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

2 Karate athletes.

3 Running title: Squat prediction of training loads

4

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

(14). 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.

Measurements

121 Prior to any exercise in the first visit to the sport science laboratory, skinfold
122 thickness was measured with a Harpenden skinfold caliper (British Indicators Ltd.,
123 UK) at 7 sites (biceps, triceps, subscapular, supraspinale, abdomen, front thigh, and
124 medial calf) following the protocol recommended by International Society for
125 Advancement of Kinanthopometry (24). Skinfolds in all athletes were taken by the
126 same nutritionist trained in anthropometric measurements. Body density was
127 determined according to the equation of Withers et al. (39), while the percentage body
128 fat was calculated from body density using the Siri's equation (33) (Table 1).
129 All athletes performed a 10 min warm-up including dynamic and static stretching.
130 After the warm-up, athletes performed one warm-up set of 6 repetitions at ~ 65% to
131 75% of their perceived maximal load of each exercise. Athletes were familiar with the
132 exercise technique as they regularly trained using these movements. Loads were
133 assessed by having the athletes perform the 6 RM tests for the back half squat,
134 bent-knee deadlift, lunge, step-up on a box (0.37 or 0.40m height depending on the
135 athletes), and 45^0 inclined leg press (Figure 1). The techniques and guidelines of these
136 exercises were described by the second author in this study and followed the
137 instructions of National Strength and Conditioning Association (11). Athletes
138 performed each exercise at their volitional velocity which was approximately 2s in
139 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

159 > 0.95).

160 RESULTS

161 The 6 RM loads for the squat, deadlift, leg press, lunge and step-up are reported
162 in Table 1. Results showed that 6 RM squat load was significantly correlated with the
163 four lower-body exercises: deadlift (r = 0.86, $p < 0.001$), leg press (r = 0.76, $p <$
164 0.001), lunge (r = 0.86, $p < 0.001$) and step-up (r = 0.92, $p < 0.001$). In addition, linear
165 regression (Figure 2) showed that 6 RM squat load was a significant ($p < 0.001$)
166 predictor for the deadlift, leg press, lunge and step-up. The respective prediction
167 equation was presented in Table 2. Results of the cross-validation procedure using the
168 PRESS statistic indicated that the predicted and actual loads were similar (Table 2).

169

170 **** insert Table 1 about here ****

171 ****insert Table 2 about here****

172 **** insert Figure 2 about here ****

173

174 DISCUSSION

175 The first major finding in the present investigation was that high correlations
176 existed between the 6 RM load of the bilateral squat and lower-body exercises (both
177 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.

246 REFERENCES

247 1. Anderson, K, and Behm, DG. Trunk muscle activity increases with unstable squat
248 movements. *Can J Appl Physiol* 30(1): 33-45, 2005.
249 2. Augustsson, J, Esko, A, Thomee, R, and Svantesson, U. Weight training of the thigh
250 muscles using closed vs. open kinetic chain exercises: a comparison of
251 performance enhancement. *J Orthop Sports Phys Ther* 27(1): 3-8, 1998.
252 3. Baechle, TR, Earle, RW, and Wathen, D. Resistance training. In: Essentials of
253 Strength Training and Conditioning. Baechel, TR, and Earle, RW, eds. 3rd ed.
254 Champaign, USA: Human Kinetics, 2008. pp. 381-412.
255 4. Baker, D, and Nance, S. The relation between strength and power in professional
256 rugby league players. *J Strength Cond Res* 13(3): 224-229, 1999.
257 5. Behm, DG, and Anderson, K. The Role of Instability with Resistance Training. *J*
258 *Strength Cond Res* 20: 716-722, 2006.
259 6. Behm, DG, Anderson, K, and Curnew, RS. Muscle force and activation under stable
260 and unstable conditions. *J Strength Cond Res* 16: 416-422, 2002.
261 7. Behm, DG, Power, KE, and Drinkwater, EJ. Muscle activation is enhanced with
262 multi- and uni-articular bilateral versus unilateral contractions. *Can J Appl*
263 *Physiol* 28: 38-52, 2003.
264 8. Behm, DG, Wahl, MJ, Button, DC, Power, KE, and Anderson, KG. Relationship

265 between hockey skating speed and selected performance measures. *J Strength*
266 *Cond Res* 19: 326-331, 2005.
267 9. Cesari, P, and Bertucco, M. Coupling between punch efficacy and body stability for
268 elite karate. *J Sci Med Sport* 11(3): 353-356, 2008.
269 10. Drinkwater, EJ, Pritchett, E, and Behm, DG. Effect of Instability and Resistance
270 on Unintentional Squat Lifting Kinetics. *Int J Sports Physiol Perform* 2:
271 400-413, 2007.
272 11. Earle, RW, and Baechle, TR. Resistance training and spotting techniques. In:
273 Essentials of Strength Training and Conditioning. Baechel, TR, and Earle, RW,
274 eds. 3rd ed. Champaign, USA: Human Kinetics, 2008. pp. 325-376.
275 12. Ebben, WP, and Blackard, DO. Strength and conditioning practices of National
276 Football League strength and conditioning coaches. *J Strength Cond Res* 15(1):
277 48-58, 2001.
278 13. Ebben, WP, Carroll, RM, and Simenz, CJ. Strength and conditioning practices of
279 National Hockey League strength and conditioning coaches. *J Strength Cond*
280 *Res* 18(4): 889-897, 2004.
281 14. Ebben, WP, Feldmann, CR, Dayne, A, Mitsche, D, Chmielewski, LM, Alexander,
282 P, and Knetgzer, KJ. Using squat testing to predict training loads for the
283 deadlift, lunge, step-up, and leg extension exercises. *J Strength Cond Res*

22(6): 1947-1949, 2008.

15. Ebben, WP, Hintz, MJ, and Simenz, CJ. Strength and conditioning practices of major league baseball strength and conditioning coaches. *J Strength Cond Res* 19(3): 538-546, 2005.

16. Ekstrom, RA, Donatelli, RA, and Carp, KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther* 37(12): 754-762, 2007.

17. Hibbs, AE, Thompson, KG, French, D, Wrigley, A, and Spears, I. Optimizing performance by improving core stability and core strength. *Sports Med* 38(12): 995-1008, 2008.

18. Holidays, D, Ballard, JE, and Mckeown, BC. PRESS-related statistics: regression tools for cross validation and case diagnosis. *Med Sci Sports Exerc* 27: 612-620, 1995.

19. Iide, K, Imamura, H, Yoshimura, Y, Yamashita, A, Miyahara, K, Miyamoto, N, and Moriwaki, C. Physiological responses of simulated karate sparring matches in young men and boys. *J Strength Cond Res* 22(3): 839-844, 2008.

20. Kibler, WB, Press, J, and Sciascia, A. The role of core stability in athletic function. *Sports Med* 36(3): 189-198, 2006.

21. Kornecki, S, and Zschorlich, V. The nature of stabilizing functions of skeletal

303 muscles. *J Biomech* 27: 215-225, 1994.

304 22. Koshida, S, Urabe, Y, Miyashita, K, Iwai, K, and Kagimori, A. Muscular outputs
305 during dynamic bench press under stable versus unstable conditions. *J*
306 *Strength Cond Res* 22: 1584-1588, 2008.

307 23. LeSuer, DA, McCormick, JH, Mayhew, JL, Wasserstein, RL, and Arnold, MD.
308 The accuracy of prediction equations for estimating 1-RM performance in the
309 bench press, squat, and deadlift. *J Strength Cond Res* 11(4): 211-213, 1997.

310 24. Marfell-Jones, M, Olds, T, Stewart, A, and Carter, L. *International standards for*
311 *anthropometric assessment.* ISAK: Potchefstroom, South Africa, 2006.

312 25. Marques, MC, Tillar, R, Vescovi, JD, and Gonzalez-Badillo, JJ. Changes in
313 strength and power performance in elite senior female professional volleyball
314 players during the in-season: a case study. *J Strength Cond Res* 22(4):
315 1147-1155, 2008.

316 26. McBride, J, Cormie, P, and Deane, R. Isometric squat force output and muscle
317 activity in stable and unstable conditions. *J Strength Cond Res* 20: 915-918,
318 2006.

319 27. Mellor, R, and Hodges, PW. Motor unit synchronization of the vasti muscles in
320 closed and open chain tasks. *Arch Phys Med Rehabil* 86(4): 716-721, 2005.

321 28. Rahmani, A, Viale, F, Dalleau, G, and Lacour, JR. Force/velocity and

power/velocity relationships in squat exercise. *Eur J Appl Physiol* 84(3): 227-232, 2001.

29. Ravier, G, Dugué, B, Grappe, F, and Rouillon, JD. Impressive anaerobic adaptations in elite karate athletes due to few intensive intermittent sessions added to regular karate training. *Scand J Med Sci Sports* 19(5): 687-694., 2009.

30. Ravier, G, Grappe, F, and Rouillon, JD. Application of force-velocity cycle ergometer test and vertical jump tests in the functional assessment of karate competitor. *J Sports Med Phys Fitness* 44(4): 349-355, 2004.

31. Ross, MD, Denegar, CR, and Winzenried, JA. Implementation of open and closed kinetic chain quadriceps strengthening exercises after anterior cruciate ligament reconstruction. *J Strength Cond Res* 15(4): 466-473, 2001.

32. Simenz, CJ, Dugan, CA, and Ebben, WP. Strength and conditioning practices of National Basketball Association strength and conditioning coaches. *J Strength Cond Res* 19(3): 495-504, 2005.

33. Siri, WE. Body composition from fluid spaces and density: analysis of methods. In: Techniques for measuring body composition. Brozek, J, and Henshel, A, eds. Washington, USA: National Academy of Science, 1961. pp. 223-244.

34. Stensdotter, AK, Hodges, PW, Mellor, R, Sundelin, G, and Hager-Ross, C.

341 Quadriceps activation in closed and in open kinetic chain exercise. *Med Sci*
342 *Sports Exerc* 35(12): 2043-2047, 2003.
343 35. Thomas, JR, Nelson, JK, and Silverman, J. *Research methods in physical activity*.
344 5th ed. Champaign, IL.: Human Kinetics, 2005.
345 36. Willardson, JM, and Bressel, E. Predicting a 10 repetition maximum for the free
346 weight parallel squat using the 45 degrees angled leg press. *J Strength Cond*
347 *Res* 18(3): 567-571, 2004.
348 37. Willson, JD, Dougherty, CP, Ireland, ML, and Davis, IM. Core stability and its
349 relationship to lower extremity function and injury. *J Am Acad Orthop Surg*
350 13(5): 316-325, 2005.
351 38. Wisloff, U, Castagna, C, Helgerud, J, Jones, R, and Hoff, J. Strong correlation of
352 maximal squat strength with sprint performance and vertical jump height in
353 elite soccer players. *Br J Sports Med* 38(3): 285-288, 2004.
354 39. Withers, RT, Craig, NP, Bourdon, PC, and Norton, KI. Relative body fat and
355 anthropometric prediction of body density of male athletes *Eur J Appl Physiol*
356 56(2): 191-200, 1986.
357 40. Witvrouw, E, Lysens, R, Bellemans, J, Peers, K, and Vanderstraeten, G. Open
358 versus closed kinetic chain exercises for patellofemoral pain. A prospective,
359 randomized study. *Am J Sports Med* 28(5): 687-694, 2000.
360

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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.