eccentric force (100%1RM only) when a squat suit was used in training. Lastly, Silver and colleagues (2009) examined the effects of a bench press shirt, observing significantly decreased ($p<.05$) vertical displacement during the bench press exercise. Unfortunately, kinetic performance data was not published in this study, thus the effects of using a bench press shirt on force production, velocity, and power have not been observed and published.

Data from the study by Blatnik and colleagues (2012) was collected in 2 training session (suit, no suit) utilizing a randomized order with a cross-over design. Each session had the same used training loads of 80, 90, and 100%1RM in a randomized order with 2 sets of single repetition sets per training load and 5 minutes rest between trials. The knee wrap study by Lake and colleagues (2012) used a similar training protocol to Blatnik and colleagues (2012) with subtle differences. Only one training load (80%1RM) was used for the training protocol, single repetition sets were used with 3 minutes rest between attempts, and lifters performed 6 sets during the protocol; 3 with knee wraps and without knee wraps (Lake et al, 2012). Traditionally, both a squat suit and knee wraps are used in conjunction to balance out assistance in the hip and knee joint. Even though both Lake (2012) and Blatnik (2012) used acute effect models and collected valuable data on the kinematics and kinetics, neither study used the knee wraps and squat suit in conjunction so more research is needed to answer questions of not only performance, but risk of injury when using ALA as a training and performance aid. Only the study previously discussed (Godawa et al, 2012) utilized both knee wraps and the squat suit together in training and 1RM testing.

Additional support for the use of ALA can be found supporting its use for recovery and sprint performance (Kraemer et al, 2010; Born et al, 2014). Within a 24 hour recovery period, lifters who wore compression garments experienced a blunted increase in CK activity, muscle soreness, swelling (measured via ultrasound), and finally a blunted decrease in performance (measured via bench press throw) (Kraemer et al, 2010). Although this study is different in both the quality of material used in compression garments and the application of usage (recovery vs during exercise), the methodology of using repeated measures to quantify soreness, enzyme activity of CK, perceived fatigue, performance, and swelling would allow researchers the

opportunity to examine how ALA contributes to enhanced performance and possibly recovery from intense RT sessions. Following the study by Kraemer and colleagues (2010), a performance study by Born and colleagues (2014) observed improved sprint performance when compression garments were utilized as an ergogenic aid. These observations were measured in the form of reduced sprint times ($p<.01$, ES-.61), reduced hip flexion angle ($p<.01$, ES-1.78), and increased step length ($p=.01$, ES-.91) for the last 10 sprints of a 30m sprint trial which was repeated 30 times (Born et al, 2014).

The literature suggests that ALA usage improves lifting mechanics (decreased bar path, increased velocity/power during eccentric and concentric phases of the lift), which in turn could increase number and or quality of successful repetitions completed during a session. However contraindications to the use of ALA exist, such as prolonged occlusion (caused by excessively tight ALA) which can be dangerous since the lifters begin to experience immediate discomfort from restricted movement and breathing. Godawa and colleagues (2012) observed partial occlusion in the popliteal artery when wearing a squat suit and complete occlusion when wearing a squat suit and knee wraps, which can cause loss of tactile sensation in the distal region of the leg. A concern with using ALA is the risk for injury during sessions requiring high intensity loads (>80%1RM) . For example, Lake and colleagues (2012) observed a significant increase ($p<.018$) vertical impulse during the lifting phase when squatting with knee wraps (192 N/s) compared to without knee wraps (169 N/s). This observation raised concern for increased risk for injury to the trunk area when knees are wrapped due to the increase in vertical impulse and increased discomfort behind the knee. However, at least 2 resources are available that give instructions on how to use ALA effectively without risking injury as well as proper fitting instruction to avoid problems associated with discomfort due to excessive tightness of ALA.

The first resource is the website of one of the ALA manufacturers (Titan Support Systems), they provide sizing charts and guidelines on what size suit or shirt is appropriate according to desired effect; training fit for novice lifters and passive support, meet fit for those seeking more support, and finally competition fit for elite level lifters seeking the most support and have prior experience with wearing tightly fit gear. The second resource is a training manual published by the IPF which gives safety tips on how to tell when a suit or shirt is fitted properly vs improperly and when to utilize ALA in training (Sheppard & Jamison, 2007). In addition to providing ergogenic aid to sports performance, research focused on ALA would help to eliminate social stigmas associated with equipped powerlifting; as currently its usage and popularity is on the decline compared to non-equipped (Raw) powerlifting.

Due to the contraindications observed in previous ALA studies, the use of EBT is becoming a more popular area of research. Despite the observed performance benefits in several studies (Table 3.3), there is too much variability in how EBT used as accommodating resistance in RT sessions. Concerns about EBT usage include the different types of band tension used and the various training loads used to optimize performance. Also, their applications may not be suitable for the general population due to the complexity of set up for different core lifts (squat, bench press, and deadlift), and the high risk nature of combining their usage with barbells during Olympic lifts (clean and jerk, snatch) or movements utilizing dumbells; which already increase instability. Therefore, the use of ALA to supplement overload RT with free weights would be a much easier task compared to elastic band training with free weights.

Conclusions

Literature has examined the effects of various RT protocols on post-exercise performance, recovery, and metabolite concentrations. However relationships between

performance (peak force/velocity, completed repetitions per session), metabolite concentration (lactate, ammonia, creatine kinase, cytokines, catecholamines), and recovery time have only been examined by a handful of studies (Izquierdo et al, 2009; Sanchez-Medina & Gonzalez-Badillo, 2011). In addition, studies are starting to explore different forms of accessory equipment that are used in conjunction with RT such as EBT and ALA (knee wraps, compression suits/shirts, and weight belts). Although acute performance benefits have been observed along with their usage in RT, research has not focused on how best to utilize these accessories (with regards to training load, set/rep schemes, and rest time) for enhancing repeat performance between sets and enhancing recovery from RT sessions. Lastly, studies examining the use of accessory equipment are lacking in data regarding their effects on the formation of metabolic stress markers such as lactate, ammonia, creatine kinase, catecholamines, and cytokines.

Table 3.1 RT Protocols that Utilize Deload Strategies during Subsequent Sets

Author	Exercise Protocol	Rest	Group	Load (Set 1)	Set 2	Set 3	Set 4	Set 5	Set 6
French et al, (2007)	Squat (6sets*10reps)	2 min	Mean F Maintainer F Reducer	122.05±12.32Kg 122.27±13.91Kg 121.82±9.38Kg	-1.3%Δ -2.6%Δ 0.0%Δ	-6.0%Δ -7.5%Δ -4.5%Δ	-10.8%Δ -14.9%Δ -6.7%Δ	-13.8%Δ -19.4%Δ -8.2%Δ	-16.0%Δ -22.0%Δ -10.4%Δ
Vingren et al, (2008)	Squat (6sets*10reps)	2 min	Men Women	116±15Kg 82±12Kg	115±11Kg 78±13Kg	108±12Kg 74±12Kg	99±15Kg 71±10Kg	95±16Kg 69±9Kg	90±16Kg 67±7Kg
Izquierdo et al, (2009)	Leg Press (5sets*10reps)	2 min	PRE REL	160.2±26Kg 198.9±33.9Kg	-0.62±1.6%Δ -0.9±1.6%Δ	-2.1±3.7%Δ -5.0±3.7%Δ	-8.9±6.6%Δ -15.5±7.9%Δ	-11.9±8.3%Δ -17.3±8.7%Δ	

Table 3.2 RT Protocols that Utilize Different Rest Times

Author	Load	Exercise	Rest	Reps (Set 1)	Set 2	Set 3	Set 4	Set 5
Kraemer et al, (1997)	10RM	Bench Press & Leg Press	1min	10	8	7.1		
			3min	10	10	10		
Richmond & Godard, (2005)	75%1RM	Bench Press	1min	11.9	6			
			3min	11.5	8			
			5min	11.5	10			
Willardson & Burkett, (2005)	8RM	Bench Press	1min	7.4	4.4	2.8	2.4	
			2min	7.7	5.7	4.2	3.9	
			5min	7.6	6.5	6.0	5.6	
		Squat	1min	7.8	5.9	4.4	4.2	
			3min	8.0	6.6	6.0	4.8	
			5min	8.0	7.8	7.0	6.0	
Willardson & Burkett, (2006)	80%1RM	Bench Press	1min	9.3	3.3	2.0	1.6	1.6
			2min	9.1	5.1	3.3	2.8	2.5
			3min	9.1	5.9	4.6	3.8	3.5
	50%1RM		1min	29.8	10.0	7.0	6.1	6.0
			2min	29.9	14.8	11.1	9.7	9.1
			3min	30.4	18.2	14.0	12.6	12.2
Willardson & Burkett, (2006)	15RM	Bench Press	30sec	14.9	4.9	2.4	1.8	1.5
			1min	14.6	5.9	3.6	3.3	2.8
			2min	14.6	8.6	5.6	5.3	4.9
		Squat	30sec	15.6	10.1	6.8	5.9	5.4

			1min	15.4	10.6	8.4	6.2	6.3
			2min	15.4	12.5	10.6	9.4	8.6

Table 3.3 RT Protocols Utilizing Elastic Band Resistance

Author	Subjects	Movement	Protocol/Group	Equipment	Measurements	Results
Wallace et al (2006)	10 trained college age males and females	Squat	Day 1- 1RM test Day 2- 6 sets* 3 reps @ 60% 1RM Day 3- 6 sets * 3 reps @ 85% Rest between sets was 3 min. Rest between conditions (NB, B1, B2) was 5 min and each condition required 2 sets.	NB- No Bands B1- 20% band resistance B2- 35% band resistance	Mean Force (N) Mean Power (W) Mean RFD (N/s)	Mean Force- B1 & B2 conditions resulted in greater force output compared to NB @ 85%1RM (p<.05) Mean Power- B1 & B2 conditions resulted in greater power output compared to NB @ 85%1RM (p<.05)
Rhea et al (2009)	48 NCAA DI athletes	Squat, Vertical Jump	Slow- Heavy loads, velocity=.2-.4m/s Fast- Light loads, velocity=.6-.8m/s FACC- Light loads with elastic bands, velocity=.6-.8m/s	Elastic Bands	Squat 1RM (kg) VJ (Watts)	Slow- Increased SQ1RM (ES-1.08) Fast- Increased VJ (ES-.80) FACC-Increased SQ1RM (ES-1.10)and VJ (ES-1.06)
Bellar et al (2011)	11 college age males	Bench Press	5 sets * 5 reps @ 85%1RM with 90 seconds rest between sets. Week 1-3 orientation Week 4-6 Band or FW Week 7-9 Switch groups	FW- 0% band resistance Band- 15% band resistance	Bench Press 1RM (Wk 1,3,6,9)	Band condition resulted in greatest increase in BP 1RM. Interaction effect for time and group (Band vs FW) was considered significant (p<.05)
Isratel et al (2010)	10 trained college males	Squat	Band- 1set*5reps with bands Wht- 1set*5reps without bands, 20Kg barbell plus weight used to equate force output during Band set.	Elastic Bands	Force (N) Velocity (m/s) Power (W) EMG (mV)	Band- Significantly increased (p<.05) Force, Velocity, Power, EMG during initial portion of eccentric phase and latter portion of concentric phase.
Joy et al (2013)	14 NCAA DII Basketball Players	Squat, Bench Press	Con- 4 RT sessions/wk for 5 weeeks. VRT- 1 RT session/wk using elastic bands (SQ	Elastic Bands	1RM (SQ, BP) VJ (height, power, rate of power	Interacton effect (time* group) for VJ rate of power development (VRT-29,546W/s, Con-21,995W/s, p<.05). VRT group had larger ES for time in the

			and BP movements only) for 5 wks + 3 RT sessions/wk for 5 weeks.		development) Lean Mass	SQ(Wk0-127.6Kg, Wk5- 159.1Kg ES-1.42), BP (Wk0-97.4Kg, Wk5-104.87Kg, ES-.60), VJ power (Wk0-7033.2W, Wk5-7459.67, ES-.70), and lean mass (Wk0-72.34kg, Wk5-74.79kg, ES-.92).

Table 3.4 RT Protocols Utilizing Assistive Lifting Apparel

Author/Year	Subjects	Movement	Protocol	Equipment	Measurements	Results
Godawa et al (2012)	18 trained males and females (18-26 yoa)	Squat (SQ), Bench Press (BP), Deadlift (DL)	3 attempts to achieve 1RM in a powerlifting contest. Testing was done before and after a 10 week training cycle.	Squat Suit, Knee Wraps, Bench Press Shirt, Deadlift Suit	1RM (SQ, BP, DL, Total), Volume, Leg Blood Flow	SQ- 1RM main effect for time (ALA-34lbs, Raw- 6lbs, p<.05). Suggested group difference (p<.10). DL- 1RM main effect for time (ALA-24lbs, Raw-15lbs, p<.05). Total- Main effect for time (ALA-67lbs, Raw-24lbs, p<.05). Suggested group difference (p=.15)
Blatnick et al (2012)		Squat	Day1- 1RM test Day 2&3- 6 sets * 1 rep (2 sets @ 80, 90, 100%1RM each) with 5 minutes rest between sets. Random order for 2 conditions (SS-Squat suit, Con- No squat suit).	Squat Suit	Force (N), Velocity (m/s), Power (W)	Force- Significant difference in eccentric force @ 100%1RM (SS-3196.2±470.6N, Con-3369.7±589.9N, p<.05) Velocity- Significant difference for concentric velocities at 80%1RM (SS-.616±.113m/s, Con-.548±.135m/s, p<.05), 90%1RM (SS-.567±.119m/s, Con-.493±.117m/s, p<.05), and 100%1RM (SS-.462±112m/s, Con-.413±.127m/s, p<.05). Power- Significant difference in concentric power @ 80%1RM(SS-1770.4±483.2W, Con-1566.5±388.4W, p<.05) and 90%1RM(SS-1723.8±449.5W, Con-1493±296.2W, p<.05)
Lake et al (2012)	10 trained males (21.9±2.2 yoa)	Squat	Day 1- 1RM test Day 2- 6 sets * 1 rep @ 80%1RM with 3 minutes rest between sets. Random order for 2 conditions (3 sets Unwrapped, 3 sets Wrapped)	Knee Wraps	Power (W), Lifting Time (s), Bar Path, Impulse (N/s)	Power significantly increased (UW-1841±835W, W-2121±1038W) (p<.019, ES=1.10) Reduction in lowering phase duration (UW-1.57±.61s, W-1.13±.46s) (p<.006, ES=.82) Horizontal bar path reduced in lowering phase (UW-.11±.04m, W-.09±.03m) Lifting vertical impulse increased (UW-

						169±66N/s, W-192±81N/s)
Silver et al (2009)	5 trained males (18-30 yoa)	Bench Press	Day 1- 1RM test Day 2- Set 1(≤75%1RM), Set 2 (90-95%1RM, Set 3 (100%1RM)	Bench Press Shirt	Bar Path (cm)	Reduced bar path for Y direction (NS-40.23±6.98cm, S-35.67±4.82cm, p<.05) Difference between observed (X-35.12±11.14cm, R-96.65±19.14cm) and optimal (X-22.67±11.41cm, R-81.38±14.19cm) bar path for NS (p<.01).

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APPENDIX II: IRB Approval

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Arnold Nelson
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: December 22, 2014

RE: **IRB#** 3578

TITLE: The effects of using knee wraps on vertical jump performance (Phase 1)

New Protocol/Modification/Continuation: New Protocol

Review type: Full ____ Expedited X   **Review date:** 12/19/2014

Risk Factor: Minimal X Uncertain ______ Greater Than Minimal______

Approved X **Disapproved**__________

Approval Date: 12/19/2014 **Approval Expiration Date:** 12/18/2015

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 20

LSU Proposal Number (if applicable)**:** __________

Protocol Matches Scope of Work in Grant proposal: (if applicable) _________

By: Dennis Landin, Chairman D. Landin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

RE:I RB #15-018 entitled "The Effects of Using Knee Wraps on Vertical Jump Performance"
Hello,
I am pleased to inform you that the Kent State University Institutional Review Board reviewed and approved your Application for Approval to Use Human Research Participants as a Level II/Expedited, category 7 project. **Approval is effective for a twelve-month period:**

March 12, 2015 through March 11, 2016

**A copy of the IRB approved consent form is attached to this email. This "stamped" copy is the consent form that you must use for your research participants. It is important for you to also keep an unstamped text copy (i.e., Microsoft Word version) of your consent form for subsequent submissions.*

Federal regulations and Kent State University IRB policy require that research be reviewed at intervals appropriate to the degree of risk, but not less than once per year. The IRB has determined that this protocol requires an annual review and progress report. The IRB tries to send you annual review reminder notice to by email as a courtesy. **However, please note that it is the responsibility of the principal investigator to be aware of the study expiration date and submit the required materials.** Please submit review materials (annual review form and copy of current consent form) one month prior to the expiration date.

HHS regulations and Kent State University Institutional Review Board guidelines require that any changes in research methodology, protocol design, or principal investigator have the prior approval of the IRB before implementation and continuation of the protocol. The IRB must also be informed of any adverse events associated with the study. The IRBfurther requests a final report at the conclusion of the study.

Kent State University has a Federal Wide Assurance on file with the Office for Human Research Protections (OHRP); FWA Number 00001853.

If you have any questions or concerns, please contact the Office of Research Compliance atResearchcompliance@kent.edu or 330-672-2704 or 330-672-8058.

Kent State University Office of Research Compliance
224 Cartwright Hall | fax 330.672.2658

Victoria Holbrook | Graduate Assistant |330.672.2384| vholbroo@kent.edu
Tricia Sloan | Administrator |330.672.2181 | psloan1@kent.edu
Kevin McCreary | Assistant Director | 330.672.8058 | kmccrea1@kent.edu
Paulette Washko | Director |330.672.2704| pwashko@kent.edu

For links to obtain general information, access forms, and complete required training, visit our website at www.kent.edu/research.

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Arnold Nelson
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: December 22, 2014

RE: **IRB#** 3579

TITLE: The effects of using knee wraps on vertical jump performance (Phase 2)

New Protocol/Modification/Continuation: New Protocol

Review type: Full ____ Expedited _X_ **Review date:** 12/19/2014

Risk Factor: Minimal __X__ Uncertain ______ Greater Than Minimal______

Approved__X__ **Disapproved**__________

Approval Date: 12/19/2014 **Approval Expiration Date:** 12/18/2015

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 20

LSU Proposal Number (if applicable): __________

Protocol Matches Scope of Work in Grant proposal: (if applicable) _________

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

RE: IRB #15-281 - entitled "The Effects of Using Knee Wraps on Back Squat and Vertical Jump Performance"

Hello,
I am pleased to inform you that the Kent State University Institutional Review Board reviewed and approved your Application for Approval to Use Human Research Participants as a Level II/Expedited, category 7 project. **Approval is effective for a twelve-month period:**

April 28, 2015 through April 27, 2016

**A copy of the IRB approved consent form is attached to this email. This "stamped" copy is the consent form that you must use for your research participants. It is important for you to also keep an unstamped text copy (i.e., Microsoft Word version) of your consent form for subsequent submissions.*

Federal regulations and Kent State University IRB policy require that research be reviewed at intervals appropriate to the degree of risk, but not less than once per year. The IRB has determined that this protocol requires an annual review and progress report. The IRB tries to send you annual review reminder notice by email as a courtesy. **However, please note that it is the responsibility of the principal investigator to be aware of the study expiration date and submit the required materials.** Please submit review materials (annual review form and copy of current consent form) one month prior to the expiration date.

HHS regulations and Kent State University Institutional Review Board guidelines require that any changes in research methodology, protocol design, or principal investigator have the prior approval of the IRB before implementation and continuation of the protocol. The IRB must also be informed of any adverse events associated with the study. The IRB further requests a final report at the conclusion of the study.

Kent State University has a Federal Wide Assurance on file with the Office for Human Research Protections (OHRP); FWA Number 00001853.

If you have any questions or concerns, please contact the Office of Research Compliance atResearchcompliance@kent.edu or 330-672-2704 or 330-672-8058.

Kent State University Office of Research Compliance
224 Cartwright Hall | Fax 330.672.2658

Victoria Holbrook | Graduate Assistant |330.672.2384| vholbroo@kent.edu
Tricia Sloan | Administrator |330.672.2181 | psloan1@kent.edu
Kevin McCreary | Assistant Director | 330.672.8058 | kmccrea1@kent.edu
Paulette Washko | Director |330.672.2704| pwashko@kent.edu

For links to obtain general information, access forms, and complete required training, visit our website at www.kent.edu/research.

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Arnold Nelson
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: October 14, 2015

RE: **IRB#** 3634

TITLE: The effects of using knee wraps on the back squat exercise, post-exercise performance, and performance recovery

New Protocol/Modification/Continuation: New Protocol

Review type: Full __X__ Expedited ____ **Review date:** 10/9/2015

Risk Factor: Minimal __________ Uncertain ____X_____ Greater Than Minimal_______

Approved _____X_____ **Disapproved** __________

Approval Date: 10/9/2015 **Approval Expiration Date:** 10/8/2016

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 20

LSU Proposal Number (if applicable):

Protocol Matches Scope of Work in Grant proposal: (if applicable)______

By: Dennis Landin, Chairman ____DLandin____

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

RE: IRB # 16-033 entitled "The effects of using knee wraps on the back squat exercise, post-exercise performance, and performance recovery"

Hello,
I am pleased to inform you that the Kent State University Institutional Review Board reviewed and approved your Application for Approval to Use Human Research Participants as a Level II/Expedited, category 4 & 7 project. **Approval is effective for a twelve-month period:**

February 19, 2016 through February 18, 2017

**If applicable, a copy of the IRB approved consent form is attached to this email. This "stamped" copy is the consent form that you must use for your research participants. It is important for you to also keep an unstamped text copy (i.e., Microsoft Word version) of your consent form for subsequent submissions.*

Federal regulations and Kent State University IRB policy require that research be reviewed at intervals appropriate to the degree of risk, but not less than once per year. The IRB has determined that this protocol requires an annual review and progress report. The IRB tries to send you annual review reminder notice by email as a courtesy. **However, please note that it is the responsibility of the principal investigator to be aware of the study expiration date and submit the required materials.** Please submit review materials (annual review form and copy of current consent form) one month prior to the expiration date. Visit our website for forms.

HHS regulations and Kent State University Institutional Review Board guidelines require that any changes in research methodology, protocol design, or principal investigator have the prior approval of the IRB before implementation and continuation of the protocol. The IRB must also be informed of any adverse events associated with the study. The IRB further requests a final report at the conclusion of the study.

Kent State University has a Federal Wide Assurance on file with the Office for Human Research Protections (OHRP); FWA Number 00001853.

If you have any questions or concerns, please contact the Office of Research Compliance atResearchcompliance@kent.edu or 330-672-2704 or 330-672-8058.

Kent State University Office of Research Compliance
224 Cartwright Hall | Fax 330.672.2658

Victoria Holbrook | Graduate Assistant |330.672.2384| vholbroo@kent.edu
Tricia Sloan | Administrator |330.672.2181 | psloan1@kent.edu
Kevin McCreary | Assistant Director | 330.672.8058 | kmccrea1@kent.edu
Paulette Washko | Director |330.672.2704| pwashko@kent.edu

For links to obtain general information, access forms, and complete required training, visit our website at www.kent.edu/research.

APPENDIX III: CONSENT FORMS

Informed Consent to Participate in a Research Study

Study Title: The effects of using knee wraps on vertical jump performance

Principle Investigator: Dr. James "Derek" Kingsley, Cardyl Trionfante and Dr. Arnold Nelson

You are being invited to participate in a research study. This consent form will provide you with information on the research project, what you will need to do, and the associated risks and benefits of the research. Your participation is voluntary. Please read this form carefully. It is important that you ask questions and fully understand the research in order to make an informed decision. You will receive a copy of this document to take with you.

Purpose: The study will investigate the acute effects of using knee wraps on vertical jump performance.

Procedures:

Orientation.
During the orientation, you will read and sign the informed consent form (provided you wish to participate) as well as the Physical Activity Readiness Questionnaire (PAR-Q). The Par-Q will only be used to see if you need to be excluded and will be destroyed once it has been reviewed. The investigator will sit down and thoroughly explain each testing day and the methods utilized on those test days. The investigator will encourage questions during this time. After you have completed the paperwork, a tour of the laboratory will be given, along with demonstration of the knee wrapping technique. At this time, height, weight and body composition using the 7-site skinfold method will be collected. Once these data are collected you will be randomly be assigned a group. One group will wear knee wraps during training days, the other group will not. This should take 30 minutes.

Testing Days:
Vertical Jump Test Protocol. For a timetable of testing see Figure 1. You will begin the testing day with 10 minutes of quiet rest. Then you will perform 2 sets of 5 vertical jumps with 20 seconds rest between jumps and 5 minutes rest between sets. You will perform one set of the vertical jump with knee wraps and one set without knee wraps. The knee wraps will be applied by one of the researchers. A linear displacement transducer (Tendo Weightlifting Analyzer) will be used to calculate force, power, and velocity and will be attached to your waist. Jump height will be determined with a Vertec device. Your weight will be checked once this day is complete. There are two days of testing before the training days and 1 after training. Each test day will take 30 minutes for each test day.

Training Days:
Vertical Jump Training Protocol. Following 10 minutes of quiet rest you will perform the vertical jumps with knee wraps or without. Both groups will perform 3 sets of 10 vertical jumps for max height with 20 seconds rest

between jumps and 5 minutes rest between sets. This protocol shall be performed on 2 separate days separated by 48 hours. Forty-eight hours after the second training day, the last testing session will be completed. Total time commitment for this study is 4 hours scattered over 4 weeks.

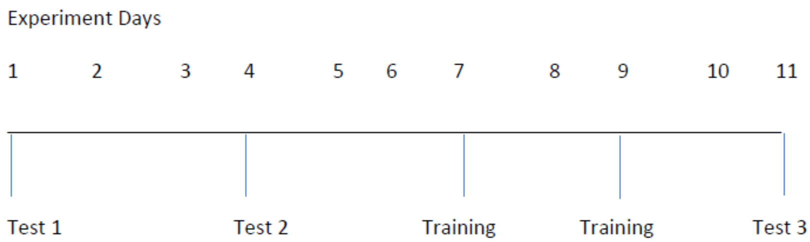

Figure 1. Timetable for Testing and Training.

Benefits: There is no direct benefit to you. However, you are contributing to the body knowledge concerning the benefits gained with the use of resistance training accessories associated with enhancing performance and you may experience improvements in your vertical leap.

Risks/Discomforts: There are no anticipated risks that are greater than those associated with normal physical activity. However, if you land incorrectly during the jump, there is possibility of injury to the lower limbs (knees, hips, ankles). Correct form and technique will be emphasized. There may be some slight discomfort associated with wearing the wrap if you deem that it is too tight, which will then be re-wrapped.

In order to reduce this risk, all protocols will be supervised by graduate students or faculty with proof of human research subjects training as recommended by the IRB. In addition, supervisors and participants will receive instructions on proper technique for the vertical jump as provided by the textbook *Essentials of Strength and Conditioning*. Investigators' certifications include CPR/FirstAid/AED from Red Cross, Health Fitness Specialist from ACSM, and Senior National Coach from USA Powerlifting.

You may terminate your participation at any time and without warning. No attempt will be made by the research personnel to stop you.

Privacy and Confidentiality: No identifying information will be collected. Your signed consent form will be kept separate from your study data, and responses will not be linked to you.

Compensation:
The project will not affect your finances in either a positive or negative manner.

KENT STATE UNIVERSITY

Medical treatment by the University Health Center is provided only to currently registered students. Please be advised that for all other injuries, emergency services will be called for those occurring on the Kent State University campus. You or your medical insurance will be billed for this service. No other medical treatment or financial compensation for injury from participation in this research project is available.

Voluntary Participation: Taking part in this research study is entirely up to you. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. You will be informed of any new, relevant information that may affect your health, welfare, or willingness to continue your study participation.

Contact Information

If you have any questions or concerns about this research, you may contact the primary researcher, J. Derek Kingsley (jkingsle@kent.edu), at 330.672.0222. This project has been approved by the Kent State University Institutional Review Board. If you have any questions about your rights as a research participant or complaints about the research, you may call the IRB at 330.672.2704.

Consent Statement and Signature

I have read this consent form and have had the opportunity to have my questions answered to my satisfaction. I voluntarily agree to participate in this study. I understand that a copy of this consent will be provided to me for future reference.

_______________________________ _____________________

Participant Signature Date

KENT STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD
"APPROVED"
March 12, 2015
To
March 11, 2016

Informed Consent to Participate in a Research Study

<u>Study Title:</u> The effects of using knee wraps on back squat and vertical jump performance.

<u>Principle Investigator</u>: Dr. James "Derek" Kingsley, Cardyl Trionfante and Dr. Arnold Nelson

You are being invited to participate in a research study. This consent form will provide you with information on the research project, what you will need to do, and the associated risks and benefits of the research. Your participation is voluntary. Please read this form carefully. It is important that you ask questions and fully understand the research in order to make an informed decision. You will receive a copy of this document to take with you.

<u>Purpose</u>: The study will investigate the acute effects of using knee wraps on back squat and vertical jump performance.

<u>Procedures</u>: If you decide to take part in this study, you will be asked to come to the Applied Exercise Physiology Laboratory (MACC Annex 167) on the Kent State University campus 8 times over an 18 day period (Figure 1). One time will be for an orientation, and the other days will be for 1 RM testing, data collection or training.

<u>Orientation.</u> During the orientation, you will read and sign the informed consent form (provided you wish to participate) as well as the Physical Activity Readiness Questionnaire (PAR-Q). The Par-Q will only be used to see if you need to be excluded and will be destroyed once it has been reviewed. The investigator will sit down and thoroughly explain each testing day and the methods utilized on those test days. The investigator will encourage questions during this time. After you have completed the paperwork, a tour of the laboratory will be given, along with demonstration of the knee wrapping technique. At this time, height, weight and body composition using the 7-site skinfold method will be collected. Once these data are collected you will be randomly be assigned a group. One group will wear knee wraps during training days, the other group will not. This should take 30 minutes.

<u>1RM Testing:</u>
This protocol will take place after orientation and is required to determine training loads for test days and training days. This protocol will be performed on 2 separate days with 3 days between 1RM protocols. You will begin the testing day with 10 minutes quiet rest. Then you will perform 1 warm up set of 10 back squats with a load equal to 50% of your estimated 1 repetition max (1RM) and then progressed to a weight you can move 1 time through a full range of motion. You will have 5 chances to perform a 1RM on the back squat exercise. Each attempt will be separated by 5 minutes rest.

<u>Test Days</u>
Vertical Jump Test Protocol. You will begin the testing day with 10 minutes of quiet rest. Then you will perform 2 sets of 5 vertical jumps with 20 seconds rest between jumps and 5 minutes

rest between sets. You will perform one set of the vertical jump with knee wraps and one set without knee wraps. The knee wraps will be applied by one of the researchers. A linear displacement transducer (Tendo Weightlifting Analyzer) will be used to calculate force, power, and velocity and will be attached to your waist.   Jump height will be determined with a Vertec device. This protocol will be performed before and after the back squat power test protocol.

Back Squat Power Test Protocol. After a 5 minute rest period following the vertical jump test, you perform a warm up set of 10 back squats using a load equal to 50% of your 1RM. Following a 5 minute rest period, you will perform another warm up set of 5 back squats using a load equal to 70% of your 1RM. Following a 5 minute rest period, you will perform 4 single repetition sets of the back squat exercise using a load equal to 80% of your 1RM with 5 minutes rest between sets and following the 4^{th} set. Next, you will perform 4 additional single repetition sets of the back squat exercise using a load of 90% of your 1RM with 5 minutes rest between sets and following the 4^{th} set. Next, the vertical jump test protocol will be repeated. Your weight will be checked once this day is complete. You will perform a total of 4 sets of back squat with knee wraps, 2 at 80%1RM and 2 at 90%1RM. Knee wraps will be applied by a researcher. A linear displacement transducer (Tendo Weightlifting Analyzer) will be used to calculate force, power, and velocity will be attached to your waist. There are 2 days of testing before the training days and 1 day after training, see figure 1 for a timetable.

<u>Training Days:</u>

Vertical Jump Test Protocol. You will begin the testing day with 10 minutes of quiet rest. Then you will perform 2 sets of 5 vertical jumps with 20 seconds rest between jumps and 5 minutes rest between sets. You will perform one set of the vertical jump with knee wraps and one set without knee wraps. The knee wraps will be applied by one of the researchers. A linear displacement transducer (Tendo Weightlifting Analyzer) will be used to calculate force, power, and velocity and will be attached to your waist.   Jump height will be determined with a Vertec device. This protocol will be performed before and after the back squat power test protocol.

Back Squat Training Protocol. After a 5 minute rest period following the vertical jump test, you perform a warm up set of 10 back squats using a load equal to 50% of your 1RM. Following a 5 minute rest period, you will perform another warm up set of 5 back squats using a load equal to 70% of your 1RM. Following a 5 minute rest period, you will perform 3 sets of 3 back squats using a load equal to 80% of your 1RM with 5 minutes rest between sets and following the 3^{rd} set. Next, you will perform 3 sets of 3 back squats using a load equal to 90% of your 1RM with 5 minutes rest between sets and following the 3^{rd} set. Next, the vertical jump will be repeated. You weight will be checked once the day is complete. Your group assignment will determine if you perform the last 6 sets of back squats with or without knee wraps.

Experiment Days

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
18

1RM 1   1RM 2   Test 1   Test 2   Training   Training
Test 3

Figure 1. Timetable for Testing and Training.

Benefits: There is no direct benefit to you. However, you are contributing to the body knowledge concerning the benefits gained with the use of resistance training accessories associated with enhancing performance and you may experience improvements in your vertical leap and/or back squat performance.

Risks/Discomforts: There are no anticipated risks that are greater than those associated with normal physical activity. Performing the squat exercise with free weight resistance and landing incorrectly during the jump may pose possibility of injury to the lower limbs (knees, hips, ankles). Researchers will emphasize correct form and technique will. There may be some slight discomfort associated with wearing the wrap which includes but is not limited to tingling sensation at and below the site of the knee wrap, headaches, redness, irritation, and/or bruising at the site of the knee wrap. If you deem the knee wrap is too tight, it will be re-wrapped to your preferred level of comfort.

In order to reduce this risk, all protocols will be supervised by graduate students or faculty with proof of human research subjects training as recommended by the IRB. In addition, supervisors and participants will receive instructions on proper technique for the back squat exercise and vertical jump as provided by the textbook *Essentials of Strength and Conditioning.* Investigators' certifications include CPR/FirstAid/AED from Red Cross, Health Fitness Specialist from ACSM, and Senior National Coach from USA Powerlifting.

You may terminate your participation at any time and without warning. No attempt will be made by the research personnel to stop you.

Privacy and Confidentiality: No identifying information will be collected. Your signed consent form will be kept separate from your study data, and responses will not be linked to you.

Compensation:
The project will not affect your finances in either a positive or negative manner.

Medical treatment by the University Health Center is provided only to currently registered students. Please be advised that for all other injuries, emergency services will be called for those occurring on the Kent State University campus. You or your medical insurance will be billed for this service. No other medical treatment or financial compensation for injury from participation in this research project is available.

Voluntary Participation: Taking part in this research study is entirely up to you. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. You will be informed of any new, relevant information that may affect your health, welfare, or willingness to continue your study participation.

Contact Information

If you have any questions or concerns about this research, you may contact the primary researcher, J. Derek Kingsley (jkingsle@kent.edu), at 330.672.0222. This project has been approved by the Kent State University Institutional Review Board. If you have any questions about your rights as a research participant or complaints about the research, you may call the IRB at 330.672.2704.

Consent Statement and Signature

I have read this consent form and have had the opportunity to have my questions answered to my satisfaction. I voluntarily agree to participate in this study. I understand that a copy of this consent will be provided to me for future reference.

________________________________ ______________________

Participant Signature Date

Do you want to be contacted for future studies?

- ❑ YES, I want to be contacted
- ❑ NO, I do not want to be contacted

Informed Consent to Participate in a Research Study

<u>Study Title:</u> The effects of using knee wraps on the back squat exercise, post-exercise performance, and performance recovery.

<u>Principal Investigator</u>: Dr. J. Derek Kingsley, Cardyl Trionfante and Dr. Arnold Nelson

You are being invited to participate in a research study. This consent form will provide you with information on the research project, what you will need to do, and the associated risks and benefits of the research. Your participation is voluntary. Please read this form carefully. It is important that you ask questions and fully understand the research in order to make an informed decision. You will receive a copy of this document to take with you.

<u>Purpose of the Study:</u> The study will investigate the acute effects of using knee wraps on the back squat exercise and vertical jump performance using training protocols matched for volume, set, and repetition schemes.

<u>Subjects:</u>

a. Inclusion Criteria

Healthy males ages 18-40 who participate in competitive powerlifting, weightlifting, or bodybuilding on a national level with >1 year experience lifting at high intensities (>80% 1RM) at least 1x per week and participate in resistance training sessions at 2x per week will be eligible for this study. If more subjects required, then males ages 18-40 who are involved in physical activity at least 2 times per week that involves high intensity exercise or resistance training.

b. Exclusion Criteria

Anyone with a history or current cardiovascular disease and/or individuals that answer “yes” to any question on the PAR-Q will be excluded from the study. Before participation, subjects must agree to discontinue use of supplements designed to enhancing performance within 24hrs of experiment days and discontinue use of supplements designed to enhance recovery for at least 2 weeks prior to start of study.

<u>Study Procedures:</u>

<u>Experiment Days</u>

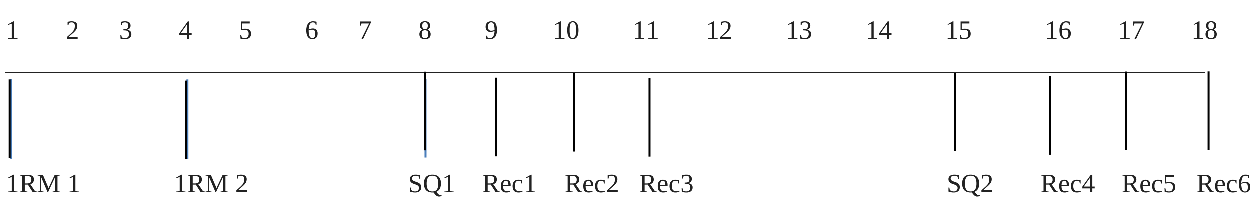

Figure 1- Timetable for Testing and Training

1RM Testing

Back Squat 1RM Protocol- Participants will perform this protocol on days 1 (1RM 1) and 4 (1RM 2) of the study. The purpose of this protocol is to determine the correct training load for back squat training protocols and so that you can become more familiar with the protocol to be used on days 8 and 15.

Warm Up Set 1-50% estimated 1RM for 10 repetitions followed by 5 minutes rest

Warm Up Set 2- 70% estimated 1RM for 5 repetitions followed by 5 minutes rest

Warm Up Set 3- 80% estimated 1RM for 3 repetitions followed by 5 minutes rest

Warm Up Set 4- 90% estimated 1RM for 1 repetition followed by 5 minutes rest

1RM Test-5 attempts to achieve a 1RM with 5 minutes rest between attempts.

Familiarization: These periods will be randomized (with or without knew wraps) between Days 1 and 4. You will be limited to performing 5 sets of no more than 5 repetitions at a load ≤85% 1RM.

Back Squat Training:

This section will describe the nature of each resistance training session involving the back squat exercise. The back squat exercise will be performed to a parallel depth as described by a previous back squat study both with knee wraps and without knee wraps (Lake et al, 2012).

Back Squat Training Protocol- Participants will perform this protocol on days 8 (SQ1) and 15 (SQ2) of the study. Participants will perform this protocol with knee wraps and without knee wraps on separate days in a randomized order.

Weigh in and rest quietly for 10 minutes

Pre-Ex Vertical Jump Test- 1 set of 5 vertical jumps with 20 seconds rest between jumps followed by 5 minutes rest.

Back Squat Warm Up Set 1-50% 1RM for 10 repetitions followed by 5 minutes rest

Back Squat Warm Up Set 2- 60% 1RM for 5 repetitions followed by 5 minutes rest

Back Squat Sets 1-5- 85%1RM for 5 repetitions with 5 minutes rest between sets

Post-Ex Vertical Jump Test (immediate post)- 1 set of the 5 vertical jumps with 20 seconds rest between jumps. This will take place immediately after the completion of the last set of back squats.

Post-Ex Back Squat- After completion of the post-ex vertical jump test, the participant will perform the back squat with 60%1RM for 5 repetitions.

Post-Ex Vertical Jump Test (10 and 30 minutes post-exercise)- 1 set of the 5 vertical jumps with 20 seconds rest between jumps. This will take place immediately after the completion of the last set of back squats.

Recovery Day Protocol- Participants will perform this protocol for three consecutive days following each back squat training session. As outlined in Figure 1, these include days 9-11 (Rec1-3) and 16-18 (Rec4-6).

Weigh in and rest quietly for 10 minutes.

Vertical Jump- 2 sets of 5 vertical jumps with 20 seconds between jumps and 5 minutes rest between sets followed by 5 minutes rest.

Back Squat- 2 sets of 5 repetitions with a load equal to 60% 1RM with 5 minutes rest between sets.

Benefits: There is no direct benefit to you. However, you are contributing to the body knowledge concerning the benefits gained with the use of resistance training accessories associated with enhancing performance and you may experience improvements in your vertical leap and/or back squat performance.

Risks/Discomforts: There are no anticipated risks that are greater than those associated with normal physical activity. Performing the squat exercise with free weight resistance and landing incorrectly during the jump may pose possibility of injury to the lower limbs (knees, hips, ankles). Researchers will emphasize correct form and technique will. There may be some slight discomfort associated with wearing the wrap which includes but is not limited to tingling sensation at and below the site of the knee wrap, headaches, redness, irritation, and/or bruising at the site of the knee wrap. If you deem the knee wrap is too tight, it will be re-wrapped to your

preferred level of comfort.

In order to reduce this risk, all protocols will be supervised by graduate students or faculty with proof of human research subjects training as recommended by the IRB. In addition, supervisors and participants will receive instructions on proper technique for the back squat exercise and vertical jump as provided by the textbook *Essentials of Strength and Conditioning.* Investigators' certifications include CPR/FirstAid/AED from Red Cross, Health Fitness Specialist from ACSM, and Senior National Coach from USA Powerlifting. The familiarization will allow you to become comfortable with the knee wraps prior to the testing day and allow you to 'break-in' the knee wraps. This may decrease the risk of injury and perceived discomfort.

You may terminate your participation at any time and without warning. No attempt will be made by the research personnel to stop you.

Privacy and Confidentiality: No identifying information will be collected. Your signed consent form will be kept separate from your study data, and responses will not be linked to you.

Compensation:
The project will not affect your finances in either a positive or negative manner.

Medical treatment by the University Health Center is provided only to currently registered students. Please be advised that for all other injuries, emergency services will be called for those occurring on the Kent State University campus. You or your medical insurance will be billed for this service. No other medical treatment or financial compensation for injury from participation in this research project is available.

Voluntary Participation: Taking part in this research study is entirely up to you. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. You will be informed of any new, relevant information that may affect your health, welfare, or willingness to continue your study participation.

Contact Information
If you have any questions or concerns about this research, you may contact the primary researcher, J. Derek Kingsley (jkingsle@kent.edu), at 330.672.0222. This project has been approved by the Kent State University Institutional Review Board. If you have any questions about your rights as a research participant or complaints about the research, you may call the IRB at 330.672.2704.

Consent Statement and Signature
I have read this consent form and have had the opportunity to have my questions answered to my

satisfaction. I voluntarily agree to participate in this study. I understand that a copy of this consent will be provided to me for future reference.

______________________________ ____________________

Participant Signature Date

From time-to time, we may have additional research studies that you may qualify for. Do we have your consent to re-contact you either by telephone or formal letter about such studies and to discuss whether you may be interested in participating in any additional studies? Your decision to be re-contacted will have no bearing on the current study or your relationship with Kent State University

- ❑ Yes, I give my permission to be re-contacted

- ❑ No, I do not want to be re-contacted

APPENDIX IV: Supplemental Statistics

Chapter II

Baseline Characteristics

Baseline characteristics were not significantly different between groups (Training Unwrapped=TU, Training Wrapped= TW) with regards to age (UW= 27±2, KW= 27±4years), height (UW= 182.5±6.8, KW= 173.3± 1.3cm), mass (UW= 92.2±12.2, KW= 88.7±17.5kg), %body fat (UW= 27.3±14.4, KW= 18.7±8.5%), and lean body mass (UW= 65.6±5.7, KW= 72.1±6.2kg).

VJ Performance

Test retest reliability of the vertical jump test was high (ICC= 0.937). ANOVAs of VJ over all three test days revealed significant 3 way day*set*group interactions ($p<0.001$). Post-hoc analyses revealed significant group differences ($p<0.0021$) in vertical jump during Set_1 of $Test_2$ (TU= 53.9±5.3cm, TW=63.6±10.4cm) and $Test_3$ (TU=53.0±6.9cm, TW=65.8±7.2cm). A significant difference between groups was also detected during Set_2 of $Test_3$ (TU= 36.2±17.6cm, TW=60.6±9.7cm). In addition, vertical jump with KW for group TW was significantly different ($p<0.001$) across all three test days ($Test_1$= 41.8±9.0cm, $Test_2$= 52.2±11.3cm, $Test_3$= 60.6±9.7cm).

Chapter III

Baseline Characteristics

Baseline characteristics were not significantly different between groups according to age (TU= 22±3, TW= 26±5cm), height (TU= 173.8±8.7cm, TW= 183.3±5.1cm), mass (TU= 81.3±4.3kg, TW= 90.5±16.1cm), %body fat (TU= 18.2±5.9, TW= 17.8±12.4%), lean body mass (TU= 66.5±5.1kg, TW= 73.0±3.5kg), and back squat (BS) one repetitions maximum (1RM) (TU= 155.9±26.8kg, TW= 142.0±27.6kg). Test-retest reliability for BS 1RM was considered high (ICC=0.996) and participants experienced significant increases in BS 1RM from first (1RM= 143.4±27.3kg) to second second (1RM= 148.2±26.5kg.

VJ

Test-retest reliability for VJ tests was high for between BS $Test_1$:$Test_2$ (ICC= 0.941) and BS $Train_1$:$Train_2$ (ICC= 0.963). A 2x5 repeated measures ANOVA revealed significant day by group

interactions ($p<0.001$). However, no significant differences were observed between groups for any BS testing or training day. Only the group training without KW (TU) had significantly different ($p\leq0.002$) average VJ when comparing $Test_1$ (56.1±6.6cm) to $Train_2$ (55.8±6.8cm) and $Test_3$ (56.1±5.1cm), and when comparing $Train_1$ to $Train_2$ and $Test_3$

BS Testing

Test retest reliability is considered moderate for velocity (AV ICC=0.803, EV ICC= 0.718, PV ICC= 0.888), high for force (PF ICC= 0.955), and power (AP ICC= 0.796, PP ICC= 0.896). Repeated measures ANOVAs revealed significant day*condition interactions such that wearing KW reduced EV during $Test_1$ (UW= 0.33±0.11m/s, KW= 0.22±0.8m/s) and $Test_3$ (UW= 0.35±0.09m/s, KW= 0.28±0.08m/s). In addition, wearing KW during BS $Test_3$ caused significantly difference ($p<0.001$) from EV of BS $Test_1$. No other day*condition or day*condition*group interactions were revealed in ANOVAs.

BS Training

Test retest reliability is considered moderate for velocity (AV ICC=0.860, EV ICC= 0.722, PV ICC= 0.871), high for force (PF ICC= 0.942), and moderate for power (AP ICC= 0.840, PP ICC= 0.679). Repeated measures ANOVAs revealed significant day*group interactions ($p<0.05$) for PV, AP and PP. Post-hoc analyses revealed group differences during $Train_1$ [PV (TU= 0.71±0.14m/s, TW= 0.83±0.16m/s), AP (TU= 666±96W, TW= 966±140W), and PP (TU= 1664±344W, TW= 1885±418W)] and $Train_2$ [AP (TU= 725±103W, TW= 967±78W)].

VITA

Cardyl Trionfante, son of Technical Sergeant Carmela Trionfante, was raised both abroad (Italy and Germany) and in the United States (Ohio, South Dakota, and North Dakota). He has resided in Ohio and completed a Bachelor's of Science and a Master's of Arts while attending Kent State University. Shortly after completing his Master's, he moved to Baton Rouge to complete a Doctorate of Philosophy from Louisiana State University. Cardyl's professional interests include physiology of exercise, strength training, and conditioning. These interests stem from a lifelong passion of participating in strength based sports such as powerlifting. While completing his graduate degrees, Cardyl was won national powerlifting championships in multiple weight classes, placed top five at powerlifting world championships, and placed top three as a professional lifter at the Arnold Sports Festival (which is run by Arnold Schwarzenegger). His notable accomplishments were being selected to represent the United States as part of the Junior World Team and helping Louisiana State University win the National Collegiate Combined Team Powerlifting Championship. In addition to lifting, he is also a certified Senior National Powerlifting Coach and has helped many lifters win national and professional competitions.

Cardyl Trionfante also has a passion for the fine arts. He plays the saxophone and has participated in jazz ensembles since the age of 13. His other personal interests include golf, improv comedy, and dance. Last of all, he enjoys spending his free time with his lovely family which includes his wife (Nicole Trionfante) daughter (Aubriella), and dog (Cali).