Title: Using squat testing to predict training loads for lower-body exercises in elite Karate athletes.

Running title: Squat prediction of training loads
Abstract

The purpose of this study was to determine the relationship between squat loads and 2 bilateral and 2 unilateral stepping lower-body exercises in predominantly unilateral movement elite athletes (Karate). Equations to predict loads for lower-body exercises based on the squat load were also determined. Fourteen male elite Karate athletes (age = 22.6 ± 1.2) performed 6 repetition maximum (RM) of the following free-weight bilateral exercises: back half squat, deadlift, leg press and unilateral stepping exercises; lunge and step-up. Results showed that 6 RM squat load was significantly ($p < 0.001$) correlated with deadlift ($r = 0.86$), leg press ($r = 0.76$), lunge ($r = 0.86$) and step-up ($r = 0.92$). Linear regression showed that the 6 RM squat load was a significant predictor for deadlift, leg press, lunge and step-up ($R^2$ range from 0.57 to 0.85, $p < 0.001$). The following 6 RM prediction equations were determined: a) Deadlift = squat load $(1.12) - 16.60$ kg, b) Leg press = squat load $(1.66) + 16.10$ kg, c) Lunge = squat load $(0.61) + 9.39$ kg, and d) Step-up = squat load $(0.85) - 10.36$ kg. Coaches and fitness professionals can use the 6 RM squat load as a time effective and accurate method to predict training loads for both bilateral and unilateral lower-body exercises with quadriceps as the prime mover. Load prescriptions for unilateral exercises should take into account the type of athletic population.

Keywords: load estimates, resistance, strength, unilateral, bilateral
INTRODUCTION

The squat is one of the most frequently prescribed exercises in high performance athletic training (12, 13, 15, 32). The multiple repetitions measurement in the back half squat has been found to be highly repeatable with an intra-class correlation coefficient of 0.95 (25), and is highly correlated with 1 repetition maximum (RM) values (r > 0.96) (23). In addition, previous studies have found that muscular strength in the back half squat had a high association with jump (38), sprint (38), power (4) and sport performance (28) in elite athletes. To prescribe strength training programs, the determination of exercise loads can be achieved objectively by calculating a percentage from the maximal strength represented by 1 RM, or subjectively by trial and error (13, 15, 32). The latter method can be employed but is inaccurate, varies between subjects, and does not conform to the guidelines of the National Strength and Conditioning Association (3, 15, 36).

The prediction of 1 RM from multiple repetitions measurement offers a practical advantage over 1 RM testing in that only core exercises that recruit large muscle groups and multiple joints are suggested for 1 RM measurement. In contrast, exercises such as the deadlift are not recommended because the weak stabilizing muscles of the lower back would become highly fatigued after several testing sets, and maintaining a correct body position throughout the test would be difficult (3). In addition, unilateral exercises such as lunges and step-ups place unequal loading on the limbs and are not
recommended for the 1 RM test (3). In this regard, the multiple repetitions measurement has an advantage over the 1 RM because the former measurement can be made on both the assistance and unilateral exercises (14, 23).

Ebben et al. (14) reported high explained variance between 6 RM loads of squat and other lower-body exercises ($R^2$ ranged from 0.62 to 0.81) among collegiate athletes and recreationally active students. However, Ebben et al. (14) suggested that the prediction equations from their study could only be generalized to similar populations. Karate for example, is a martial art that places emphasis on unilateral striking patterns. While 1 RM testing typically involves core exercises such as squat, bench press, cleans and other large muscle group bilateral activities, it is not known if the regression equations and correlations derived from Ebben’s study for collegiate and recreationally active individuals could specifically apply to elite athletes in whom unilateral actions are emphasized. Furthermore, Ebben’s results showed that the lowest correlations occurred between squats and unilateral actions such as lunges ($R^2 = 0.62$), step-ups ($R^2 = 0.71$) and single leg knee extensions ($R^2 = 0.67$). The greatest correlation occurred between the bilateral squat test and the bilateral deadlift test ($R^2 = 0.81$). Hence, Karate athletes with their unilateral striking emphasis may require substantially different correlation and regression equations between the 6 RM bilateral squat and unilateral actions such as the lunge and step-up.
Stability is a mitigating factor in the production of force during a resisted action. A number of studies report decreased force output in less stable conditions (5, 6, 10, 21, 22, 26). Lunges and step-ups are performed with unilateral stepping actions reducing the area of support and decreasing stability as compared to bilateral actions such as squats, leg presses and deadlifts with wider support bases. Behm et al. (8) reported a significant correlation between the maximum skating speed and static balance scores in young ice hockey players. Athletes who participate in team sports that emphasize stability such as ice hockey or in individual sports such as Karate that require great stability when kicking, striking or evading a blow, may express a different relationship between more stable resistance activities such as 6 RM squats and leg presses as compared to more unstable resisted activities such as lunges and step-ups.

The unique nature of Karate athletes who use unilateral striking actions under relatively unstable conditions suggests that previous prediction equations that were based upon individuals using predominately stable bilateral actions may not be appropriate for this type of population. Therefore the purpose of this study was to determine the relationship between 6 RM loads of bilateral and unilateral exercises such as the bilateral squat, deadlift and leg press versus the unilateral stepping actions of lunges and step-ups in a group of elite athletes (Karate) in whom the emphasis is
placed on stability and unilateral actions. It was hypothesized that significant

correlations exist between the bilateral squat and the unilateral stepping actions of the

lunge and the step-up and that these correlations would exceed the reported
correlations of collegiate and recreationally active individuals (11). This study also
aimed to create prediction equations, based on the squat load, to determine the loads
for lower-body exercises in these types of athletes (elite athletes with a unilateral
striking emphasis).

METHODS

Experimental Approach to the Problem

To test the hypothesis that a correlation exists between the 6 RM of squat and
other bilateral and unilateral low-body exercises, tests of deadlift, inclined leg press
(bilateral), lunge and step-up (unilateral stepping actions) capacity were undertaken.

Athletes performed five exercises in three visits separated by a 48-hour period. The
exercise order during the testing day was counterbalanced in order to limit exercise
order effect on performance (35). All athletes were instructed not to participate in
resistance training 48 hours before testing. The present exercises were selected
because these are frequently used in resistance training performed by high
performance elite athletes (12, 13, 15, 32) and could be quantified by external loads
The 6 RM was chosen in order to compare findings with those reported in a previous study (14). Furthermore, assistance type and unilateral exercises such as lunge and step-up are not commonly tested for 1 RM because the high external loading can place athletes at risk of injury (3). These exercises were included in this study since one of the objectives was to investigate if correlations between squats and unilateral type exercises were high in unilateral predominant athletes. The 6 RM squat load was the predictor variable of the other four exercises.

Subjects

Fourteen male elite Karate athletes participated in the study during the pre-competition preparation phase. All of these were national senior athletes from Malaysia, and three were world championship medalists. Their age, body mass, height, and body mass index are reported in Table 1. All athletes were properly informed of the experimental risks and benefits of this study and signed an informed consent document before the investigation. The study was conducted according to the Declaration of Helsinki, and the study was fully approved by the Clinical Research Ethics Committee.
Prior to any exercise in the first visit to the sport science laboratory, skinfold thickness was measured with a Harpenden skinfold caliper (British Indicators Ltd., UK) at 7 sites (biceps, triceps, subscapular, supraspinale, abdomen, front thigh, and medial calf) following the protocol recommended by International Society for Advancement of Kinanthropometry (24). Skinfolds in all athletes were taken by the same nutritionist trained in anthropometric measurements. Body density was determined according to the equation of Withers et al. (39), while the percentage body fat was calculated from body density using the Siri’s equation (33) (Table 1).

All athletes performed a 10 min warm-up including dynamic and static stretching. After the warm-up, athletes performed one warm-up set of 6 repetitions at ~ 65% to 75% of their perceived maximal load of each exercise. Athletes were familiar with the exercise technique as they regularly trained using these movements. Loads were assessed by having the athletes perform the 6 RM tests for the back half squat, bent-knee deadlift, lunge, step-up on a box (0.37 or 0.40m height depending on the athletes), and 45° inclined leg press (Figure 1). The techniques and guidelines of these exercises were described by the second author in this study and followed the instructions of National Strength and Conditioning Association (11). Athletes performed each exercise at their volitional velocity which was approximately 2s in both concentric and eccentric phases. All athletes attained at least six repetitions of
the 6 RM loads, and 4 min of recovery was allowed between exercises (14). Strong
verbal encouragement was given to each athlete during all test sessions. The second
author in this study, who is a Certified Strength and Conditioning Specialist (CSCS),
monitored all test sessions to ensure proper exercise technique and safety. Exercise
testing was performed over 3 days with 48 hours of recovery between testing. The
exercise order during the testing day was counterbalanced in order to limit exercise
order effect on performance (35).

**** insert Figure 1 about here ****

Statistical Analyses

Values are presented as mean ± SEM. Pearson’s product moment correlation
coefficient was used to examine the relationship between squat and the other four
exercises. Linear regression analysis was used to develop the prediction equations for
each of the four exercises with squat load being a predictor. The prediction equations
for each of the exercises were cross-validated using the predicted residual sum of
squares (PRESS) statistic, as previously recommended and described in the literature
(18). The significant level was defined as \( p \leq 0.05 \). Ten athletes were instructed to
perform the reliability test seven days after the initial tests. Intra-class correlation
coefficient (ICC) across tests showed that the 6 RM tests were highly repeatable (ICC
RESULTS

The 6 RM loads for the squat, deadlift, leg press, lunge and step-up are reported in Table 1. Results showed that 6 RM squat load was significantly correlated with the four lower-body exercises: deadlift ($r = 0.86, p < 0.001$), leg press ($r = 0.76, p < 0.001$), lunge ($r = 0.86, p < 0.001$) and step-up ($r = 0.92, p < 0.001$). In addition, linear regression (Figure 2) showed that 6 RM squat load was a significant ($p < 0.001$) predictor for the deadlift, leg press, lunge and step-up. The respective prediction equation was presented in Table 2. Results of the cross-validation procedure using the PRESS statistic indicated that the predicted and actual loads were similar (Table 2).

DISCUSSION

The first major finding in the present investigation was that high correlations existed between the 6 RM load of the bilateral squat and lower-body exercises (both bilateral and unilateral) in high performance Karate athletes who predominantly
perform unilateral movement (Table 1). The present study also found that the 6 RM squat load was a significant ($p < 0.001$) predictor for the deadlift, leg press, lunge and step-up (Figure 2). Moreover, linear regression equations were developed to determine the loads for the four lower-body exercises based on the squat load. Our results agreed with the findings reported by Ebben et al. (14) in that high explained variance ($R^2$) was observed between squat and the lower-body exercises (Figure 2). Ebben et al. (14) reported that the squat accounted for 81%, 62%, and 71% of variance for deadlift, lunge, and step-up, respectively. Furthermore, it has been previously reported that the squat accounts for 55% of the variance in leg press (36), a value that is in close agreement with that observed (57%) in the present study (Figure 2).

However, in contrast to the findings of Ebben et al. (11) in collegiate athletes and recreationally active students, the present elite Karate athletes had heavier predicted loads in the lunge (70.39 kg vs. 66.82 kg) and the step-up (74.64 kg vs. 53.32 kg). It therefore appears that elite Karate athletes demonstrate superior performance in these unilateral exercises. This finding could be explained by an emphasis in training on performing unilateral striking actions. Indeed during sparring/fighting, Karate athletes perform mainly unilateral single-leg actions such as frontal (i.e. mae-geri), lateral (i.e. yoko-geri) and circular (i.e. mawashi-geri) kicks that heavily challenge balance, core
muscles and single-leg muscle strength/power (9, 17, 19, 20, 30). Stronger trunk/core muscle groups are necessary during unilateral exercises in stabilizing the body (7) during Karate performance (1, 9, 16, 19, 29, 30, 37) and may have contributed to greater stability and force output during lunges and step-ups. Therefore, the 6 RM prediction equations must be specific to the population. For example, 6 RM may be under-estimated in elite unilateral-emphasis athletes when performing unilateral exercises and not induce a sufficient training effect while measures may be over-estimated in lower-level performers thereby increasing the risk of musculoskeletal injury.

Nevertheless, given the same 6 RM squat load, (e.g. 100 kg), these results showed that elite Karate athletes have a similar predicted load in a bilateral activity such as the deadlift as compared with collegiate and recreational athletes (95.40 kg vs. 97.92 kg) (14). Thus the high emphasis on stability or balance in Karate provides high correlations for both more (bilateral) and less (unilateral) stable resisted activities.

Leg extensions which are open kinetic chain exercise (31) were used by Ebben et al. (11) to examine the prediction ability of 6 RM squat loads, whereas in the present study, a leg press was employed. Leg extension has been reported to induce higher shear force at the knee joint which stresses the anterior cruciate ligament (ACL) (31). Moreover, a higher proportion of motor unit synchronization has been observed
between vastus medialis obliquus (VMO) and vastus lateralis in exercises such as the leg press, indicating better coordination within the quadriceps (27, 34), and greater improvements in muscular strength and functional performance (2, 40).

Finally, the measurements of the present study were performed in Karate athletes. The present results may not be representative of other high performance athletic groups and additional work on the use of squat testing to predict training loads for lower-body exercises is therefore necessary.

PRACTICAL APPLICATION

Previous studies have shown that some strength and conditioning coaches prescribe training loads for their high performance elite athletes via the subjective trial and error method due to limited time allocated to training/testing (13, 15, 32). However, this method is inaccurate and does not conform to the guidelines of National Strength and Conditioning Association (3). The squat is a major core strengthening exercise performed by elite athletes (12, 13, 15, 32), but other forms of lower-body exercises with quadriceps as the prime mover induce different training effects on quadriceps, hamstrings and gluteus muscles. The results of the present study demonstrate that coaches and fitness professionals when calculating 6 RM loads for unilateral type exercises such as lunges and step-ups should be cognizant of the
type of athlete involved. Previously published predictions of 6 RM loads for lunges
and step-ups based on collegiate and recreational athletes (11) were substantially
lower than the loads predicted in the present study in elite athletes who predominantly
use unilateral movements. Thus the use of these equations has to be specific to the
individual athletic population, otherwise loads could be either under-estimated in elite
athletes and not induce a sufficient training effect, or over-estimated in collegiate and
recreational athletes increasing the risk of musculoskeletal injury. Karate and other
martial art coaches and athletes should consider using these simple prediction
equations when prescribing resistance training exercises in order to reduce training
and testing time and ensure sufficient training effects.
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Figure Legend:

Figure 1. Illustration of starting position (90 degree at knee joint) during the 45 degree inclined leg press.

Figure 2. Linear regression of the deadlift, leg press, lunge, and step-up using the squat as a predictor.