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Bodyweight Squat Movement Changes after a High-Intensity Short-Rest Workout

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Master of Arts Thesis

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Short-Rest Workout

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Abstract

High intensity (≥75%1RM), short rest (≤30 seconds) workouts (HISR) have increased in popularity in recent years despite very little scientific study as well as contradicting the American College of Sports Medicine (ACSM) position stand. The purpose of this study was to assess the changes in movement associated with the fatigue resulting from a HISR workout. 14 males underwent a 3 dimensional analysis of 5 bodyweight squats before and after a HISR workout. Peak angle, total displacement and rate were assessed for knee flexion, trunk flexion, hip flexion, hip rotation and hip adduction. Subjects were split in to two groups: high lactate (n=7) and low lactate (n=7). Separate 2x2 mixed model ANOVAs were used to assess differences between time points (pre-test, post-test) and groups (high lactate, low lactate) for the dependent variables. We observed a significant group x time interaction for peak knee flexion (F=5.55, P=0.036). Post hoc tests revealed that the high blood lactate group had a significantly lower peak knee flexion than the low blood lactate group after the HISR workout. We observed a significant main effect for time for the following variables: knee flexion peak, displacement and rate; hip flexion peak, displacement and rate; hip adduction peak, displacement and rate; hip rotation displacement and rate. When analyzing the movement of the bodyweight squat before and after a highly fatiguing resistance exercise protocol, it is clear that many of variables were significantly different, which could lead to an increased risk of injury.

Review of Literature

In recent years, there has been an increase in popularity in high-intensity, short rest workouts (HISR). These types of workouts are in direct contradiction to the most recent American College of Sports Medicine position stand [1].

More specifically, for example, ACSM [1] suggests rest periods of 2-3 minutes when using exercises for the purposes of increasing maximal strength, such as squat and bench press, whereas HISR workouts frequently combine heavy loads with very short rest. ACSM [1] also suggests that novice individuals use slow to moderate velocities in resistance training. In contrast, HISR workouts frequently include Olympic lifts with very high velocity, and programming is not altered based on training status. Furthermore, ACSM [1] suggests novice individuals perform resistance training 2-3 times per week, however HISR workouts are often performed 5-6 times per week. Many other discrepancies between HISR workouts and ACSM recommendations can be found.

Despite the contradictions with the ACSM position stand, HISR workouts continue to gain in popularity and despite widespread use, the affects of combining heavy weights and short rest have not been well studied. However, insight in to the combination of heavy loads and short rest might be gained by observing their affects when studied separately.

Kraemer et al. [2] compared the acute affects of a heavy (5RM), long rest (3 minute) protocol with a ligher (10RM), shorter rest (1 minute) protocol. The study found that the

shorter rest protocol induced a greater growth hormone response, but that both protocols resulted in a similar increase in serum testosterone. With both an increase in growth hormone as well as testosterone, short rest protocols might provide a greater anabolic environment. A later study, by Gordon et al. [3] found that the greater growth hormone response in short rest protocols may be in part due to the increase in hydrogen ion concentration, commonly found in short rest resistance training protocols.

In a more recent study by Ratamess et al. [4], the metabolic and performance effects of a continuum of rest periods (30s, 1, 2, 3, 5 min) on a five-set bench press protocol at 75-85% 1RM were analyzed. Similarly to Kraemer et al. [2], a greater metabolic response was seen in the shorter rest intervals, as measured by differences in energy expenditure, oxygen consumption, heart rate and blood lactate concentration. These greater metabolic demands in short rest period protocols might be more beneficial in terms of body compositional changes, which suggests that this might be an advantage of HISR workouts.

These high blood lactate concentrations associated with short rest resistance training protocols might be beneficial in terms of training for specific sports. Studies have documented high blood lactate concentrations in rugby (7.4 ± 2.5mmol$\cdot$L^{-1})[5], soccer (15.9 ± 1.9 mmol$\cdot$L^{-1})[6], martial arts (up to 20.7 mmol$\cdot$L^{-1}) [7] and wrestling (up to 20 mmol$\cdot$L^{-1})[8] to name a few. This would suggest a scientific basis for the use of short rest resistance training that would improve the athlete's ability to produce force and power

under high metabolic stress, allowing them to jump higher, sprint faster or gain an advantage during physical contact.

However, Ratamess et al. [4] also found that shorter rest periods had negative affects on the total volume of the workout as well as on the resistance lifted, as if the desired repetition range could not be achieved, the resistance was lowered for the subsequent set. The authors suggested that performance is reduced as short rest periods lead to inadequate recovery between sets and therefore the subsequent set is performed in a prefatigued state. Although this conclusion stands to reason, there may be long-term negative consequences of lifting with reduced resistance due to short inter-set rest periods and these reduce the weight being lifted and therefore the development of maximum strength.

Robinson et al. [9] investigated the chronic effects of 3 different rest periods of 0.5 minutes, 1.5 minutes and 3 minutes on the same resistance training protocol over the course of 5 weeks. The investigators measured the subjects' strength (1RM), power (vertical jump) and high intensity exercise endurance (cycle ergometer test, 15 five-second rides with 50 minutes of rest). With short rest periods high intensity exercise endurance improved, but power gains were not different between groups and strength performance was significantly lower in the group that used 0.5 minutes of rest.

Similar results were also found by Pincivero et al. [10], who measured isokinetic strength before and after an isokinetic strength training protocol using concentric knee flexion and

concentric knee extension for 4 weeks. One group trained using 40 seconds rest between each set of exercise whereas another group used 160 seconds rest. Pincivero et al. [10] also found that a longer rest period resulted in greater strength gains than a shorter rest period.

With the results from Robinson et al. [9] and Pincivero et al. [10] in mind, it appears that although short rest resistance training increases metabolic response, it appears to negatively affect strength gains in moderately trained men and untrained men respectively. However, it has been suggested that individuals that are more experienced in short rest resistance training might be able to produce high forces even with little rest.

Kraemer et al. [11] observed the differences in performance over varied rest periods between bodybuilders, who were accustomed to short rest intervals, and powerlifters who were accustomed to much longer rest periods. The bodybuilders were able to perform significantly better at repeated attempts with a 10RM load than powerlifters, even when rest was as short as 30 seconds. This lead the author to conclude that bodybuilders were able to resist the effects of fatigue because of adaptations association with short rest programming. This suggests that perhaps individuals that are new to resistance training should utilize longer rest periods, such as those used in the research by Robinson et al. [9] and Pincivero et al. [10]. However, as the individual progresses they can reduce rest periods and continue to be able to produce maximal force, therefore gaining the metabolic benefits of short rest workouts without the negative affects of reduced gains in strength.

With the use of short rest periods as previously described and quickly moving from one exercise to the next, a look at circuit weight training studies can also provide insight in to the demands of HISR workouts. Although HISR workouts are relatively new and have so far not been observed in the scientific literature, the benefits of circuit training have been well documented. In 1978, Wilmore et al. [12] studied a 10 week circuit training program that used 40-55% 1RM, lifted as quickly as possible for 30 seconds per set, with 15 seconds rest between each of the 10 resistance machine stations and 3 circuits in total. The study observed improvements in body composition (lean body mass), strength (1RM increase in many of the lifts) and cardiovascular (VO_2Max) parameters. Wilmore [12] concluded that many different physiological parameters can be improved concurrently.

In a similar 10 week circuit training study, Marcinik et al. [13] also used 10 resistance machine stations with a shorter lifting period of 15 seconds and used 15 seconds rest. Two lifting groups were used with either 40% 1RM or 60% 1RM loads. The two circuit protocols lasted 11 minutes and were compared to a running only and a callisthenic program. Significantly greater increases in strength (1RM) were seen in the circuit training groups, although surprisingly there was no greater improvement in strength in the 60% 1RM group compared with the 40% group. Also, as was found by Wilmore [12], the circuit resistance training lead to improvements in cardiovascular performance, this time measured by a maximal cycle ergometer test.

In a more recent study, Harber et al. [14] studied the affects of circuit weight training and found similar results as the previous studies. With a similar load (40-60% 1RM) and rest

period (starting at 30 seconds and reducing), again strength gains were seen as measured by 1RM. This study, however, also observed blood lactate concentrations as well as changes in muscle fiber types. The authors concluded that circuit weight training at this intensity is an adequate stimulus for changes in muscle fiber typing, resulting in changes from type IIb to type IIa and also modest gains in hypertrophy. The authors suggested that these adaptations most likely occur from the high glycolytic demand, as evidenced by high concentrations of lactic acid in the blood immediately after the exercise. Interestingly, the authors also noted that in comparison to resistance training with higher intensities (75% or greater), the strength and hypertrophy gains were modest, and the lower intensity used in this study does not provide an optimal environment for muscle adaptation.

One significant difference between HISR and traditional circuit training, however, is the heavier loads and types of exercises used. As circuit weight training is time economical and has also been found to provide cardiovascular gains, it could be inferred that circuit weight training with higher intensities (75% and greater) could also provide more substantial strength gains as well, thus providing a scientific basis for HISR workouts. However, as previously mentioned this has not been studied and individuals continue to participate in HISR workouts without any scientific support.

Although Harber et al. [14] highlighted the benefits of workouts that produce high concentrations of blood lactate, this could also be a reason for some concern with HISR workouts. With higher loads, it would be reasonable to suggest that blood lactate

concentrations would be higher and would be indicative of higher levels of fatigue. Higher blood lactate concentrations and fatigue could lead to positive physiological adaptations, but also, fatigue might need to be balanced with the observations that high levels of fatigue negatively affect exercise technique.

There have been a number of studies published that have observed reduced proprioception with high levels of fatigue [15-17]. If proprioception is reduced, it would be reasonable to suggest that exercise techniques would change under fatigue too. Johnston et al. [15] induced fatigue to 50% initial strength level with the use of an isokinetic dynamometer at varying speeds (20cm·s^{-1}- 60cm·s^{-1}) for 10 minutes. Balance was measured before and after fatigue and a significant reduction was found. The authors suggested that fatiguing the muscle around a joint inhibits the joint's neuromuscular feedback system. Although unable to state definitively how, the authors suggested it was plausible some form of muscle spindle desensitization or perhaps ligament relaxation and golgi tendon desensitization occurs with excessive fatigue. It was concluded that if fatigue reduces balance, fatigued athletes are at a greater risk of injury.

The conclusion from Johnston et al. [15], has been echoed in other studies. Lattanzio et al. [17] found that after 3 different cardiovascular exercise fatiguing protocols that subjects were less accurate when trying to recreate knee joint angles from a standing position than they were before fatigue was induced. Lattanzio et al. [17] did conclude, however, that although the results were statistically significant, they were unable to determine if the

results would be clinically significant and whether or not it could mean a greater injury risk.

A study by Miura et al. [16] directly compared the effects of fatigue by cardiovascular exercise and resistance exercise on the ability to reproduce knee joint angle, but this time from a seated rather than standing position. Fatigue was achieved by resistance exercise through 60 consecutive maximal contractions using an isokinetic dynamometer at 120º/second. Cardiovascular fatigue was induced by 5 minutes of running at 10km/h with a 10% uphill grade. The results showed that although the resistance exercise reduced the peak torque of the knee flexors and extensors, no significant change in ability to reproduce knee angles was seen. However, although no force reductions were observed after cardiovascular fatigue, there was a significant reduction in the ability to reproduce knee angles. The authors concluded that they may have begun to determine where in the proprioceptive pathway fatigue affects proprioception. The authors suggested that decreased reproduction ability after cardiovascular fatigue is not due to the loss of peripheral afferent signals, but to other factors, especially deficiency of central processing of proprioceptive signals. The authors also acknowledged that cardiovascular fatigue might have been better measured by blood lactate concentrations. It is therefore interesting to note that if blood lactate concentrations can be high in circuit weight training, reduced proprioception could still be seen in resistance training.

As well as fatigue being shown to reduce proprioception, the effects of fatigue on exercise technique specifically has also been studied. McNeal et al [18] observed the

effects of fatigue over the course of 60 seconds of jumping by analyzing the subject's joint angles at the lowest position of the squat jump. There were significant differences in knee, thigh, trunk and shank angles as well as ankle dorsiflexion over the course of the 60 seconds, with greatest differences often occurring in the last 10 seconds. The authors concluded that these technique changes showed that as fatigue increased the subjects used their legs less in the jump and instead relied more on trunk movement.

Similar conclusions have been made when observing the affects of fatigue in the legs on lifting techniques. Trafimow et al. [19] found that during a box lift as the quadriceps became fatigued that subjects would move toward a stoop technique, where the hips and spine are more flexed than in the squat technique. Hagen et al. [20] conducted a similar box lifting study and made the same conclusions; that as the quadriceps become fatigued that the lifter reduces range of motion in the legs during the lift and increases the range of motion in the lower trunk. These changes in technique might be disadvantageous as Potvin et al. [21] found that greater trunk flexion significantly increases shear force in the lumbar spine, thus increasing the risk of injury.

Similarly, Hattin et al. [22] observed the effect of fatigue on knee forces and found that during a set of fifty half-squats, anterior-posterior shear force increased significantly during the second half of the set. The authors also found that fatigue increased all articular force components. Therefore fatigue might increase compressive and shear forces at the joints, suggesting another possible route to injury with excessive fatigue.

If fatigue has been shown to make unfavorable changes in technique in box lifting tasks involving 17kg [20] or 30kg [19], it is reasonable to suggest that in demanding resistance training protocols using much heavier loads that the risk of injury would be greater.

Although many of these studies that have been described have found alterations in exercise technique with fatigue, the protocols used to induce fatigue vary greatly between studies. A review by Cairns [23] highlighted the multifactorial nature of fatigue, showing that fatigue can be quantified in a vast number of ways depending on the measurement variable (i.e. muscle work, force, power) or the device used (i.e. force plate, optical length detector). Cairns [23] also suggested that associated variables could be used to measure fatigue, such as the use of the rating of perceived exertion.

In conclusion, if the popularity of HISR workouts are increasing without a substantial research base, it is necessary to begin to study both the physiological effects as well the affects that these types of workouts have on exercise technique so that both the benefits and risks of these workouts can be better understood.

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Introduction

In recent years, there has been an increase in popularity in high-intensity, short rest workouts (HISR). These types of workouts are in direct contradiction to the most recent American College of Sports Medicine (ACSM) position stand [1], which suggests combining high loads with longer periods of rest of 3 minutes or longer. Furthermore, ACSM [1] suggests that novice resistance trained individuals use slow velocity resistance exercises at a frequency of 2-3 times per week, whereas those who follow HISR workout regimens often perform high velocity Olympic lifts at a frequency of 5-6 times per week, regardless of resistance training experience. Despite contradictions with the ACSM position stand, HISR workouts continue to be performed without having been scientifically evaluated, leaving the positive or negative effects of these workouts relatively unknown.

The use of short rest workouts has been previously studied, often in a circuit-style fashion, but with comparatively lower loads. Marcinik et al. [13] used 10 resistance machine stations and observed two lifting groups who used either 40% 1RM or 60% 1RM loads, with each group resting 15 seconds between exercises. Both groups saw significant increases in strength (1RM), although surprisingly there was no greater improvement in strength in the 60% 1RM group compared with the 40% group. Furthermore, both groups saw an improvement in cardiovascular performance as measured by a maximal cycle ergometer test.

In a more recent study, Harber et al. [14] studied the affects of circuit weight training and found similar results. With a similar load (40-60% 1RM) and rest period (starting at 30 seconds and reducing), again strength gains were seen as measured by 1RM. This study, however, also observed blood lactate concentrations and also observed changes in muscle fiber types. The authors concluded that circuit weight training at this intensity is an adequate stimulus for changes in muscle fiber typing, resulting in changes from type IIb to type IIa and also modest gains in hypertrophy. The authors suggested that these adaptations most likely occur from the high glycolytic demand, as evidenced by high concentrations of lactic acid in the blood immediately after the exercise. Interestingly, the authors also noted that in comparison to resistance training with higher intensities (75% or greater), the strength and hypertrophy gains were modest, and the lower intensity used in this study does not provide an optimal environment for muscle adaptation.

If workouts using short rest can lead to an improvement in cardiovascular performance, but when using lighter loads fail to provide an adequate stimulus to maximal strength gains, then there is reason to suggest that HISR workouts might be able to provide gains in both cardiovascular performance as well as maximal strength.

Although there is a clear potential benefit of HISR workouts, there is also a potential concern. The study by Harber et al. [14] found a high blood lactate concentration associated with circuit style resistance training even at low loads (13.87mmol/L). The highly fatiguing nature of such workouts might lead to degradations in exercise technique.

Several studies have found differences in movement following a fatiguing protocol [15-18]. Johnston et al. [15] induced fatigue to 50% initial strength level with the use of an isokinetic dynamometer at varying speeds (20cm·s⁻¹- 60cm·s⁻¹) for 10 minutes. Balance was measured before and after fatigue and a significant reduction was found. Lattanzio et al. [17] found that after 3 different cardiovascular exercise fatiguing protocols that subjects were less accurate when trying to recreate knee joint angles from a standing position than they were before fatigue was induced. Miura et al [16] also found discrepancies in the ability to reproduce knee angles after cardiovascular exercise, but also studied the affects of resistance exercise and found no changes in reproducing knee angles. In more dynamic movement, McNeal et al. [18] found changes in jumping technique, which progressed towards the end of a fatiguing 60 second repeated jump assessment.

Similar conclusions have been made when observing the affects of fatigue in the legs on lifting techniques. Trafimow et al. [19] found that during a box lift as the quadriceps became fatigued that subjects would move toward a stoop technique, where the hips and spine are more flexed than in the squat technique. Hagen et al. [20] conducted a similar box lifting study and made the same conclusions; that as the quadriceps become fatigued that the lifter reduces range of motion in the legs during the lift and increases the range of motion in the lower trunk. These changes in technique might be disadvantageous as Potvin et al. [21] found that greater trunk flexion significantly increases shear force in the lumbar spine, thus increasing the risk of injury.

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If fatigue has been shown to make unfavorable changes in technique in box lifting tasks involving 17kg [20] or 30kg [19], it is reasonable to suggest that in demanding resistance training protocols using much heavier loads that the risk of injury would be greater.

Although many of these studies that have been described have found alterations in exercise technique with fatigue, the protocols used to induce fatigue vary greatly between studies. A review by Cairns [23] highlighted the multifactorial nature of fatigue, showing that fatigue can be quantified in a vast number of ways depending on the measurement variable (i.e. muscle work, force, power) or the device used (i.e. force plate, optical length detector). Cairns [23] also suggested that associated variables could be used to measure fatigue, such as the use of the rating of perceived exertion.

The potential benefits of combining heavy resistance training loads with short rest are that optimal maximal strength gains could be made in conjunction with cardiovascular gains. However, such a workout would clearly be extremely fatiguing and reduction in exercise technique combined with a possible increased risk in injury are the possible pitfalls. At present, though, these types of workouts have not been adequately assessed in the body of literature. This study, therefore, aims to assess the changes in movement

associated with the fatigue resulting from a HISR workout. Furthermore, this study aims to observe several ways of assessing fatigue, and observing the contributions of each assessment method to changes in exercise technique.

Hypotheses

There will be significant changes in several technique variables shown during the bodyweight squat after the HISR protocol when compared with the bodyweight squats performed prior to the HISR protocol.

The contribution of fatigue to technique alteration will vary depending on the measure used to quantify fatigue.

Experimental Approach to the Problem

Research in to the affects of fatigue on proprioception has assessed the ability to reproduce knee angles [15, 17] and also use a single exercise protocol designed to induce fatigue. This study will attempt to add greater practical application by observing the affects of a workout including typical resistance exercises (squat, bench press and deadlift) on the technique of an athletic movement (bodyweight squat). The workout is also designed to replicate a HISR workout, using loads higher than have been previously studied combined with a minimal rest period where subjects were asked to simply perform the prescribed workout as quickly as possible. In order to compare the contributions of different definitions of fatigue, fatigue measures evaluated included

blood lactate concentration, rate of perceived exertion, relative reduction in load, and reduction of force and power.

Methods

A 3 dimensional analysis of 5 bodyweight squats was conducted before and after a HISR workout. The primary dependent variables were knee flexion, trunk flexion, hip flexion, hip rotation and hip adduction. Data were collected on the last 4 squats and averaged. Pre and post fatigue squats were compared with the pre fatigue squats used as a control.

Subjects

14 male subjects volunteered for the study. All subjects had at least 6 months of previous resistance training experience.

Subject Characteristics

Age	23.3±4.3
Height	173.6±3.6
Weight	76.9±7.2
Bodyfat percentage	8.8±2.8
Squat 1RM	277.5±34.8
Bench 1RM	206.8±37.7
Deadlift 1RM	319.3±47.7

Procedures

Before all experimental visits, subjects were assessed for hydration level using a urine specific gravity (USG) refractometer (Reichert, Lincolnshire, IL). Subjects would not participate in the visit unless USG was ≤1.025. If USG exceeded 1.025, subjects were instructed to drink water and USG was measured repeatedly until the desired level was reached.

Familiarization

Before familiarization body composition was measured using the Jackson-Pollock method [24] with skinfold calipers (Bodycare, England) and body mass was measured using calibrated electronic scales (Ohaus, Florham Park, NJ). Subjects were then familiarized with the warm up protocol to be used before all experimental visits, which included five minutes using a cycle ergometer at resistance level 5 with a speed of 60 RPM. This was followed by dynamic stretches including body weight squats, forward and lateral lunges, knee hugs, quadriceps stretches and a straight leg march. The three lifts used in the HISR workout, which were barbell back squat, barbell bench press and barbell deadlift were then taught to the subjects who performed two sets of 8-10 repetitions with light loads and 2 minutes rest between sets.

1Repetition Maximum (RM) Testing

Subjects performed the back squat and bench press 1RM tests on the same day, with the 1RM deadlift test taking place 48 hours later to ensure the squat and deadlift exercises would not comprimise each other. Each 1RM test followed the same protocol. Before

testing, the subjects performed the standardized warm-up. A warm up weight of 50% of predicted 1RM was then performed with 8-10 repetitions. Following 3 minutes of rest, a second warm-up set of 80% predicted 1RM was performed. After another 3 minutes rest, a weight was selected that the subject believed they could lift once. After each successful lift, the weight was increased and another lift was attempted. 1RM was considered the most amount of weight the subject could lift one time with appropriate technique. 1RM was reached within 5 attempts for all subjects.

3 Dimensional Analysis

Kinematic data for the lower extremity were collected using the Flock of Birds electromagnetic motion analysis system (Ascension Technologies, Inc., Burlington, VT) at a sampling rate of 144 Hz. Electromagnetic tracking sensors were placed on each subject over the spinous process of C7, apex of the sacrum, midpoint of the lateral thigh, and shank of the tibia. Sensors of the thigh and tibia were placed on the dominant leg in areas consisting of the least amount of muscle mass to minimize potential artifact induced by muscle contraction. The sensors were affixed to the body by double-sided tape and an elastic wrap. Prior to sensor application, the skin was dried and an alcohol swab used to remove any dead skin cells.

Once the electromagnetic sensors were attached, the subjects were asked to stand in a neutral posture with their arms relaxed at their sides. The following bony landmarks were digitized, in the following order, using a mobile electromagnetic sensor attached to a stylus: spinous process of T12, medial femoral condyle, lateral femoral condyle, medial

malleolus, lateral malleolus, left anterior superior iliac spine, and right anterior superior iliac spine. Digitization of bony landmarks serve to define the segment end-points and joint centers of the lower extremity segments. The ankle joint center is located at the midpoint between the medial and lateral malleoli. Knee joint center is located at the midpoint between the medial and lateral femoral condyles. The hip joint center will be determined by the Bell method [25]. This method consists of estimating the hip joint center using the left and right anterior superior iliac spine as landmarks to mathematically estimate the hip joint center.

Once the subject was digitized, they were instructed to stand relaxed with their arms at their side allowing the computer to calibrate the subject's neutral position. The subject was then asked to perform 5 bodyweight squats, with arms extended out in front of the body.

HISR Workout

75% 1RM was used on each of the three lifts; back squat, bench press and deadlift. Subjects performed 10 repetitions of each lift, then 9 repetitions of each, then 8 and all the numbers down to 1. Subjects were instructed to perform all of the prescribed repetitions as quickly as possible. If the prescribed repetitions for a set were not able to performed in one single set (i.e. rest was taken mid-set), the following set was performed at 5% RM less (i.e. 70%). The subject was instructed to perform the routine with as little load reduction as possible.

At the completion of the workout, the electromagnetic sensors were reattached and the digitization procedure was repeated as previously described. The subjects then performed 5 more bodyweight squats with the arms extended out in front of the body.

Fatigue Indices

Blood lactate concentration was measured immediately before and after the workout. For the resistance exercise protocol session, an indwelling cannula (catheter) was inserted into the antecubital vein. The cannula was kept open with a saline solution. Prior to each blood draw, 3 mL of blood was extracted to avoid inadvertent saline dilution of the blood sample. For each blood draw, ~22 mL of blood was collected. Resulting serum was spun, aliquoted, and stored at -80C until subsequent analyses. Blood samples were analyzed in-house using biochemical assays for lactate. Rate of perceived exertion (RPE) was measured using the Borg [26] scale. Data was taken after each set of the squat exercise was completed. Relative weight reduction was calculated as the difference between the average %1RM used and the prescribed %1RM of 75. Force and power were measured using a force place (Fitness Technology, South Australia, Australia) and linear transducer during all repetitions of the squat movement.

Statistical Analysis

An average of all variables measured during the last four bodyweight squats before and after the HISR workout were taken. The data were normalized by breaking the average squat down in to 101 time points. Peak angles for each variable were assessed by taking the average maximum value. Angle displacement was measured by subtracting the

average minimum value from the average maximum value. To calculate rate, the time between the minimum and maximum value was divided by the displacement value. Separate 2x2 mixed model ANOVAs were used to assess differences between time points (pre-test, post-test) and groups (high lactate, low lactate) for the following variables: knee flexion, hip flexion, hip adduction, trunk flexion and hip rotation. A Bonferroni correction was used for post hoc tests if a significant interaction was found. An a-priori alpha level of 0.05 was used for all analyses.

Results

Table 1. Interaction effects for peak, displacement and rate of each movement assessed before and after a high-intensity short rest workout.

| Movement	Variable	Pre (mean SD)	Post (mean SD)	F (1,12)	P
Knee Flexion	Peak	120.28±11.93	104.46±9.85	5.55	0.036*
	Displacement	115.56±10.55	103.35±10.49	3.23	0.097
	Rate	2.20±0.20	1.98±0.20	0.28	0.606
Hip Flexion	Peak	-109.42±12.49	-95.8±12.30	1.54	0.239
	Displacement	97.94±10.69	90.51±13.22	0.83	0.380
	Rate	1.92±0.20	1.76±0.27	0.36	0.561
Hip Adduct.	Peak	-23.32±7.04	-17.30±8.79	0.29	0.598
	Displacement	17.79±7.36	11.89±4.34	3.94	0.071
	Rate	-0.44±0.17	-0.31±0.17	0.39	0.545
Hip Rotation	Peak	16.39±13.56	14.09±9.56	1.87	0.197
	Displacement	30.72±12.28	20.48±10.12	0.23	0.637
	Rate	0.59±0.23	0.38±0.21	0.30	0.592
Trunk Flex.	Peak	24.11±11.45	23.24±7.87	0.24	0.633
	Displacement	29.35±8.60	30.28±8.24	0.01	0.923
	Rate	0.55±0.18	0.56±0.16	0.05	0.834

*=High blood lactate post significantly lower than low blood lactate post.

Table 2. Main effect for time for peak, displacement and rate of each movement assessed before and after a high-intensity short rest workout.

Movement	Variable	Pre (mean±SD)	Post (mean±SD)	$F_{(F(1,12))}$	P
Knee Flexion	Peak	120.28±11.93	104.46±9.85	28.05	0.000*
	Displacement	115.56±10.55	103.35±10.49	33.36	0.000*
	Rate	2.20±0.20	1.98±0.20	15.56	0.002*
Hip Flexion	Peak	-109.42±12.49	-95.8±12.30	13.18	0.003*
	Displacement	97.94±10.69	90.51±13.22	10.34	0.007*
	Rate	1.92±0.20	1.76±0.27	5.47	0.038*
Hip Adduct.	Peak	-23.32±7.04	-17.30±8.79	7.41	0.019*
	Displacement	17.79±7.36	11.89±4.34	12.45	0.004*
	Rate	-0.44±0.17	-0.31±0.17	6.78	0.023*
Hip Rotation	Peak	16.39±13.56	14.09±9.56	0.36	0.558
	Displacement	30.72±12.28	20.48±10.12	15.00	0.002*
	Rate	0.59±0.23	0.38±0.21	13.18	0.003*
Trunk Flex.	Peak	24.11±11.45	23.24±7.87	0.05	0.825
	Displacement	29.35±8.60	30.28±8.24	0.17	0.686
	Rate	0.55±0.18	0.56±0.16	0.12	0.736

We observed a significant group x time interaction for peak knee flexion (F=5.55, P=0.036). Post hoc tests revealed that the high blood lactate group had a significantly lower peak knee flexion than the low blood lactate group after the HISR workout. We did not observe any other significant interactions for group main effects (P≤0.05) (Table 1).

We observed a significant main effect for time for the following variables: knee flexion peak, displacement and rate; hip flexion peak, displacement and rate; hip adduction peak, displacement and rate; hip rotation displacement and rate (Table 2). No other significant main effects for time were observed (P≤0.05). These findings indicate that subjects squatted with less knee flexion, hip flexion and hip adduction and at a slower rate of knee flexion, hip rotation, hip flexion and hip adduction (Figures 1-3). No group main effects were observed (P≤0.05).
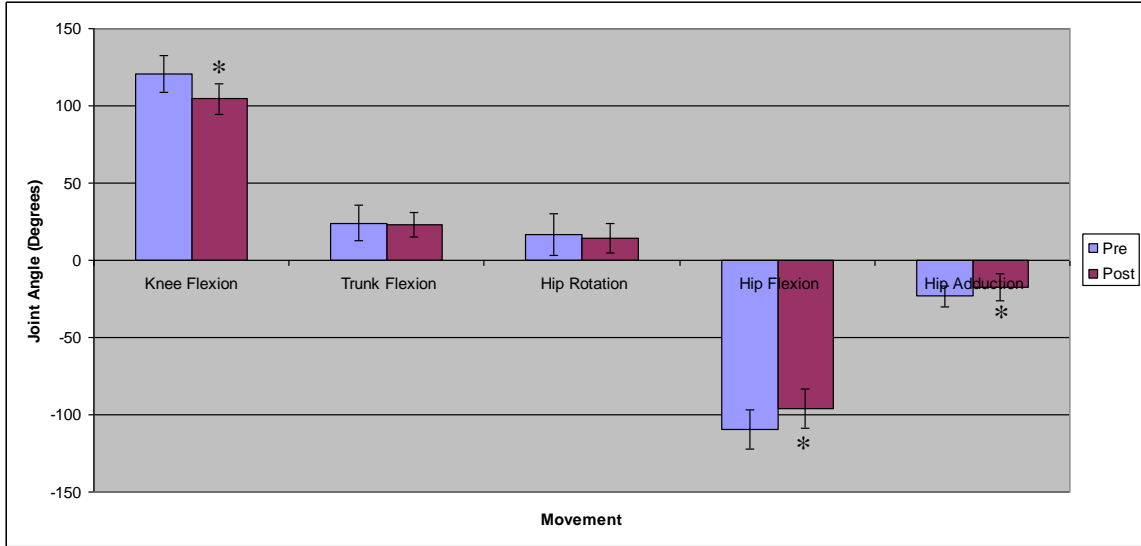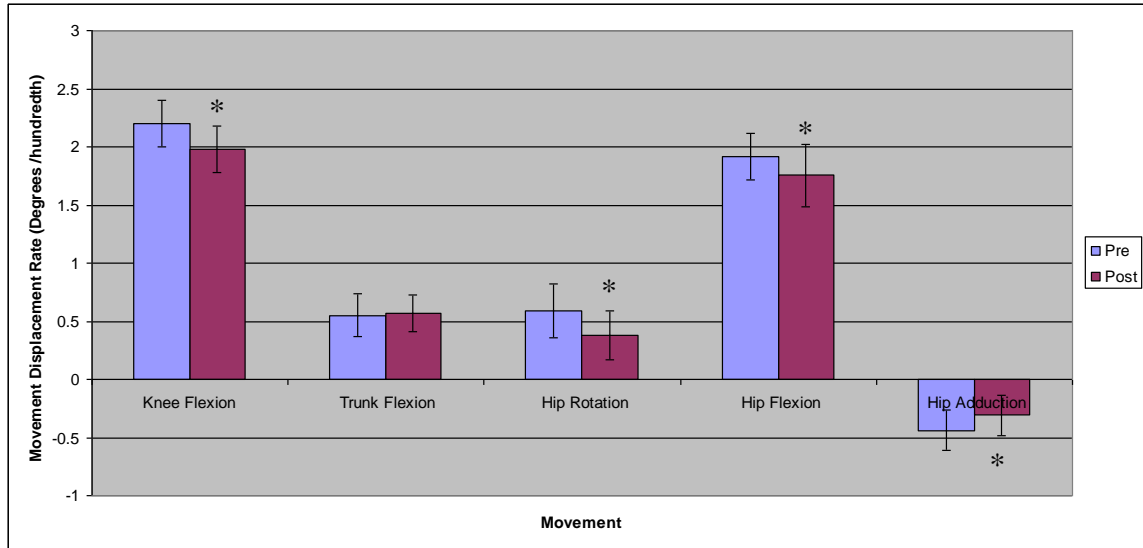
Figure 1. Average peak joint angles during body weight squat before and after a high intensity short rest workout.
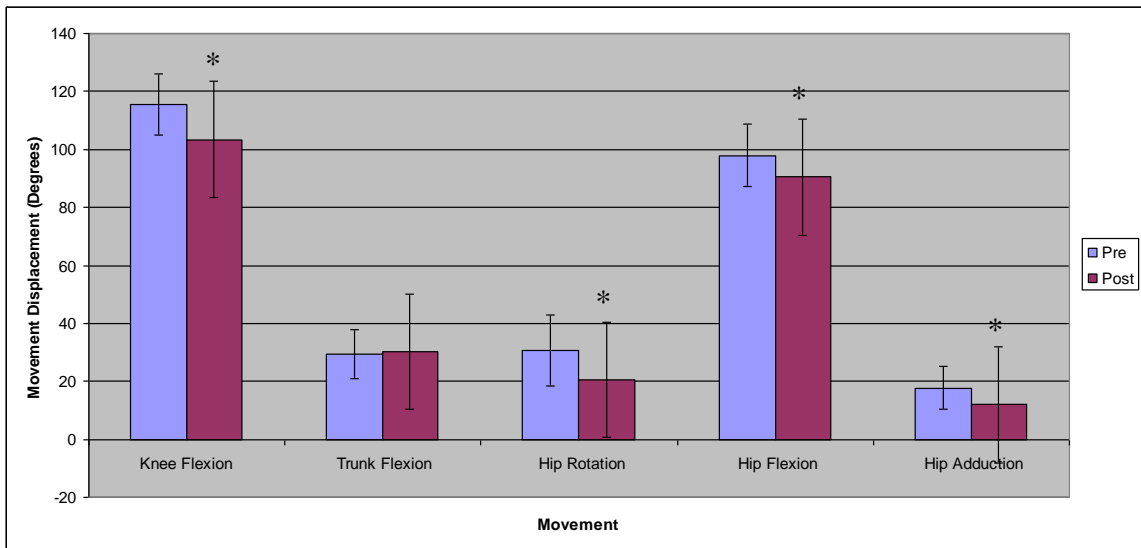
Figure 2. Average movement displacement during body weight squat before and after a high intensity short rest workout.

Figure 3. Movement displacement rate during body weight squat before and after a high intensity short rest workout.

Fatigue Contributions

Table 3. Average values for fatigue measures.

Subject	Lactate	RPE	%RM	Force Decline	Power Decline
1	15.07	8.3	62.5	372	321
2	14.88	9.4	70.1	131	300
3	16.52	8.6		510	539
4	13.71	8.2	67.3	225	718
5	11.77	8.7	72.5	191	446
6	16.48	6.5	66.3	455	841
7	9.88	4.4	69.3	369	1075
8	15.24	6.7	75	316	797
9	13.32	9.9	72	295	907
10	15.29	9.2	72	306	1114
11	11.73	6.3	69.2	364	515
12	17.30	8.8	71	221	328
13	17.15	6.3		1081	1159
14	15.81	5.3	71.5	163	892
Average	**14.58±2.23**	**7.61±1.68**	**69.89±3.31**	**357.07±235**	**710.86±303.45**

Discussion

The primary findings of this study are that resistance exercise fatigue leads to substantial alterations in exercise technique. As seen from figures 1-3, all of the changes seen in the squat movement after the HISR workout were an overall reduction in movement. Considering that subjects were given no instruction as to exactly how to perform the squat exercise, the changes seen can be attributed to the fatigue induced by the HISR workout. Reductions in movement after fatigue might be expected considering that the further the subject descends in to the squat, the more the lever arms extend and the greater the torque that is required to ascend back to the standing position. If a subject is fatigued, it would be reasonable to suggest that the subject would perform less movement and reduce the amount of force that they are required to produce during the squat. These changes in movement, however, could be detrimental as changes in athletic movements have been associated with injury [27].

Reducing the amount of force that the subject is required to produce might explain the changes in the sagittal plane movements (hip flexion, knee flexion) but there may also be an alternative explanation for the changes in the frontal plane, such as the increase in hip adduction (Figure 1). Hoy et al. [27] suggested that as hip flexion increases, there is an increase in the contribution of hip adductors to assist in hip extension. However, this study found that despite a decrease in hip flexion, surprisingly, an increase in hip adduction was still seen (Figure 1). This suggests that even though less hip flexion occurred, the subjects appeared to recruit hip adductors both to eccentrically control the descent of the squat as well as to produce the concentric force to ascend back the neutral

position. This would likely occur due the fatigue of the muscles that provided the movement in the sagittal plane during the HISR workout such as the hamstrings and gluteus maximus during the squat and deadlift.

An increase in hip adduction as seen in this study (Figure 1) has been associated with injury. Shultz and Schmitz [28] found increases in hip adduction and knee abduction to be associated with elevated risk of anterior cruciate ligament (ACL) injury. Furthermore, McLean et al. [29] found that increases in knee abduction during a sidestep cutting activity may be associated with elevated ACL injury risk. Although knee abduction was not specifically analyzed in this study, as previously mentioned it has been associated with hip adduction [28]. This study found increased hip adduction in the bodyweight squat movement, a much more simple task. As a result, it could be inferred that even greater changes in hip adduction might be seen in a cutting task after a HISR workout, suggesting another possible route to injury resulting from the fatigue associated with this type of workout.

When comparing the blood lactate concentrations from previous studies, it is clear that the HISR workout used in this study caused substantial fatigue. With the use of lighter loads (40-60% 1RM) but similarly short rest, Harber et al. [14] found average blood lactate concentrations of 13.87 mmol/L in previously untrained subjects. This study found comparatively higher blood lactate concentrations of 14.58 mmol/L in a subject population that has extensive resistance training experience. In a study comparing two volume controlled workouts, including 5RM loads with 3 minutes of rest and 10RM

loads with 1 minute rest, Kraemer et al. [2] observed blood lactate concentrations of 4.39 mmol/L and 8.61 mmol/L respectively in males. In another study by Kraemer et al. [11], a workout much more similar to the one used in this study, including 10RM loads with only 30 seconds rest periods produced blood lactate concentrations of over 21 mmol/L. In this study, trained bodybuilders were used with the workout designed to mimic their typical workout. Therefore, these results show that well trained individuals are able to physically tolerate even more demanding workouts than the one used in this study, emphasizing the importance of understanding the technique changes that occur in such workouts.

Whatever the measure used to assess fatigue, or the fatigue protocol, there consistently seems to be a change in movement after fatigue. Johnston et al. [15] and Miura et al. [16] both used a decline in the production of force as the measure of fatigue in their studies. Johnston et al. [15] found that after subjects were fatigued to the extent that they were only able to produce 50% of their initial force, subjects performance in several balance tests significantly declined, indicating a reduction in motor control. Although this study did not specifically assess motor control, if motor control is reduced with force reduction, one would expect to see changes in exercise technique. However, when the subjects in this study were split in to groups consisting of the highest force decline and the lowest force decline (Table 3), surprisingly, it was those with less force decline that showed the only significant changes in any technique variable, which was knee flexion.

With a different test used to assess the effects of fatigue, Miura et al. [16] found that the ability to reproduce knee angles while in a seated position was not significantly different despite subjects showing a significant reduction in the peak torque. After Miura et al. [16] found no change in proprioception, they suggested that a local load to the knee is not enough to induce dysfunction to the muscle mechanoreceptor. However, this would not explain why in this study those with less force decline did show significant changes in technique. Interestingly, Miura et al. [16] also observed the effects of 5 minutes of treadmill running at 10km/h and unlike after fatigue from the isokinetic dynamometer, subjects did show reduced proprioception after running. As a result, Miura et al. [16] concluded that the effects of fatigue on proprioception are more a central phenomenon rather local. This study did not make a distinction between local and general fatigue, but it would be reasonable to suggest that with the combination of heavy loads being lifted as well as being performed in a circuit fashion, that both types of fatigue were seen with this HISR workout.

Miura et al. [16] suggested that if proprioception is reduced after a short burst of anaerobic activity such as running, then observing indicators of fatigue such as blood lactic acid concentration might be beneficial. In this study, an interaction between peak knee flexion angle and blood lactate group (Tables 1 and 2) was found, suggesting that those who developed greater fatigue as shown by greater blood lactate concentrations saw significantly greater changes in peak knee flexion. These results lend support to the idea that it might be a central fatigue that is leading to reduced proprioception.

Also using a knee joint reproduction method of measuring proprioception, Lattanzio et al. [17] observed the effects of three different cycling protocols, with all three tests terminating at maximal exhaustion. Although these protocols differ considerably from the HISR workout, the authors did measure RPE which allows for a comparison with this study. Lattanzio et al. [17] reported mean RPE values of 9.2 and 9.6 for two of the three fatigue protocols (the value for the third protocol was not reported). This level of perceived exertion is even greater than that seen in this study, where subjects reported a mean RPE of 7.61 (Table 2). Lattanzio et al. [17] showed significantly reduced proprioception after all three fatigue tests. In this study, however, breaking the subjects down in to high and low RPE responders shows mixed results (Table 3). High RPE responders showed significant differences in knee flexion displacement as well as hip flexion displacement and rate. However, low RPE responders also showed significant differences, this time in knee flexion peak and displacement as well as hip rotation displacement. As a result, it appears the use of RPE exclusively to measure fatigue, especially in resistance training, is not a reliable indicator of the level of technique change.

Other studies have observed the effects of fatigue on technique change in box lifting tasks to observe the potential injury risk [19, 20]. After a protocol designed to fatigue the quadriceps both studies found an increase in trunk movement, which has been highlighted as a potential route to injury [21]. Although differences were found in variables in several movements (Figures 1-3), this study failed to find any differences in trunk flexion after a fatiguing protocol. This might be explained by the use of a

bodyweight squat as the method of assessment. In the aforementioned studies, the lifting technique was assessed while lifting a box, thus the subjects were required to carry a load in the front of the body. In a bodyweight squat task, there is no load for the trunk musculature to tolerate; therefore it is unsurprising that the trunk movement was not significantly different. In future studies, it would be necessary to analyze the squat movement with a load to improve the comparison to real life situations.

Although the specific movement effects of fatigue on the bodyweight squat have not been previously studied, changes in proprioception [16, 17], motor control [15] and jumping technique [18] have all been previously shown to result from fatigue. However, these studies all used contrasting fatigue protocols. Lattanzio et al. [17] used a variety of cycling protocols, Miura et al. [16] and Johnston et al. [15] used an isokinetic dynamometer, and McNeal et al. [18] used 60 seconds of repeated jumping. As well as all of these fatigue protocols differing significantly in physical demands, varying from cardiovascular exercise, to strength, to jumping, they also do not replicate a program of exercises that would be performed during a typical exercise regimen. By using common exercises such as the squat, bench press and deadlift and also performing the exercises in conventional repetitions ranges, the HISR protocol used was able to create a fatigue more specific to common practices. In addition to providing a more specific fatigue, the use of the bodyweight squat as the measure to analyze technique changes also provided a way of assessing the effects of fatigue in a real-life situation.

Conclusions/Practical Applications

When analyzing the movement of the bodyweight squat before and after a highly fatiguing resistance exercise protocol, it is clear that many of variables were significantly different, which could lead to an increased risk of injury. However, when subjects were broken down in to high and low levels of fatigue based on many interpretations of fatigue, it is possible that some individuals are able to tolerate such high levels of fatigue without significant alterations in technique. Finally, depending on how fatigue is assessed, fatigue may or may not lead to significant changes in exercise technique, emphasizing the need for clear definitions in the type of fatigue being assessed.

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