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METHODOLOGICAL CONSIDERATIONS FOR THE DETERMINATION OF THE CRITICAL RESISTANCE FOR THE DEADLIFT

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METHODOLOGICAL CONSIDERATIONS FOR THE DETERMINATION OF THE CRITICAL RESISTANCE FOR THE DEADLIFT

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Education
at the University of Kentucky

By

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ABSTRACT OF THESIS

METHODOLOGICAL CONSIDERATIONS FOR THE DETERMINATION OF THE CRITICAL RESISTANCE FOR THE DEADLIFT

This study determined if plate movement during conventional deadlifting affects critical resistance (CR) estimates derived from the linear work limit (W_{lim}) versus repetitions relationship. Eleven subjects completed 1-repetition maximum (1RM) deadlift testing followed by 8 visits, to determine the number of repetitions to failure at 50%, 60%, 70%, and 80% 1RM for both reset (RS) and touch-and-go (TG) methods, respectively. The CR was calculated as slope of the line of total work completed (repetitions × load [in kilograms]) versus total repetitions for each of four intensities (50-80% 1RM). The number of repetitions to failure were determined at CR_{RS} and CR_{TG}. The kg values and repetitions to failure at CR_{RS} and CR_{TG}, as well as total repetitions at each intensity (50-80%) for each method (RS and TG) were compared using paired-samples t-tests and simple linear regression. There were no significant mean differences in kg values (mean difference = -0.4 ± 7.9 kg, $p = 0.856$, 95% CI = -5.8 – 4.9 kg, $d = -0.028$), %1RM (mean difference = -1.2% ± 5.6%, $p = 0.510$, 95% CI = -4.9 – 2.6%, $d = -0.234$), or total repetitions completed (mean difference = 2.8 ± 15.7 reps, $p = 0.565$, 95% CI = -7.7 – 13.4, $d = 0.188$) for CR_{RS} and CR_{TG}. There was a significant correlation between CR_{RS} and CR_{TG} kg resistance ($r = 0.888$, $p < 0.001$). These findings indicated that plate movement did not affect mean estimation of CR or number of repetitions completed at submaximal loads. Thus, the estimates of CR from the modeling of total work versus repetitions were relatively robust to variations in deadlifting methodologies. However, individual variability (wide range in difference scores) in kg values and repetition to failure at CR_{RS} and CR_{TG} indicated that deadlifting methods may differ in anatomical region of fatigue.

KEYWORDS: critical resistance, resistance training to failure, repetitions to failure, deadlift, muscle endurance

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CHAPTER 1. INTRODUCTION

Monod and Scherrer (1965) defined critical power (CP) (critical force [CF]) as a quantification of work a muscle can execute prior to fatigue during dynamic, isometric, and intermittent isometric muscle actions. The CP and CF were derived from the linear relationship between the total work (W_{lim}) and the maximal time (T_{lim}) until the onset of muscular exhaustion at a given power output (P) for a series of 3 to 4 work bouts. The slope of this W_{lim} versus T_{lim} relationship was defined as CP, and the y-intercept was termed the anaerobic work capacity (AWC). The AWC denotes the total amount of work that can be accomplished utilizing only stored energy reserves within the muscle (33). The CP is equivalent to the asymptote of the hyperbolic P versus T_{lim} relationship (33).

Moritani et al. (1981) applied the CP concept of Monod and Scherrer (1965) to whole body cycle ergometry exercise and identified the same linear relationship between the W_{lim} vs. T_{lim}. Experimental results indicated there were significant correlations between the gas exchange threshold (GET), $\dot{V}O_2$max, and CP (r = 0.907 – 0.927). In addition, CP was reduced under hypoxia, but AWC was not affected (34). Based on these findings, the researchers concluded that CP is dependent on oxygen supply and AWC reflects a finite energy reserve that includes the ATP bound to the myosin heads, phosphocreatine, and muscle glycogen stores (34). Furthermore, it was determined that the T_{lim} at any P above CP could be estimated from the CP test parameters using the hyperbolic P versus T_{lim} curve (34).

The CP and AWC parameters have several applications including prescriptions for intermittent high-intensity and endurance exercise training programs (5,37,38). One of the primary applications of CP is the demarcation of exercise intensity domains (5,37,38). There are three distinct exercise intensity domains, moderate, heavy, and severe. Exercise within each domain results in specific acute physiological responses (24). Previous studies (5,37,38) have suggested that CP defines the upper boundary of the heavy intensity domain and represents the highest sustainable power output where $\dot{V}O_2$ and blood lactate responses reach a steady state. Above CP (severe intensity exercise) exhaustion occurs within 20 minutes and is characterized by $\dot{V}O_2$ responses equal to $\dot{V}O_2$max and a blood lactate concentration that increases to exhaustion. Thus, CP is described as the highest metabolic rate associated with ‘wholly-oxidative’ energy provision (37,38). ‘Wholly-oxidative’ refers to when the body’s energy supply is met through substrate-level phosphorylation with a steady state response, and there is no increasing buildup of blood lactate or breakdown of intramuscular phosphocreatine (PC). Therefore, at or below CP, the rate of lactate production in active muscle is matched by its rate of clearance in muscle and other tissues (37). Also, CP coincides with other measures of intramuscular homeostasis like the maintenance of blood pH level and bicarbonate, as well as, correspondence with no significant increase in pulmonary $\dot{V}O_2$ and ventilation (37,38). Thus, CP is described as the demarcation of heavy from severe exercise intensities (13,26,27,37).

The CP model has been applied to other modes of dynamic exercise like rowing (11) and swimming (41,45). In addition, several mathematical models have been examined to derive the CP and AWC parameters. Gaessar et al. (1995) compared estimates of critical power CP and AWC among five different models: t = AWC / (Pmax-CP) (two-parameter nonlinear); t = (AWC / (P – CP)) - (AWC / (Pmax - CP)) (three-parameter nonlinear); $P \cdot t = AWC + (CP*T)$ (linear ($P \cdot t$)); $P = (AWC/t) + CP$ (linear (P)); $P = CP + (Pmax-CP)\exp(-t/\tau)$ (exponential). The results indicated that although all the equations were significantly correlated ($r = 0.78$ through 0.99), the three-parameter model may provide the most reasonable estimate of AWC and CP (17).

Recently, Morton et al. (2014) applied the three-parameter CP model to the resistance exercise of bench press. Morton et al. (2014) tested the equation $N= ALC/(m - CL) + ALC/(CL - L_{max})$, where N is the number of reps to failure, m is the sub-maximal weight lifted (kg), ALC is the anaerobic lift capacity (kg), CL is the critical lift (the maximal continuous aerobic ability at bench pressing, kg), and L_{max} is the maximal 'instantaneous' lift (kg). The authors found that the 3-parameter critical power model provided a good fit for the relationship between the recorded reps to failure and weight lifted for most subjects ($r^2 = 0.956 - 0.999$). For 12 out of 16 subjects, however, the CL values were reported to equal zero kg. The researchers attributed this to the brevity of the sessions and the aerobic component of the bench press exercise being negligible. A single, fixed cadence of three seconds was used but researchers suggested that future studies should examine the determination of a more suitable cadence, as well as, the application of the equation to other exercises. The investigators did suggest, however, the three-parameter CP model could be applied accurately to the bench press (35).

Based on previous applications of the CP model (11,35,41), a more reliable and valid parameter is needed to measure the true amount of work that a subject can perform before exhaustion; especially, in the mode of resistance exercise. The identification of a CL or critical resistance (CR) may allow researchers to identify intensity domains for resistance exercise that are defined by specific physiological responses. In addition, although the 3-parameter model has been previously applied to resistance exercise, the complex mathematical modeling compared to linear models, may reduce its applicability. Recently (15), the CR has been derived from a linear model that relates the total work completed (resistance [kg] x distance [m] x repetitions) (W_{lim}) and the total distance that a barbell is moved vertically (TVDM) for the deadlift. The CR was defined as the slope of the W_{lim} vs TVDM relationship. Theoretically, the CR provides an estimate of the highest sustainable resistance and has been hypothesized to reflect the point where blood flow becomes compromised during Dynamic Constant External Resistance Training (DCER) exercise.

The deadlift and its variations are widely accepted by strength and conditioning coaches as one of the “big three” exercises prescribed to develop total body strength, specifically the hip and knee extensors, spinal erectors, quadratus lumborum, core abdominal musculature, back, and forearm muscles (4). However, while there are several reports addressing correct teaching technique of the deadlift (4,16,20,22,36), the exercise has notoriously been loosely defined (20,36). Typically, the term “deadlift” is associated with two broad categories: the conventional deadlift (CD) and non- conventional styles (i.e., sumo) (4). The CD is characterized by a starting position of placing the feet approximately shoulder width apart, toes pointed slightly outward, with the balls of the feet directly under the bar (16). However, there may be evidence to support breaking the CD category down into several other subcategories. Beckham et al. (2012) cited that force generation increases as the height of the bar increases for the CD. Komph and Arandielovic (2016) observed that “sticking points” exist in the CD where the bar is at its lowest point. The authors (28) defined a “sticking point” as the part of the range of motion (ROM) in a resistance exercise in which a disproportionately large increase in the difficulty associated with continuing the lift is experienced. In the CD specifically, one suggestion from these studies was for lifters to bounce the plates off the ground slightly to "overcome the sticking point" (29). It is possible, plate movement may be acting as a confounding variable. To account for this possible influence, two new subcategories of CD must be defined: the reset (RS) and the touch-and-go (TG). The RS method refers to the lifter allowing the barbell to come to a complete rest on the floor between repetitions for a defined period of time (e.g., 1 second). The TG method refers to the process whereby the lifter touches the weight plates of the barbell to the ground but does not allow the plates to fully come to rest after the downward movement phase, and immediately performs another repetition through the upward movement phase. Thus, there are two unique subcategories of the CD (or unconventional deadlift), the RS and TG, which may result in different performance capabilities for repetitions performed to failure. Currently, it is unknown how the plate movement method of assessment (RS versus TG) may affect the number of repetitions to failure and if this alters the CR estimates. Therefore, the primary purpose of the current study was to determine if the plate movement technique (RS and TG) utilized during the CD affects estimates of the CR derived from the linear W_{lim} versus repetitions relationship. It was hypothesized that the TG method of CD would elicit a higher CR than the RS method.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Development of the Critical Power Model

Monod & Scherrer (33)

This investigation pioneered the idea of critical power (CP) as the maximum amount of static and dynamic muscular work without exhaustion. This was based on the parameters of maximum work and maximum time of work. This preceded the cycle ergometer testing and instead used dynamic, isometric, and intermittent isometric muscle actions to determine CP and critical force (CF) to quantify the amount of work a muscle or synergistic muscle group could perform before exhaustion. The time to exhaustion or limit time to exhaustion (T_{lim}) at a given power output (P) was recorded. The amount of work performed to exhaustion was defined as the work limit (W_{lim}) through the equation $W_{lim} = P \times T_{lim}$. The linear relationship between W_{lim} versus T_{lim} produces two parameters: CP (slope) and anaerobic work capacity (AWC) (y-intercept). AWC was thought to result from the use of an energy reserve (a) and CP was the maximal rate of energy reconstitution (b). This relationship was expressed by the equation: $W_{lim} = a + bT_{lim}$. Overall, the results were that the CP can be theoretically defined as the highest P that can be sustained over time without exhaustion. The asymptote of the hyperbolic P versus T_{lim} relationship also corresponds with the CP value. Thus, three parameters were defined from this study: AWC, CP, and estimated T_{lim} at any power output above CP.

Moritani et al. (34)

This study applied the critical power (CP) concept to whole-body cycle ergometry exercise. Sixteen subjects (eight males and eight females) performed a graded exercise test on an electrically braked cycle ergometer to assess $\dot{V}O_2$max and to identify the anaerobic threshold (AT). Three workbouts at a constant cadence were performed to calculate CP. Then, the total amount of work for each power output (W_{lim}) was plotted against time to exhaustion (T_{lim}) to compare the relationship between the two. A regression analysis showed linearity of individual plots to be $0.982 < R^2 < 0.998$ ($p < 0.01$). The W_{lim} versus T_{lim} relationship was highly linear ($r > 0.98$) and was used to define CP (slope) and the anaerobic work capacity (AWC = y-intercept). The $\dot{V}O_2$max was found to be significantly correlated with CP ($r = 0.919$), and $\dot{V}O_2$ at CP was correlated to $\dot{V}O_2$ at AT ($r = 0.927$). From previous studies (33), W_{lim} was thought to be the sum of energy reserve use and maximal rate of energy reconstitution. The results indicated that the maximal energy reconstitution rate was highly correlated with anaerobic threshold (AT) ($r = 0.928$, $p < 0.01$). The sum of energy reserve and maximal rate of energy reconstitution was found to be highly correlated with $\dot{V}O_2$max ($r = 0.956$, $p < 0.001$). The regression equation: $\dot{V}O_2$max (1/min) = 0.00795 x [energy reserve + maximal rate of energy reconstitution] + 0.114 could be used to predict $\dot{V}O_2$max. Two important equations related to the power-duration relationship were identified from this study: $P(T_{lim}) = AWC + CP(T_{lim})$ and $T_{lim} = AWC/(P - CP)$.

Burnley et al. (7)

The objective for this investigation was to test the reliability and validity of the three-minute all-out cycle ergometry test in its determination of the peak oxygen uptake ($\dot{V}O_2$peak) and estimation of the maximal steady-state power output. Eleven recreationally active subjects (nine male, mean ± SD: age 27 ± 7 years; height 1.76 ± 0.10 m; body mass 68.4 ± 12.0 kg) performed a ramp test, three 3-min all-out tests against a fixed resistance, and two submaximal tests lasting up to 30 minutes at 15 Watts (W) below or above the power output attained in the last 30 seconds of the 3-min test (the end-test power). These tests were all completed on an electronically braked cycle ergometer. The pedaling resistance was set using the linear factor of the ergometer (linear factor = power/cadence^2). The power output was 50%Δ of the difference between gas exchange threshold (GET) and $\dot{V}O_2$peak (GET + 50% Δ; where Δ is the magnitude of the interval between GET and $\dot{V}O_2$ peak). The cadence for the formula was the subjects' preferred cadence (80-90 rev·min^{-1}) recorded during the ramp test. The results indicated the $\dot{V}O_2$peak for the 3-min all-out test (mean ± SD = 3.78 ± 0.68 L·min^{-1}) was not significantly different from that of the ramp test (3.84 ± 0.79 L·min^{-1}; $P = 0.75$). The power at the end of the 3-min all-out test (257 ± 49 W) was significantly lower than the power at the end of the ramp test (368 ± 73 W) and significantly higher than that at the GET (169 ± 55 W; $P < 0.001$). Nine of the subjects completed 30 minutes of exercise at 15 W below the end-test power. None of the subjects completed the 30 minutes at 15 W above the end-test power. Blood lactate and $\dot{V}O_2$, for these subjects, rose until exhaustion; which occurred in approximately 13 ± 7 minutes. The conclusions were that a three-minute all-out cycle ergometer test can elicit $\dot{V}O_2$peak, and a single workbout test may be used as a reproducible measure of the maximal steady-state power output.

Bergstrom et al. (2)

The purpose of this study was to introduce a potential new method for determining the critical power (CP) and anaerobic work capacity (AWC) estimations through a single three-minute workbout instead of multiple workbouts lasting approximately 30 minutes. Critical Power is traditionally estimated through cycle ergometry testing of multiple workbouts. This is very time consuming and is extremely strenuous. For this study, twelve moderately trained adults (6 male and 6 female) performed rides to exhaustion on Monark cycle ergometers. CP and AWC were assessed in four different ways. First, the parameters were projected using the traditional method of the work limit (W_{lim}) versus limit time (T_{lim}) relationship (CP_{PT}). The next methods were a 3-minute all-out test (CP_{3min}) with constant resistance and two new 3-min tests that used a resistance of 3.5% and 4.5% of the subject's body weight (kg), respectively ($CP_{3.5\%}$ and $CP_{4.5\%}$). The four methods (CP_{PT}, CP_{3min}, $CP_{3.5\%}$ and $CP_{4.5\%}$) were then compared using separate one-way repeated measures ANOVAs and follow-up Bonferroni corrected paired samples t-tests showing no significant mean differences between CP_{PT} (178 ± 47 W), $CP_{3.5\%}$ (173 ± 40 W), and $CP_{4.5\%}$ (186 ± 44). However, the CP_{3min} mean (193 ± 54 W) was significantly greater than those of CP_{PT} and $CP_{3.5\%}$. All methods were highly inter-correlated at 0.90 – 0.97. For AWC, there were no significant mean differences between the CP_{PT} (13,412 ± 6,247 J), CP_{3min} (10,895 ± 2,923 J), and $CP_{4.5\%}$ (9842 ± 4394 J). The CP_{PT} and CP_{3min} AWC values were significantly greater than $CP_{3.5\%}$ (8,357 ± 2,946J). Also, all methods showed high inter-correlation at 0.76 – 0.91 for AWC values. Furthermore, the $CP_{4.5\%}$ method was shown to accurately assess CP, but the $CP_{3.5\%}$ did not do so accurately. These results suggested that a resistance of 4.5% body weight could be used to accurately assess CP and AWC on the Monark cycle ergometer.

Summary:

The articles in this section describe the development of the mathematic model used to identify two separate parameters, critical power (CP) and anaerobic work capacity (AWC). Critical power can be defined as the maximum power output that can be maintained indefinitely without exhaustion (2,33,34). The AWC is described as the power output above CP that is derived from muscular energy reserves and independent of oxygen supply (2,33,34). These studies outlined the evolution of the CP test from the measurement of CP and AWC in isometric and intermittent isometric of local muscle groups to total body dynamic cycle ergometry (33,34).

Furthermore, these investigations proposed that the parameters work limit (W_{lim}) and time to exhaustion (T_{lim}) exhibit a highly linear relationship (r=0.98). This relationship is described by the equation $W_{lim} = a + b(T_{lim})$. The slope (b) represents the CP, and the y-intercept approximates the AWC (34). The hyperbolic relationship between the CP variables can be used to predict the T_{lim}. The CP is represented by the asymptote of the T_{lim} vs. power output relationship (33,34). Recently, the CP test has been modified from the original multiple (3-4 workbouts) workbout cycle ergometry test to a 3-min single workbout cycle ergometry test. The 3-min all-out test provided estimates of CP and AWC that were not different form the multiple workbout protocol and required a single visit (2,7). This recent modification reduces the time required to complete the testing and may improve the applicability of the test.

2.2 Metabolic Factors Associated with CP

2.2.1 Critical Power as a Measure of Endurance

Poole et al. (37)

This article attempts to examine critical power (CP) and its physiological implications. The researchers investigate studies about the power vs time hyperbolic relationship and expound two parameters that can be estimated from this relationship. These parameters are the asymptote for power (critical power, CP) and the work performable above CP (W′). Together, these parameters predict how long a person can exercise above the CP value. W′ might be best conceptualized as the ‘buffer’ available to resist exercise intolerance during supra-CP exercise, where the source of the buffer will vary dependent on the conditions. The CP manifests itself metabolically as both respiratory, metabolic and contractile. The article defines the cooperation of these categories by looking at CP’s ability to predict how long it takes to use up W’, reach $\dot{V}O_2$ max, and reach exhaustion. The CP threshold theoretically lies in the middle of the lactate threshold (LT) or gas exchange threshold (GET) and the maximum power output achieved during incremental exercise. This leads researchers to believe that CP represents a fatigue threshold that demarcates the heavy from severe exercise domains and may set the boundary above which the slow component drives $\dot{V}O_2$ to its maximum, and the loss of efficiency is associated with a predictable rate of muscle fatigue development. This study determined that CP, as a measure of muscular aerobic endurance, grants insight into the development of fatigue through various intensities of exercises and mechanisms of cardiovascular and metabolic control. The researchers also state that it is not yet known whether the distinction between heavy and severe intensity domains is a rigid, fixed point or a more fluid idea that may vary from any number of confounding variables from person to person.

Dekerle et al. (13)

This investigation attempts to examine the use of critical power (CP) and second ventilatory threshold (VT_2) as indicators of maximal lactate steady state (MLSS). Eleven healthy and well-trained male students [mean (SD) age 23 (2.9) years] performed an incremental test (25 $W \cdot min^{-1}$) to determine $\dot{V}O_2$max, maximal aerobic power (MAP) and the first and second ventilatory thresholds (VT_1 and VT_2) associated with break points in minute ventilation ($\dot{V}E$), carbon dioxide production ($\dot{V}CO2$), $\dot{V}E/\dot{V}CO_2$ and $\dot{V}E/\dot{V}O_2$ relationships. On the subjects second session, three to four 30-min constant load tests set at power outputs ranging from 65% to 85% $\dot{V}O2max$ were performed to determine MLSS and the corresponding blood lactate concentration. The third and final session consisted of subjects performing four all-out tests set at 90%, 95%, 100% and 110% $\dot{V}O_2max$ to calculate the CP. MAP and $\dot{V}O_2max$ values were 344 (29) W and 53.4 (3.7) ml·min−1·kg−1, respectively. CP [278 (22) W; 85.4 (4.8)% $\dot{V}O_2max$] and VT_2 power output [286 (28) W; 85.3 (5.6)% $\dot{V}O_2max$] were not significantly different ($p=0.96$). But these two parameters were both significantly higher ($p<0.05$) than the MLSS work rate [239 (21) W; 74.3 (4.0)% $\dot{V}O_2max$] and VT_1 power output [159 (23) W; 52.9 (6.9)% $\dot{V}O_2max$]. Though MLSS work rate was significantly correlated ($p<0.05$) with VT_1 and VT_2 ($r=0.74$ and $r=0.93$, respectively), VT_2 overestimated MLSS by 10.9 (6.3)% $\dot{V}O_2max$. This was significantly higher than VT_1's estimation [+21.4 (5.6)% $\dot{V}O2max$; $p<0.01$]. The researchers then concluded that CP, when calculated from a range of times to exhaustion, does not correspond to MLSS.

Jones et al. (27)

The principle aim of this investigation was to examine the validity of critical power (CP) and its measurement of the amount of work a muscle group can perform without exhaustion [measured using ^{31}P magnetic resonance spectroscopy (MRS)]. Six male subjects first performed single-leg knee-extensions at three to four different continual work rates to exhaustion (range 3–18 min) for CP calculation (mean ± SD, 20 ± 2 W). The subjects then exercised at work rates 10% below CP (<CP) for 20 min and

10% above CP (>CP) to exhaustion. During these times, the ^{31}P-MRS was used to estimate the metabolic responses in the active quadriceps muscle, i.e., phosphorylcreatine concentration ([PCr]), Pi concentration ([Pi]), and pH. Subjects performed <CP exercise for 20 minutes without stopping at any point. With >CP exercise, subjects exercised to volitional exhaustion (14.7 ± 7.1 minutes). Within three minutes of beginning <CP exercise, steady values for [PCr], [P_i], and pH were reached (end-exercise values = 68 ± 11% of baseline [PCr], 314 ± 216% of baseline [P_i], and pH 7.01 ± 0.03). >CP exercise did not produce a steady state for [PCr] and instead showed a steady decline until exhaustion had been reached. [P_i] and pH drastically increased to values typical of those after high intensity exercise (end-exercise values = 26 ± 16% of baseline [PCr], 564 ± 167% of baseline [P_i], and pH 6.87 ± 0.10, all $P < 0.05$ vs. <CP exercise). The researchers concluded that CP is a valid measure of the highest amount of work that can be sustained without breaking a steady state of high-energy phosphates like [PCr] and metabolites associated with fatigue (i.e. H^+ concentration and [P_i]).

Jones et al. (26)

The purpose of this study was to review other studies to examine the time-to-exhaustion or limit of tolerance (t) versus power (P) or velocity (V) relationship. It also covers the historical bases of critical power (CP) and how it has been developed over time. The investigation highlights the point that, throughout history, man has been limited by the power to time relationship. That is to say, over time, human beings inevitably become fatigued. If the amount of how much work one can perform without fatigue (known as CP) can be measured and trained, aerobic endurance could be vastly improved. The article defines CP as being representative of “the highest rate of energy transduction (oxidative ATP production, $\dot{V}O_2$) that can be sustained without continuously drawing on the energy store curvature constant (W') (composed in part of anaerobic energy sources and expressed in kilojoules)." The researchers also explore the differences in mathematical models of the two-parameter and the three-parameter CP concepts. What makes these models different from each other is that the horizontal asymptote of the rectangular hyperbola (P vs. t) is no longer constrained to t = 0, as in the two-parameter model, but rather regarded as a real third parameter that can be estimated from the data at t = k, where k is the temporal asymptote. Thus, the equation, $t = W'/ (P – CP) - k$, can be formulated for a three-parameter model. In conclusion, this article was a brief synopsis of CP mathematical models and their practical implications toward improving aerobic endurance and human athletic performance.

2.2.2 CP demarcates heavy-intensity from severe-intensity exercise domains

Brickley et al. (5)

The principle aim of this investigation was to observe physiological reactions to exercise at subjects' critical power (CP) values. This was accomplished by measuring oxygen uptake, heart rate, and blood lactate concentrations. Seven trained males completed five exercise tests on a modified Monark 814E cycle ergometer. Subjects performed an incremental ramp protocol test ($25\ W\cdot min^{-1}$) to exhaustion to establish $\dot{V}O_2max$ (4.6 ± 0.7 l·min-1) and the maximum power output (P_{max}) (410 ± 60 W). Subjects were able to utilize a cadence of their own choosing (Mean ± SD; 90 ± 5 rpm). Exhaustion was defined as the point at which this cadence decreased by 5 $revs\cdot min^{-1}$ for at least 5 seconds and was volitional. The subjects then completed three rides to exhaustion (1-10min) at continual power outputs; each on separate days. These were at work rates of 120%, 100%, and 95% P_{max}. On another separate day, subjects performed a workbout at their estimated CP values. The CP test (mean CP = 273 ± 38 W) showed a highly linear relationship ($R^2 = 0.985$). All seven subjects completed 20 min of exercise with the range of time to failure at CP from 20 min 1 s to 40 min 37 s (Mean ± SD; 29 min 34s ± 8 min 22 s). Significant differences over time ($p < 0.001$) were discovered in blood lactate concentration (4.3 ± 1.8 to 6.5 ± 2.0 $mmol \cdot l^{-1}$), heart rate (118 ± 24 to 177 ± 5 $beats \cdot min^{-1}$) and oxygen consumption (3.7 ± 0.6 to 4.1 ± 0.5 $l \cdot min^{-1}$). Thus, the researchers concluded that CP does not represent a sustainable steady-state intensity of exercise. This study showed that CP could be more precisely expressed as the maximum "non-steady-state" intensity that could be sustained between 20 and 40 minutes.

Burnley & Jones (8)

This article reviews studies with the purpose of dissecting the physiological phenomena of the power versus time relationship. It also investigates the fatigue mechanisms which coincide with this relationship, and the events that lead to eventual muscular exhaustion. The major highlights of this study were the modelling of the oxygen uptake response to ramp exercise, the power versus duration relationship, and the $\dot{V}O_2$ response to constant load exercise in the moderate, heavy, and severe-intensity domains. By doing this, several aspects became evident. All power outputs above the critical power value were unsustainable while values below were found to be maintainable over time. Moderate and heavy intensity exercise showed that $\dot{V}O_2$ steady states were reached. Heavy intensity was somewhat delayed by the $\dot{V}O_2$ slow component). However, there was no apparent $\dot{V}O_2$ steady state for severe intensity exercise. Instead, the continued increase in $\dot{V}O_2$ is constrained by the attainment of

$\dot{V}O_2max$. This study also modelled compiled data of muscle activity (EMG of vastus lateralis), peripheral fatigue, and muscle phosphorylcreatine (PCr) at severe intensity exercise. At exhaustion, peripheral fatigue reached consistent values, PCr virtually regressed to zero, and $\dot{V}O_2max$ was attained. However, muscle activity was not shown to reach a constant. This means that neuromuscular activation/fatigue may be independently occurring of these other fatigue responses that reach a steady state at severe intensity exercise. Neuromuscular fatigue varies greatly depending on the intensity of the exercise. In conclusion, this investigative review showed how mechanisms of neuromuscular fatigue are intensity-domain specific and how fatigue mechanisms coincide with one another to influence exercise performance. This was evident through the reduction of the drive to exercise during extremely prolonged exercise (in the moderate-intensity domain), by drawing heavily on muscular fuel reserves (heavy-intensity), and by the accumulation of fatigue-inducing metabolites (severe-intensity).

Meyer et al. (31)

This investigation sought to thoroughly examine studies involving the physiological indicators defining exercise thresholds. It also delves into the concept of these thresholds being practically applied within exercise testing and prescription for both athletic and older populations. The researchers discussed two broad categories of gas exchange thresholds. The first, aerobic (AerTGE), represents the initial blood lactate escalation throughout incremental exercise. The second, anaerobic (AnTGE) corresponds with the maximal lactate steady-state. The study continues with investigations of the application of these thresholds to further validate this 2-threshold model. The authors concluded that AerTGE and AnTGE are reliable and indicative of separations in states of endurance capacity. Also, these thresholds can highlight training-induced changes for diseased, athletic, and older populations.

Hofmann & Tschakert (23)

This article emphasizes the importance of general physical activity; especially concerning exercise thresholds. The purpose was to gather information to optimize the use exercise thresholds in exercise testing and prescription. The authors highlighted several different methodologies behind exercise intensity prescription. The intensities could be determined by means of maximum heart rate (HRmax) and heart rate reserve (HRR), $\dot{V}O_2$max and oxygen uptake reserve ($\dot{V}O_2R$), and by submaximal markers. The HR and $\dot{V}O_2$ methods were found to have the limitation of being vastly different amongst subjects across studies. The researchers indicated that each of these methods is both directly and indirectly affected by unique physiological responses and adaptations between subjects. The conclusion to this limitation was to strictly employ the use of objective submaximal markers, such as thresholds or turn points, to individualize exercise intensities to the desired subject.

2.2.3 Factors affecting the estimation of CP

Housh et al. (25)

This study examined the difference between actual and predicted time to exhaustion during the Critical Power (CP) test. Fourteen male subjects (Mean ± SD, age = 22.36 ± 2.13 years) performed four constant power output rides at a pedal rate of 70 rev·min^{-1} on a Monark cycle ergometer. The CP values (range = 176-360 W) of these rides were computed and used for calculating the predicted time to exhaustion (PT_{lim})

from the equation T_{lim} = AWC/ (P – CP) and from the power-curve analysis. Then, the subjects performed workbouts at CP – 20%, CP, CP + 20%, CP + 40% and CP + 60% to determine actual time to exhaustion (AT_{lim}). AT_{lim} and PT_{lim} were found to be highly correlated ($r = 0.841$ to $r = 0.893$; $p < 0.05$) for the power loading above CP. The power loadings for the PT_{lim} of 60 minutes were estimated from the power curve and compared to the CP values for significant changes. The mean AT_{lim} (33.31 ± 15.37 min) was significantly greater (17%; $p < 0.05$) than the PT_{lim} (164 ± 32 W). The researchers concluded that while the equation T_{lim} = AWC/(P – CP) may be a valid predictor of time to exhaustion for power loadings above CP, CP derived from the CP test was 17% greater than the power loading of the 60-minute PT_{lim}.

Pringle & Jones (38)

The purpose of this study was to determine if the maximal lactate steady state (MLSS), critical power (CP) and electromyographic fatigue threshold (EMG_{FT}) coincide at a uniform power output in cycle ergometry. Also, the researchers wanted to determine if oxygen uptake ($\dot{V}O_2$), blood lactate concentration ([La]) and integrated electromyogram (iEMG) reach a steady state or continue to increase with exercise above the power output at MLSS (P-MLSS). Eight physically active subjects (one female) [mean (SD), age = 25 (3) years, body mass = 72.1 (8.2) kg] performed tests over two weeks and nine different sessions. Subjects first completed an incremental exercise test to task failure to assess the lactate threshold (Th_{la}) and $\dot{V}O_2$max. Next, subjects completed a series of four exhaustive workbouts (on separate days) of between 2 to 15 min in duration to determine CP on a cycle ergometer. In the following visits, subjects performed a series of four 30-min trials. From these 30-min trials, the researchers determined the MLSS as the highest power output at which the increase in blood [La] was less than 1.0 mM across the last 20 min of the workbout. The EMG_{FT} was calculated from four 2-minute trials at unique power outputs. Surface electrodes for electromyography were applied to the right leg over the vastus lateralis muscle. CP and P-MLSS were found to be strongly correlated ($r=0.95$; $p<0.01$), although CP was significantly higher [242 (25) vs. 222 (23) W; $p<0.05$]. The EMG_{FT} could only be determined in the ‘‘less-fit’’ half of the subject group. For these four subjects, the similar power output at CP and EMG_{FT} was entirely coincidental and there was no consistent trend to suggest that the EMG_{FT} was related to the other physiological variables investigated. In the well-trained subjects exercising at high power outputs, there was not a proportional linear relationship between external power output and the rate of increase in iEMG. Blood [La], $\dot{V}O_2$ and minute ventilation all increased significantly with time for exercise at power outputs above the P-MLSS. The researchers concluded that the P-MLSS, not the CP, demarcates heavy from severe intensity domains in the mode of cycle ergometry. With exercise above the P-MLSS, there was no continual increase in $\dot{V}O_2$, blood lactate concentration, or iEMG.

Smith & Hill, (39)

This study investigated the reliability of the parameters W’ and θ_{PA}. The equation $t = W' / (P - \theta_{PA})$ describes the hyperbolic relationship between power output (P) and time to exhaustion (t); where θ_{PA} represents the highest sustainable power output (i.e. the power asymptote) and W’ indicates aerobic capacity. On separate days for each bout, twenty-six untrained college students, 13 men (Mean ± SD, height = 181 ± 7 cm and mass = 81.8 ± 9.4 kg), and 13 women (Mean ± SD, height = 167 ± 7 cm and mass = 60.8 ± 8.4 kg), performed five high-intensity exercise workbouts to exhaustion (Trial I) on a cycle ergometer. Subjects then performed a second set of five high-intensity bouts (Trial 2) at the same relative work rates used in Trial 1. Subjects were instructed to maintain a cadence of 90 to 100 rev*min^{-1} for as long as possible. Tests were terminated when subjects could no longer maintain a cadence above 50 rev*min^{-1}. Four tests were performed at predetermined relative work rates; for the women these were 3.5, 4.5, 5.5, and 6.5 W*kg^{-1}, and for the men these were 4.0, 5.5, 7.0, and 8.5 W*kg^{-1}. A fifth work rate was selected based on responses to the first four, so that subjects would have exercise times of about 1 to 10 min. For example, if after the first four bouts a subject had no time shorter than 2 min, the fifth work rate was made higher than the four standard rates, to elicit exhaustion after about 1 min. If after the first four bouts a subject had no time longer than 5 min, a lighter work rate was selected. Individual θ_{PA} and W' were calculated from Trial 1 and Trial 2 results, using the power vs. time relationship. A repeated-measures ANOVA revealed no effect of Trial on estimates of W', F(l, 24) = 0.00, p=0.944. There was no Gender by Trial interaction effect on W', F(l, 24) = 0.35, p=0.559. However, there was a significant Trial effect on θ_{PA}, F(1, 24) = 1 1.96, p=0.002, with Trial 2 estimates about 5% higher than Trial 1 estimates. For women, the increase was 6% of the Trial 1 mean, with an effect size of 1.1; for men the increase was 5% of the Trial 1 mean, with an effect size of 1.0. There was no Gender by Trial interaction effect on θ_{PA}, F(1, 24) = 0.23, p=0.634. The researchers concluded that though θ_{PA} may be underestimated by 5%, it is reliable across testing sessions. Both women and men showed a strong trial-to-trial correlation for θ_{PA} (r=0.90 and r=0.92, respectively). The W' parameter was not reliable and showed no consistency in trials (r=0.64, p=.019).

Carnevale et al. (10)

The purpose of this investigation was to examine the effect of pedaling cadence on the power-duration relationship for high-intensity cycle ergometry. Seven males (age = 20.4 +/- 0.3 year) performed four rides at 60 rpm and four rides at 100 rpm, all to exhaustion. Task failure was defined as when the subject could no longer continue at a cadence of 60 or 100 rpm. A nonlinear regression analysis was performed to examine power output (P), time to exhaustion (t), the power asymptote (θ_{PA}) in watts [W], and limit work (W’) in joules [J] that all make up the equation (P - θ_{PA}). t = W'. θ_{PA} represents a limit point in aerobic exercise that work cannot be sustained over. θ_{PA} at 60 rpm (235 +/- 8 W) was significantly (15.9 +/- 4.5%, $P < 0.05$) greater than θ_{PA} at 100 rpm (204 +/- 11 W). However, W' was not significantly ($P > 0.05$) affected by pedal cadence (16.8 +/- 1.7 kJ at 60 rpm vs 18.9 +/- 2.2 kJ at 100 rpm). The researchers concluded that the power asymptote of the time-duration relationship is significantly influenced by the rate of cadence, but that W’ was not.

Summary:

These articles illustrate the complexity of critical power (CP) and its implications physiologically. The majority of studies conclude that CP is a measure of aerobic endurance (13,26,27,37). The CP threshold lies approximately equidistant between the so-called lactate threshold (LT) or gas exchange threshold (GET) and the maximum power output attained during incremental exercise. This leads researchers to believe that CP represents a fatigue threshold that demarcates the heavy from severe exercise domains (5,8,23,31) and may set the boundary above which the slow component drives $\dot{V}O_2$ to its maximum, and the loss of efficiency is associated with a predictable rate of muscle fatigue development (37). CP does not, however, correspond to maximal lactate steady state (MLSS) (13,38). CP was found to be significantly higher ($p<0.05$) than the MLSS work rate (13). It is argued that the power output at MLSS (P-MLSS), not the CP, demarcates heavy from severe intensity domains (38). Furthermore, another valid theory is that the distinction between heavy and severe intensity domains is not a fixed point that can be measured accurately from person to person. Perhaps, these domains are demarcated by a more fluid point that varies between subjects and their unique body chemistries (37).

The validity of CP and what it represents physiologically has been somewhat in question. However, the cadence rate of the exercise being performed has been shown to significantly influence the parameters of the power-duration relationship (10). Researchers have found that the power asymptote of the time-duration relationship at 60 rpm (235 +/- 8 W) was significantly (15.9 +/- 4.5%, $P < 0.05$) greater than the power asymptote (θ_{PA}) at 100 rpm (204 +/- 11 W) (10). When cadence is adhered to, significant physiological differences can be observed in responses over time ($p < 0.001$) to exercise at CP. These differences were discovered in blood lactate concentration (4.3 ± 1.8 to 6.5 ± 2.0 $\text{mmol}\cdot\text{l}^{-1}$), heart rate (118 ± 24 to 177 ± 5 $\text{beats}\cdot\text{min}^{-1}$) and oxygen consumption (3.7 ± 0.6 to 4.1 ± 0.5 $\text{l}\cdot\text{min}^{-1}$). Thus, CP can be more accurately defined as the highest "non-steady-state" intensity that can be maintained between 20 and 40 minutes (5). It is a valid measure of the highest constant work rate that can be sustained without a continual depletion of muscle high-energy phosphates and a rapid accumulation of metabolites (i.e., H^+ concentration and $[P_i]$); which have been related to exhaustion (27).

2.3 Applications of the CP Model

Cheng et al. (11)

The purpose of this investigation was to apply the critical power (CP) model to the analog of rowing through a three-minute all-out rowing test (3-min RT). This included examining the hyperbolic relationship between P and T_{lim}. Eighteen male rowers (age 17.7 ± 1.9 years; height 178.0 ± 4.3 cm; weight 70.7 ± 5.0 kg; 2,000 m time 418.7 ± 11.7 s) completed an incremental exercise test (IRT), three constant-work rate tests to approximate CP values and limit work (W'), and two 3-min RTs against a constant resistance (maximum setting) to establish the end-test power (EP) and work-done-above-EP (WEP) on a rowing ergometer. Though the subjects were instructed to maintain the highest possible stroke count that could be managed throughout the test, there was no fixed cadence utilized for pacing. $\dot{V}O_2$peak and $\dot{V}O_2$max parameters were estimated as the highest 30 second average attained for the 3-min RT and IRT tests. The results indicated that there was a significant correlation between the $\dot{V}O_2$peak (60 ± 3 ml kg^{-1} min^{-1}) and $\dot{V}O_2$max (61 ± 4 ml kg^{-1} min^{-1}) ($P = 0.003$). The EP and WEP determinations from the 3-min RT were shown to have moderate reproducibility ($P = 0.002$). Linear regression was used to provide two sets of CP and W' estimates from the results the 3-min RT, using the work - time ($W = CP \times t + W'$) and the power - [1/time] ($P = W' \times 1/t + CP$) models. EP (269 ± 39 W) was significantly correlated with CP (work - time, 272 ± 30 W; power - [1/time], 276 ± 32 W) ($P = 0.000$), with no significant differences observed between the EP and CP values ($P = 0.474$). However, WEP did not significantly correlate with W' ($P = 0.254$) and was significantly higher than the W' values. The researchers determined that the 3-min RT has moderate reliability and can accurately assess CP and $\dot{V}O_2max$ in rowing ergometry.

Wakayoshi et al. (45)

The principle aim of this study was to apply the parameter of critical power to the exercise mode of competitive swimming. The researchers accomplished this by using the parameter critical swimming speed (CS) as determined both in a swimming flume (CS-flume) and in a normal (25m length) swimming pool (CS-pool). The goal was to examine the validity of this new application and evaluate its ability to truly measure a swimmer's endurance performance. CS was defined as "the swimming speed which could be theoretically maintained continuously without exhaustion" (45). This was calculated by plotting the slope of the linear regression between swimming distance (D) and time to exhaustion (T) collected at each swimming speed. Eight advanced swimmers performed four swimming workbouts until exhaustion at four swimming speed levels in the swimming flume. Then, the subjects performed four bouts at maximal effort over four different swimming distances in the swimming pool. For the CS-flume, the water was circulated in a deep loop by a motor driven propeller, providing a water flow velocity from 0 to 2.0 m/s with an increment of 0.01 m/s. The dimensions of the swimmers' area were 4 m long, 2 m wide and 1 m deep. The D versus T relationship showed an r^2 value of 0.998 ($p<0.01$) and indicated excellent linearity for the equation $D = a + b \times T$. Furthermore, three additional parameters were measured in the subjects. These parameters included: maximal oxygen uptake ($\dot{V}O_2max$) for the incremental swimming test, swimming speed at 4 mM of blood lactate concentration (V-OBLA), and mean 400m freestyle velocity (V-400). There were significant correlations between CS-pool and CS-flume ($r = 0.824$, $p < 0.05$), CS-pool and V-400 ($r = 0.998$, $p < 0.01$), V-OBLA and CS-pool ($r = 0.898$, $p < 0.01$), V-OBLA and CS-flume ($r = 0.856$, $p < 0.01$), and CS-flume and V-400 ($r = 0.823$, $p < 0.05$). The mean of CS-pool (1.555 m/s) was slightly higher than that of CS-flume (1.543 m/s). This may have resulted from the difference between flowing water and still water and from the turns in the CS-pool. In conclusion, it was found that CS can be approximated by the relationship between the swimming distance, the swimming speed, and the time to exhaustion in both a swimming flume and a normal swimming pool. The researchers suggested that CS-pool could be adopted as a valuable index for indicating swimming endurance performance without blood sampling and without employing highly expensive equipment.

Toussaint et al. (41)

The purpose of this study was to examine the validity of the critical power (CP) model, as well as, the parameter of anaerobic swimming capacity (ASC) in front crawl swimming. Eight experienced competitive male collegiate swimmers (weight, 65.74 ± 8.23 kg; height, 1.79 ± 0.058 m; and $\dot{V}O_2max_{(swimming)}$, 3.54± 0.67 $L \cdot min^{-1}$) performed a continuous incremental swimming test to exhaustion for the determination of the $\dot{V}O_2max$ and formulation of CP modelling. Subjects exercised in a calibrated swimming flume (Unidyne, Minneapolis, MN) at the International Center for Aquatic Research, Colorado Springs, CO., and the water temperature was kept at a constant 26.5°C for all trials. Oxygen uptake ($\dot{V}O_2$) and minute ventilation ($\dot{V}E$) were calculated based on measurements from a specially designed underwater respiratory valve. The CP and ASC were approximated two different ways. The first examined the relationship of energy for specific swimming distances (50-1500m) with turns in a 25m pool and overall time. The second looked at the relationship between the cost of energy for specific distances at maximal exertion and time to exhaustion. This approach left out turns and the initial dive to simulate a swimming flume. The first method produced the equation Energy = 114.4·time + 1184, while the second resulted in Energy = 114.5·time + 1462. This means that both methods produced a similar CP of approximately 114.5W. The "pool" condition showed an ASC of 1184J and the swimming flume condition resulted inn an ASC of 1462J. Using a sensitivity analysis, the researchers concluded that though the critical swimming velocity was an accurate measure of front crawl swimming endurance, the ASC was deemed to be unreliable and negatively biased. This was due to the nonlinearity of the power production.

Vanhatalo et al. (43)

The purpose of this article was to review other studies that examine critical power's applicability to sport performance. The authors stated that critical power (CP) can be applied to virtually any sport that requires a significant period spent within the severe-intensity domain. By illustrating what CP is and how it is estimated, the researchers then highlighted things that athletes may be able to do to improve upon this parameter. Many aerobic and anaerobic training programs can be instituted to impact the power-time relationship. Improvements to VO_2max and/or the rate of increase of VO_2 may reflect changes in this relationship. The researchers suggest that both high intensity interval training and endurance training can increase CP values in a relatively short amount of time (4-6 weeks). In contrast, these interventions have been associated with a subsequent decrease in the amount of work available above CP (W′). In conclusion, this article provides support for the physiological phenomena behind the power-time relationship, developing a single-visit CP test, and clarifying the practical applications of the CP and W′ parameters to sport performance. Future challenges lie in fully understanding the multiple and interrelated causes of the CP and W′, in refining methods for their assessment, and in developing interventions which positively impact on the CP and/or W′ parameters and enhance sports performance.

Morton et al. (35)

The purpose of this study was to determine if the 3-parameter critical power (CP) model derived for cycling could be applied to the exercise of bench press. Sixteen resistance-trained, male subjects performed a modified YMCA 1RM test and four sets of bench press at a constant cadence to exhaustion at submaximal percentages of their 1RM. The equation Morton et al. tried to test was $n= ALC/(m – CL) + ALC/(CL – L_{max})$. N is the number of repetitions before exhaustion, m is the submaximal resistance lifted (kg), ALC is the anaerobic lift capacity (kg), CL is the newly defined ‘critical lift’ that acts as version of CP (the maximal continuous aerobic ability for resistance exercise, kg), and L_{max} is the maximal ‘instantaneous’ lift (kg). The results indicated that the CP model approximates 1RM at a significantly greater value ($p<0.05$) than those obtained using the YMCA procedure. It was concluded that the 3-parameter CP model can be applied accurately to the bench press. Also, 1RM prediction is possible but ill-advised.

Summary:

The articles in this section describe how the critical power (CP) model has been applied to various other analogs of exercise besides i cycle ergometry. These exercises include rowing (11), swimming (41,45), and resistance training (35). In rowing, CP was determined through a three-minute all-out rowing test (3-min RT). End power (EP) (269 ± 39 W) was significantly correlated with CP (work - time, 272 ± 30 W; power - [1/time], 276 ± 32 W) ($P = 0.000$), with no significant differences observed between the EP and CP values ($P = 0.474$). Thus, the researchers concluded that the 3-min RT has moderate reliability and can appropriately estimate CP and V̇O2max (11). For swimming, researchers used the parameter critical swimming speed (CS) as determined both in a swimming flume (CS-flume) and in a normal (25m length) swimming pool (CS-pool). CS was defined as the swimming speed which could be theoretically maintained continuously without exhaustion. It was found that CS can be determined by relationship between the swimming distance, the swimming speed and the time to exhaustion in both a swimming flume and a normal swimming pool ($r = 0.824$, $p < 0.05$) (45). Recently, the three parameter CP model was applied to resistance training through the exercise of bench press with the equation $n= ALC/(m – CL) + ALC/(CL – L_{max})$. N is the number of reps to failure, m is the sub-maximal weight lifted (kg), ALC is the anaerobic lift capacity (kg), CL is the critical lift (the maximal continuous aerobic ability at bench pressing, kg), and L_{max} is the maximal ‘instantaneous’ lift (kg). The results were that the CP model produces estimates significantly greater ($p<0.05$) than those obtained using the YMCA procedure for 1RM. It was concluded that the three parameter CP model can be applied accurately to the bench press. The one limitation of this was that CL showed a value of zero in almost all subjects (35). Through these applications, sport-specific performance can be better influenced by the training of CP in the athlete’s given sporting area (43).

2.4 Development and validation of the Conventional Deadlift subcategories of Reset and Touch-and-Go

2.4.1 Deadlifting Variables

Bird & Barrington-Higgs (4)

The purpose of this article was to categorize different forms of deadlifting to better validate the exercise in scientific study. It also highlights the many sport-specific applications of many different deadlifting variations and how useful each exercise is at measuring full-body power and strength. The authors state that the deadlift is one of the "big 3" exercises that are geared toward whole-body development. It also advocates for the implementation of Romanian Deadlifts (RDL) to train athletes to use proper deadlifting technique and positioning. The researchers explain specific deadlift terminology and accepted varieties in deadlifting styles. The key classifications that were provided were the categories of conventional deadlift (CD) and non-conventional deadlift (non-CD). CD refers to the standard Olympic deadlift utilizing a shoulder width stance and alternating hand grip. Non-CD is a very broad category that includes any variations of the standard Olympic deadlift (i.e. sumo, straight-legged, etc.). The conclusions were that the deadlift is developing into an extremely useful measurement of full-body strength as it is being more clearly defined.

Kompf and Arandjelović (28)

This article attempts to examine the biomechanical and physiological relationships of "sticking points" among three different exercises: the bench press, squat, and deadlift. Researchers examined results of other studies on each exercise. A "sticking point" was defined as "the part of the range of motion (ROM) in a resistance exercise in which a disproportionately large increase in the difficulty associated with continuing the lift is experienced” (28). For the deadlift exercise this typically coincides with a thigh angle of 60◦ (relative to the ground). A squat exercise generally has a sticking point at a thigh angle of 30◦. Much like in the squat, the trunk and shank angles at the sticking point exhibited greater variability (standard deviation of approximately 7◦) but with a much greater mean (approximately 60◦ vs. 40◦ for the deadlift and the squat respectively) for the trunk and a somewhat lower mean for the shank (approximately 75º vs. 70º for the deadlift and the squat, respectively). This suggests that people of different morphologies and heights may have different degrees of sticking points. One sticking point may require much more force exertion than another.

Kompf and Arandjelović (29)

This article provides information about ways to overcome the “sticking point” in resistance exercise. In other words, researchers examined ways to surmount or improve the hardest part of a given movement or exercise. This was an observational study that took previously performed research and compiled data from other studies. One of the main points of the article illustrates how “momentum” can be used to overcome or circumvent sticking points. The question becomes, “Should the sticking point be circumvented, or is it advantageous to train at the point of momentary muscular failure?”. Strength and power athletes have traditionally trained to overcome sticking points by working on force development in lifting phases before the sticking point. In conclusion, the investigation demonstrated that the term “sticking point” is extremely, loosely defined in literature and refers to significantly different phenomena. This has the potential to confound both past and future findings reported on this topic.

Lockie et al. (30)

This investigation examined the conventional deadlift (CD) and high-handle hexagonal bar deadlift (HHBD) for relationships between arm (AL) and leg length (LL). Twenty-three resistance-trained subjects (14 males and 9 females) performed a 1RM for CD and HHBD. Right Arm and leg lengths were measured and calculated into ratios (AL: LL). Lift distance and duration, peak and mean power, velocity, and force; time to peak power and velocity; and work were all measured with a linear position force transducer. Finally, a Spearman's Rank-Order Correlation (ρ; $p < 0.05$) was performed on the variables to determine correlation. Taller and longer LL males who performed HHBD exhibited greater values for lift distance and work ($\rho = 0.54$-0.68). In females who performed the CD, height, LL, and AL showed a relationship with lift distance ($\rho = 0.67$-0.92). AL was also negatively related to lift time ($\rho = -0.83$). This meant that longer arms typically gave rise to in quicker HHBD lift times. The influence of AL for females may have been due to the hexagonal bar’s inability to be adjusted to the size of the participant. Also, individuals of different body sizes appear to have different amounts of work exerted in the CD and HHBD.

Hammer et al. (22)

This study attempted to analyze deadlift performance differences in shod (shoe-wearing) subjects as compared to barefoot. Ten male subjects performed deadlifts with four sets of four repetitions per session. There were two sets for each shoe condition at two different loads (60% 1RM, and 80% 1RM). The recorded parameters included: peak vertical force (PF), rate of force development (RFD), time to peak force (TPF), anterior-posterior (COP-AP) and medio-lateral (COP-ML) center of pressure excursion, and barbell peak power (PP). Session, wearing of shoes, and load showed no significant interactions (p range from 0.944 to 0.086). But there were significant differences found in COP-ML and RFD ($p<0.05$). Since no other significant differences were shown, it was concluded that there was limited evidence to show that the barefoot deadlift technique is any more efficient that the shod technique.

2.4.2 Impacts on force production

Beckham et al. (1)

The purpose of this investigation was to examine force production at different stages of the deadlift exercise. To accomplish this, researchers recruited fourteen powerlifters to complete isometric lifts standing on a force plate at four separate phases of the deadlift. These phases included: at the floor, above the knee, 5-6 cm before lockout at the top of the movement, and the mid-thigh pull position (MTP). Paired samples t-tests and 1x4 repeated measures ANOVA showed that each bar height produced a significantly different force ($p<0.05$). Force generation increased as the height of the bar increased with the highest force output observed at the MTP position.

Witt et al. (46)

This study attempted to establish a relationship and reliability between isometric midthigh pull (IMTP) peak force and 1RM in conventional deadlifting. Nine subjects (5 men and 4 women) performed both IMTP and 1RM deadlifts in two testing sessions. Peak force and peak rate of force development (RFD) were calculated by force plate equipment. IMTP peak force was determined to be reproducible, by an Intraclass correlation coefficient (ICC) calculation, both within (ICC = 0.98 and 0.97) and between sessions (ICC = 0.89). Through Pearson product-moment correlations and linear regression analysis, IMTP was determined to be significantly correlated with deadlift 1RM ($r = 0.88$, $p \leq 0.05$), but intermediate force outputs and RFD were not. The study concluded that explosive force and maximal force may not be interrelated. It also determined that the IMTP test is a reliable for estimating maximal deadlift strength and is strongly correlated with the 1RM deadlift.

Moir et al. (32)

The purpose of this investigation was to examine the effects of varied repetition configurations within a set of deadlifts. The factors that were examined were concentric force, concentric time under tension (TUT), impulse, work, power, and fatigue. Eleven resistance-trained men performed four repetitions of deadlifts with a load equivalent to 90% of their 1RM under three different set configurations. These configurations were as follows: Traditional (continuous repetitions); Doubles cluster (repetitions 1 and 2, and 3 and 4 performed continuously with a 30 second rest inserted between repetitions 2 and 3); Singles cluster (30 s rest provided between repetitions). An ANOVA was then performed to determine significant set configuration × repetition interaction. Adding rest periods to the cluster sets resulted in longer TUT ($p < 0.001$) and therefore, higher impulse per repetition ($p < 0.001$) than the Traditional set. Also, there was a reduction in power ($p=0.001$). The Doubles cluster set reported significantly higher fatigue scores than the Traditional set ($p = 0.04$). The conclusion was that the Doubles cluster may offer more stimulus for lifters and therefore result in more strength and hypertrophy gains.

Summary:

The articles in this section describe the exercise of the deadlift and the many pros and cons of its use in scientific study. The deadlift is one of the “big 3” exercises that are geared toward whole-body development. The Olympic deadlift can be broken up into several different categories to help eliminate confounding variants. These two classifications include the conventional deadlift (CD) and non-conventional deadlift (non-CD). CD refers to the standard Olympic deadlift utilizing a shoulder width stance and alternating hand grip. Non-CD is a very broad category that includes any variations of the standard Olympic deadlift (i.e. sumo, straight-legged, etc.) (4). By specifically categorizing the method of deadlift being utilized in a study, reliability may be improved. Another confounding variable in any form of deadlift can be plate movement. If the subject bounces the weight to overcome a “sticking point”, results of an investigation can be inadvertently impacted (28,29). Several studies have shown that bouncing the weight at the end of a deadlift repetition may be skipping over normal effort that would exerted at the bottom of the movement (1,46) Whether the subject wears shoes or not for deadlifting has also been shown to have minimal confounding effects (22).

CHAPTER 3. METHODS

3.1 Experimental Approach and Design

This was an experimental, randomized crossover design. Two separate protocols for determining the CR for the deadlift were examined. The RS method referred to the subject allowing the barbell to come to a complete rest on the floor between repetitions. The TG method described when a subject touched the weight plates of the barbell to the ground slightly, and without allowing the plates to fully come to rest, performed another repetition. As soon as the weight contacted the ground, after the eccentric phase of movement, the subject immediately performed another repetition. The CR was determined from the relationship between total work versus repetitions completed. The completion of the RS and TG protocols were randomized; as well as the completion of the 50, 60, 70, and 80% trials. This study examined the CR value differences between these two methods.

The subjects performed deadlifts on eleven different visits with at least 24 hours in between each visit. The first day involved the determination of the subjects' one repetition maximal (1RM) for the CD. For visits two through nine, four different intensities were utilized with both the RS and TG methods of CD. Day two began by randomly selecting a method from the two choices of methods. Once a selection was randomly made, that method was used for visits three, four, and five. Each day (two through five) consisted of a randomly selected intensity of 50, 60, 70, or 80% of the subject's 1RM. After a method and intensity was selected, the subject performed the CD at the appropriate load/mass following the appropriate cadence until exhaustion. Visits six through nine utilized the other CD plate movement method. Again, these visits consisted of a randomly selected intensity of 50, 60, 70, or 80% of the subject's 1RM. Subjects performed repetitions of the CD method at the specified intensity until volitional exhaustion. Critical resistance values were then determined from the data collected. During visit ten, the subject performed deadlifts of a randomly selected method at the subject's determined critical resistance value. During visit eleven, the subject again performed deadlifts at the corresponding critical resistance value, but this time using the method that was not selected for visit ten.

3.2 Subjects

Eleven healthy, resistance trained male and female subjects (seven males and four females, age 22.6 ± 2.4 years, height 173.6 ± 10.6 cm, weight 83.3 ± 16.5 kg, full extension 0.56 ± 0.07m) volunteered to participate in this study. The subjects were selected through convenience sampling from students attending the University of Kentucky. The subjects had experience with resistance training and were proficient at the deadlift. For deadlift proficiency, all subjects completed deadlifts for sets and repetitions at least once in the past month. Subjects demonstrated proficiency on the first visit, during the 1RM testing. This was judged by the researcher to determine if the subject demonstrated correct technique/form and confidence with the lift. In addition, the subjects did not have any disabilities or pre-existing injuries that would impede them from performing physical activity in any way. All subjects completed a health history questionnaire and signed a written informed consent document before participation in this study. This study was approved by the University of Kentucky's Institutional Review Board for Human Subjects (IRB# 50546).

3.3 Instruments

The instruments that were used in this study were a barbell with weighted bumper plates of the same diameter for deadlifting and a measuring tool (tape measure) to quantify the total vertical distance the barbell has moved. The diameter of the bumper plates remained constant to ensure the reliability of this measurement. An Olympic lifting platform with rubber mats was used as the deadlifting surface. An auditory metronome (make, model, manufacturer location) was used to ensure a constant cadence was utilized during CD repetitions. GymAware software was also used to create force/velocity profiles for all participants. For the warm-up routine, a Monark cycle ergometer and an exercise band of moderate thickness were required.

3.4 Procedures

3.4.1 Warm-up Routine

Each day began with a standardized warm-up routine. The warm-up consisted of the following, in order. First, the subjects pedaled for three-minutes on a Monark (Ergomedic 828 E) cycle ergometer at 60 revolutions per minute ($rev \cdot min^{-1}$) with 1.5kg resistance (~90 W). Next, an exercise band of moderate thickness was placed under the arches of both feet of the subject. Holding the other end of the band stretched to shoulder height, the subjects took ten resisted steps laterally to the left and ten to the right. The subjects then kept the band underneath the arches of the feet and stretched the other end overhead, resting it at the posterior base of the neck. Ten back extensions, or “good mornings”, were performed by contracting the musculature of the low back (i.e., erector spinae) against the resistance of the band. Next, ten squats were performed with the resistance band in the same position. Finally, the subject completed three to four warm-up sets of CD. The first set consisted of eight to ten repetitions at a weight chosen by the subject (~50% of estimated 1RM). The second set consisted of four to six repetitions that was slightly heavier (~70% of estimated 1RM). The third set was composed of two to three repetitions, again at an increased weight (~80% of estimated 1RM).

3.4.2 One-repetition maximum test and determination of total vertical distance moved

Day one consisted of signing the informed consent document, acquiring general history information, obtaining resting blood pressure, and determining a 1RM for the subjects. The subjects underwent a 1RM test following the guidelines of the National Strength and Conditioning Association’s (NSCA) 1RM testing protocol. According to the NSCA (21), 1RM testing should begin by instructing the individual to warm-up with a light resistance that easily allows 5 to 10 repetitions (approx. 50% predicted 1RM). Then, a 1-minute rest period is provided. Next, a warm-up load that will allow the athlete to complete three to five repetitions by adding 30 to 40 pounds (14-18 kg) or 10% to 20% of the weight lifted (approx. 80% of predicted 1RM) was estimated. A 2-minute rest period was provided. A conservative, near-maximal load was estimated that allowed the athlete to complete two to three repetitions by adding 30 to 40 pounds (14-18 kg) or 10% to 20% of the weight lifted. A 2- to 4-minute rest period was provided. A load increase of 30 to 40 pounds (14-18 kg) or 10% to 20% of the weight lifted was made. The athlete is instructed to attempt a 1RM. If the athlete was successful, a 2- to 4-minute rest period was provided and the load was increased by 30 to 40 pounds (14-18 kg) or 10% to 20% of the weight lifted. This process was repeated until failure. Once the individual failed to successfully complete a repetition, a 2- to 4-minute rest period was provided and the load was decreased by subtracting 15 to 20 pounds (7-9 kg) or 5% to 10% of the weight lifted and the 1RM attempt repeated. The highest successful weight lifted is the subject's 1RM (21).

After the 1RM was determined, the subjects performed a CD with an unweighted barbell and held the position at full extension. The vertical distance between center of the barbell and the floor was then measured. The radius of the weight plate (PR) was measured and subtracted from the distance to full extension (DFE). This number was the basis for determining the total vertical distance moved (TVDM). Each repetition was recorded (RPT), and the TVDM was calculated using the following formula: Number of Repetitions x (The Distance to Full Extension – Plate Radius) = Total Vertical Distance Moved, or RPT x (DFE – PR) = TVDM.

3.4.3 Determination of the Critical Resistance

During visits 2-5 and 6-9, the subjects performed, in a randomized order, repetitions to failure for the deadlift at four percentages of their 1RM (50, 60, 70, and 80 percent) for the RS and TG protocols. The CD plate movement protocol was randomized as well as the order of the four trials within each protocol. Throughout the deadlift testing, a constant cadence of 45 beats per minute was kept for the TG method of CD using an auditory metronome. This allowed for approximately 1.33 seconds per phase of the deadlift. In other words, 1.33 seconds for the concentric (upward) phase and another 1.33 seconds for the eccentric (downward) phase. Each beat corresponded with the beginning of the next phase. The same cadence was used for the RS method, but a 1.33 second pause was added to the ending of each repetition. This allowed the plates to fully come to rest before the subject performed another repetition. The total amount of work performed during each of the four trials was calculated (total resistance [load] x repetitions) and plotted against the repetitions. The CR was determined as the slope of the total work versus total repetitions relationship for both the RS (CR_{RS}) and TG (CR_{TG}) methods.

3.4.4 Trials at CR_{RS} and CR_{TG}

During visits 10 and 11, the subjects completed as many repetitions as possible at CR_{RS} and CR_{TG}. The CR_{RS} and CR_{TG} trials were performed in a randomized order. The total number of repetitions completed was be recorded.

3.5 Statistical Analyses

The r^2 and SEE values from the linear regression of the total work versus total distance relationships for the CR_{RS} and CR_{TG} were calculated. The CR_{RS} and CR_{TG} estimates (kg) were compared using paired samples t-tests and bivariate regression analyses. In addition, the total number of repetitions to failure at CR_{RS} and CR_{TG} as well as the total number of repetitions completed at 50%, 60%, 70%, and 80% 1RM for RS versus TG were compared using a paired samples t-test and bivariate regression analyses. The comparisons for CR values and number of repetitions completed for each loading (CR_{RS}, CR_{TG}, 50%, 60%, 70%, and 80% 1RM for RS and TG) were presented using Bland-Altman plots with 95% levels of agreement. A zero-order Pearson product-moment correlation was used to determine if there was systematic bias. The data were analyzed using IBM SPSS Statistics 24 software (IMB SPSS Inc., Chicago, Illinois, USA). An alpha level of $p \leq 0.05$ was considered statistically significant for all analyses.

CHAPTER 4. RESULTS

4.1 Absolute and Relative CR Values

Table 1 includes the individual values as well as the mean ± standard deviation (SD) and 95% confidence intervals (CI) for the absolute 1RM (kg) values as well as the submaximal absolute (kg) and relative (%1RM) values for CR_{RS} and CR_{TG}. There were no significant mean differences in the kg values (mean difference = -0.4 ± 7.9 kg, *p* = 0.856, 95% CI = -5.8 – 4.9kg, *d* = -0.028) or %1RM (mean difference = -1.2% ± 5.6%, *p* = 0.510, 95% CI = -4.9 – 2.6%, *d* = -0.234) for CR_{RS} and CR_{TG} (Figure 1A). In addition, there was a significant correlation between CR_{RS} and CR_{TG} kg resistance (r = 0.888, $p < 0.001$) (Figure 1B).

Table 1. Individual values as well as the mean (±SD) and 95% confidence intervals (CI) for the one repetition maximum strength (1RM) as well as the absolute (kg) and relative (%1RM) values for the critical resistance (CR) derived from the reset (CR_{RS}) and touch-and-go (CR_{TG}) methods.

Subject #	1RM (kg)	%1RM (kg) TG	%1RM (kg) RS	CR_{TG} (kg)	CR_{RS} (kg)	Difference (kg)
1M	179	27.4%	36.9%	49.1	66.1	17.0
2M	120	42.9%	35.5%	51.5	42.7	-8.8
3F	79	41.2%	32.8%	32.7	26.1	-6.7
4F	113	41.0%	34.5%	46.5	39.1	-7.3
5M	184	28.4%	30.5%	52.2	56.0	3.8
6M	143	34.9%	36.6%	49.8	52.3	2.4
7F	134	41.5%	46.2%	55.5	61.8	6.3
8M	161	41.1%	36.1%	66.2	58.1	-8.1
9M	206	40.9%	42.3%	84.3	87.4	3.1
10F	84	41.1%	39.1%	34.5	32.8	-1.7
11M	170	37.8%	34.9%	64.3	59.4	-4.9
Mean	**143.1**	**38.0%**	**36.9%**	**53.3**	**52.9**	**-0.4**
SD	**41.3**	**5.4%**	**4.4%**	**14.5**	**17.1**	**7.9**
95% CI	**(115.3, 170.8)**	**(34.4%, 41.7%)**	**(33.9, 39.8)**	**(43.6, 63.1)**	**(41.4, 64.4)**	**(- 5.8, 4.9)**

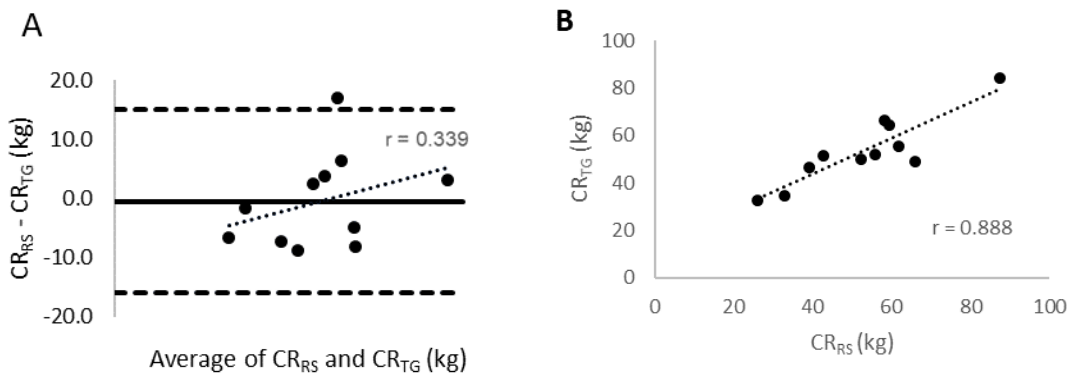


Figure 1.1A. Bland Altman plot of the agreement between critical resistance determined from the reset (CR_{RS}) and touch-and-go (CR_{TG}) methods. The middle solid line represents the average difference between the CR estimates from the two methods. The upper and lower dotted lines represent the bias ±1.96 SD (95% Limits of Agreement). There was no systematic bias for the RS vs TG methods (r = 0.339). Figure 1.1B shows the relationship between the kg value at critical resistance from the reset (CR_{RS}) and touch-and-go (CR_{TG}) methods.

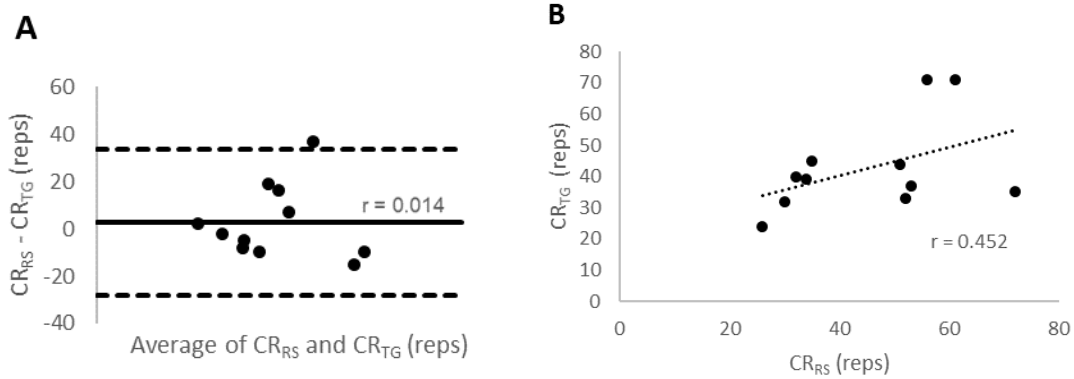
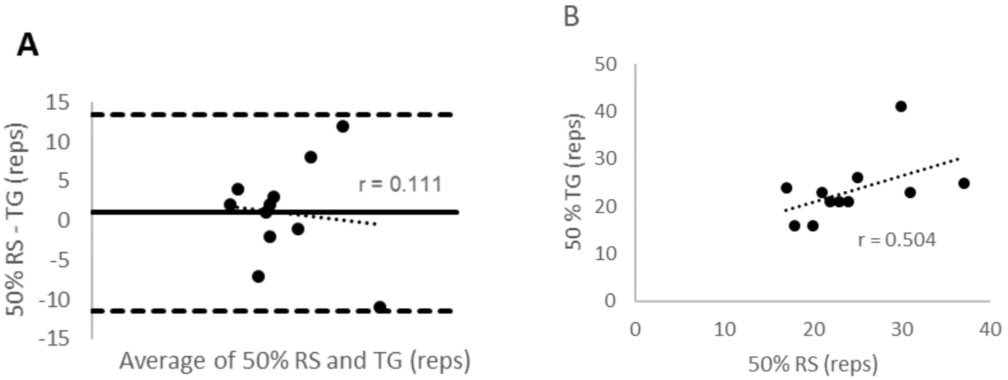
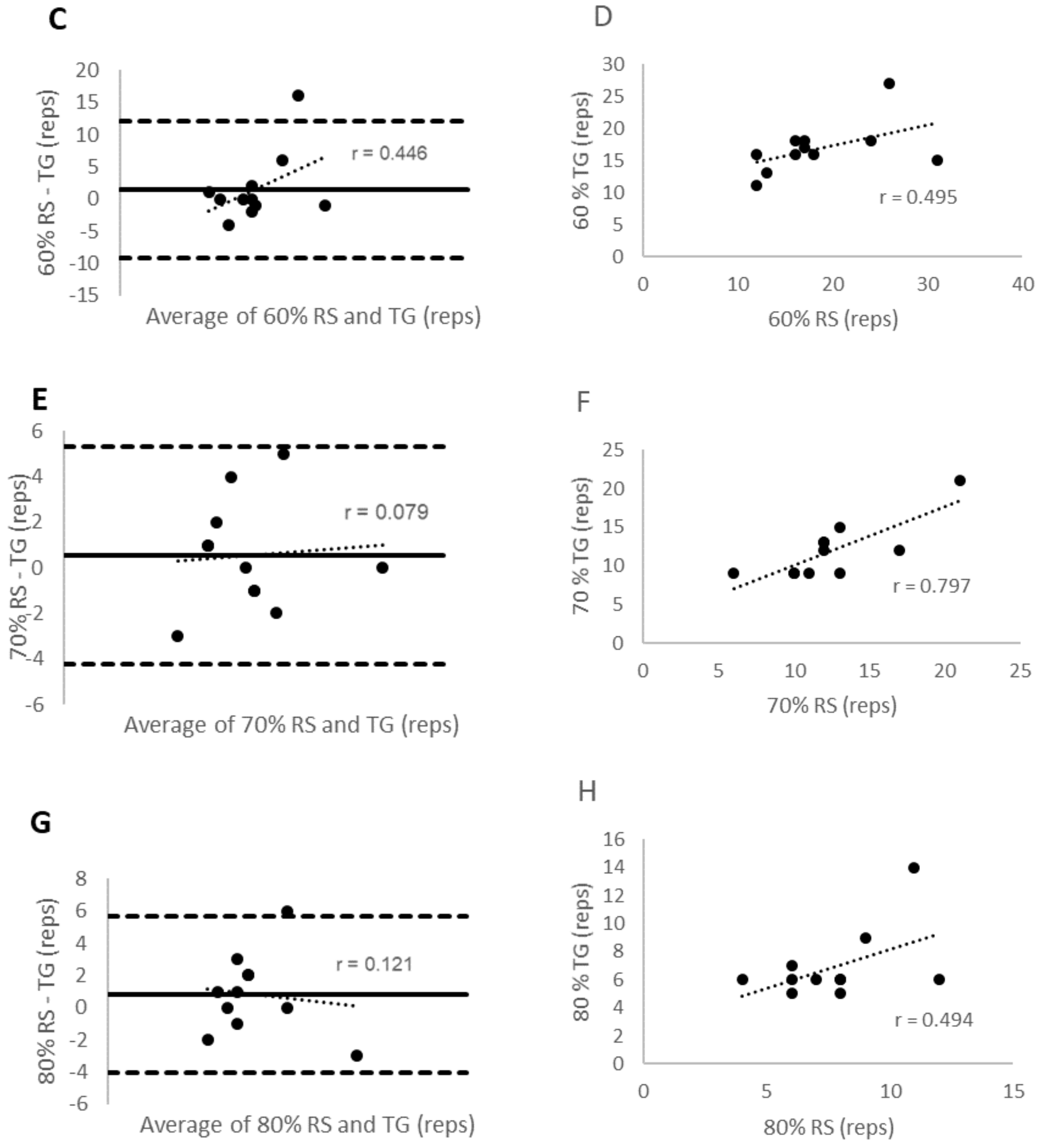


Figure 2.1A. Bland Altman plot of the agreement between the number of repetitions (reps) completed at the critical resistance determined from the reset (CR_{RS}) and touch-and-go (CR_{TG}) methods. The middle solid line represents the average difference between the number of reps at each of the CR estimates from the two methods. The upper and lower dotted lines represent the bias ±1.96 SD (95% Limits of Agreement). There was no systematic bias for the RS vs TG methods (r = 0.014). Figure 2.1B shows the relationship between the number of reps completed at CR_{RS} and CR_{TG}.

4.2 Total Repetitions Completed

Table 2 includes individual values, the mean ± SD, and 95% CI's for the total number of repetitions completed at CR_{RS} and CR_{TG}. There was no difference between the CR_{RS} and CR_{TG} for the total number of repetitions completed (*p* = 0.565, *d* = 0.188) (Figure 2A), but they were not significantly correlated (r = 0.452, *p* = 0.163) (Figure 2B). Table 3 includes the individual values as well as the mean ± SD and 95% CI's for the total number of repetitions completed at each of the four intensities (50, 60, 70, and 80% 1RM) used to derive the CR_{RS} and CR_{TG}. There were no significant mean differences in the number of repetitions completed between the CR_{RS} and CR_{TG} for any intensity (*p* = range of p-values included in Table 3) (Figures 3A, C, E, G). There were moderate correlations between the CR_{RS} and CR_{TG} for 50% (r = 0.504), 60% (r = 0.495), and 80% (r = 0.494) (Figures 3B, D, H). A strong correlation was found at 70% 1RM (r = .797) (Figure 3F).





Figures 3.1A, 3.1C, 3.1E, and 3.1G. Bland Altman plots of the agreements between the number of repetitions (reps) completed at each given intensity (50, 60, 70, and 80%) from the reset (RS) and touch-and-go (TG) methods. The middle solid line represents the average difference between the number of reps at each of the given intensities from the two methods. There was no systematic bias for the RS vs TG methods (r = 0.079 – 0.446). Figures 3.1B, 3.1D, 3.1F, and 3.1H depict the relationships between the number of reps completed from the RS and TG methods.

Table 2. Individual values as well as the mean (±SD) and 95% confidence intervals (CI) for the number repetitions completed at the critical resistance (CR) derived from the reset (CR_{RS}) and touch-and-go (CR_{TG}) methods.

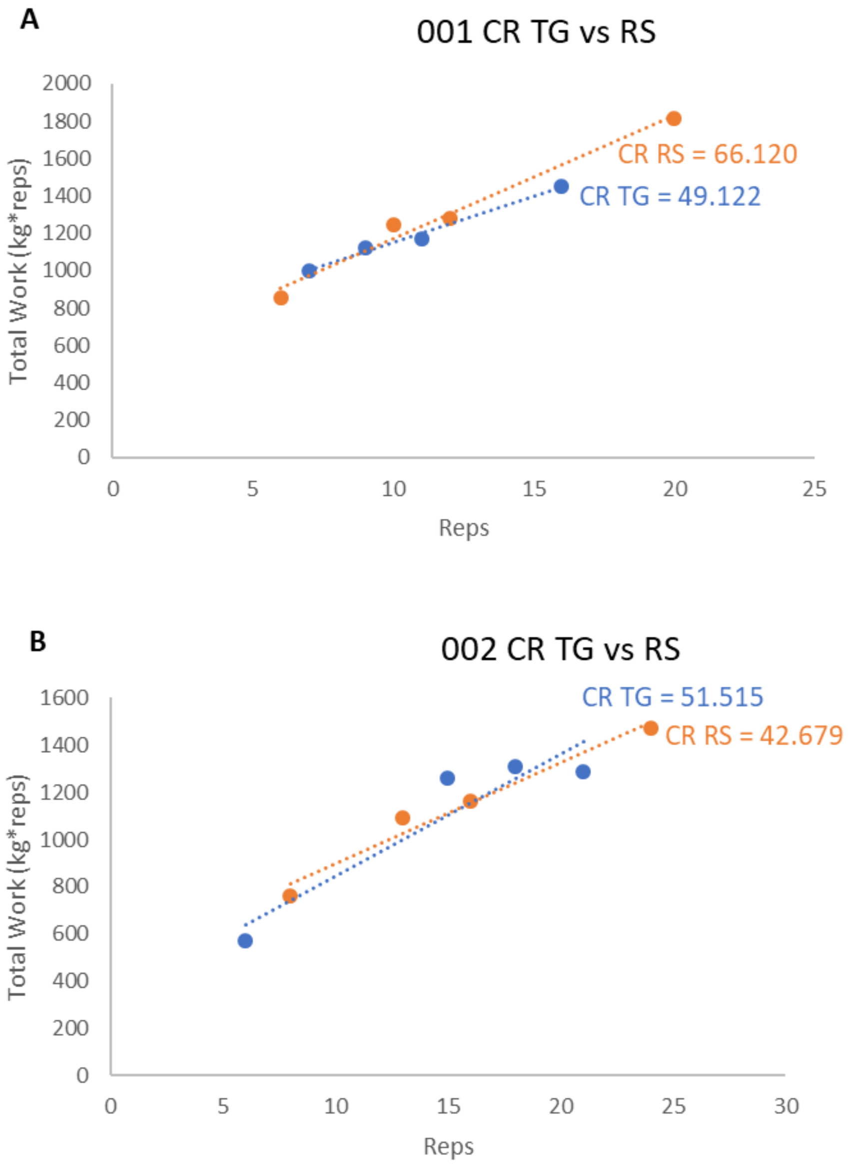
Subject #	**CR_{TG} reps**	**CR_{RS} reps**	**Difference**
1M	71	61	-10
2M	44	51	7
3F	35	72	37
4F	37	53	16
5M	40	32	-8
6M	71	56	-15
7F	33	52	19
8M	45	35	-10
9M	32	30	-2
10F	39	34	-5
11M	24	26	2
Mean	**42.8**	**45.6**	**2.8**
SD	**15.1**	**14.9**	**15.7**
95% CI	**(32.7, 53.0)**	**(35.6, 55.7)**	**(-7.7, 13.4)**

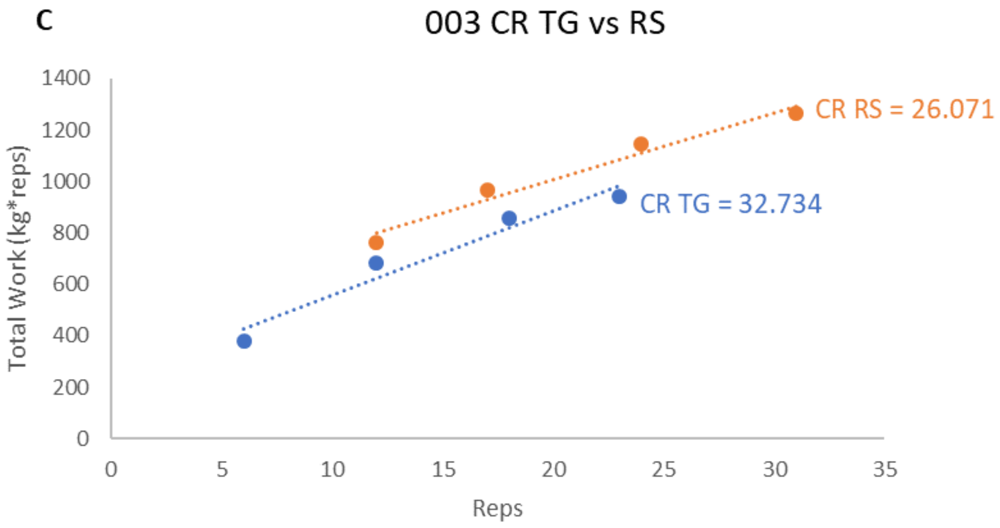
Table 3. Individual values with mean (±SD), 95% confidence intervals (CI), p-values, and effect sizes (d) for repetitions completed at individual trials for both reset (RS) and touch-and-go (TG) methods and the difference (dif) between them.

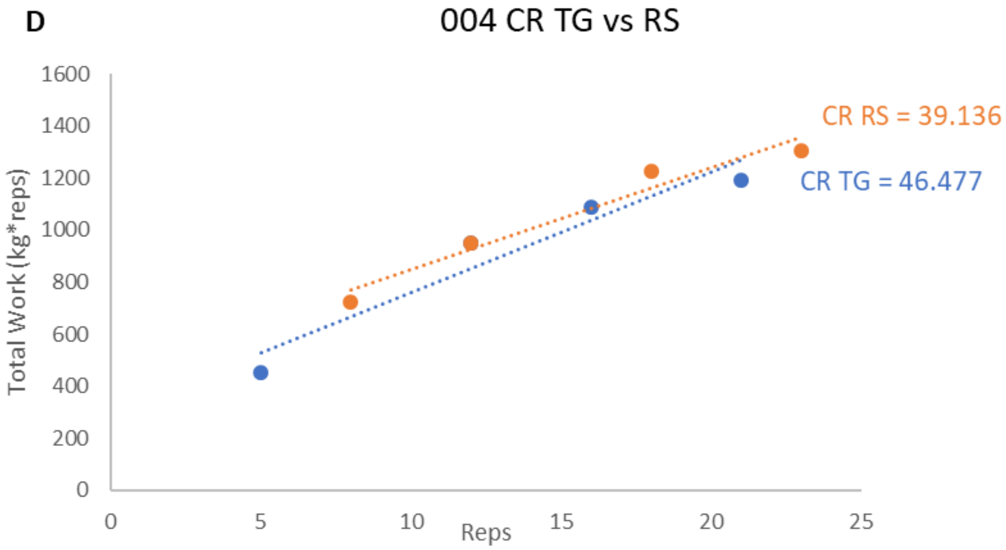
Subject	**50% TG (reps)**	**50% RS (reps)**	**50% Dif**	**60% TG (reps)**	**60% RS (reps)**	**60% Dif**	**70% TG (reps)**	**70% RS (reps)**	**70% Dif**	**80% TG (reps)**	**80% RS (reps)**	**80% Dif**
1M	16	20	4	11	12	1	9	10	1	7	6	-1
2M	21	24	3	18	16	-2	15	13	-2	6	8	2
3F	23	31	8	18	24	6	12	17	5	6	12	6
4F	21	23	2	16	18	2	12	12	0	5	8	3
5M	21	22	1	17	17	0	13	12	-1	9	9	0
6M	41	30	-11	27	26	-1	21	21	0	14	11	-3
7F	25	37	12	15	31	16	9	13	4	6	7	1
8M	26	25	-1	18	17	-1	13	12	-1	6	8	2
9M	24	17	-7	16	12	-4	9	6	-3	6	4	-2
10F	23	21	-2	16	16	0	9	11	2	6	6	0
11M	16	18	2	13	13	0	9	10	1	5	6	1
Mean	**23.4**	**24.4**	**1.0**	**16.8**	**18.4**	**1.5**	**11.9**	**12.5**	**0.5**	**6.9**	**7.7**	**0.8**
SD	**6.7**	**6.1**	**6.4**	**4.0**	**6.1**	**5.4**	**3.7**	**3.9**	**2.4**	**2.6**	**2.3**	**2.5**
95% CI	**(18.9, 27.9)**	**(20.3, 28.4)**	**(-3.3, 5.3)**	**(14.1, 19.5)**	**(14.3, 22.5)**	**(-2.1, 5.2)**	**(9.4, 14.4)**	**(9.9, 15.1)**	**(-1.1, 2.2)**	**(5.2, 8.7)**	**(6.2, 9.3)**	**(-0.9, 2.5)**
***p*-values**			**0.614**			**0.366**			**0.473**			**0.300**
d			**-0.157**			**-0.305**			**-0.144**			**-0.333**

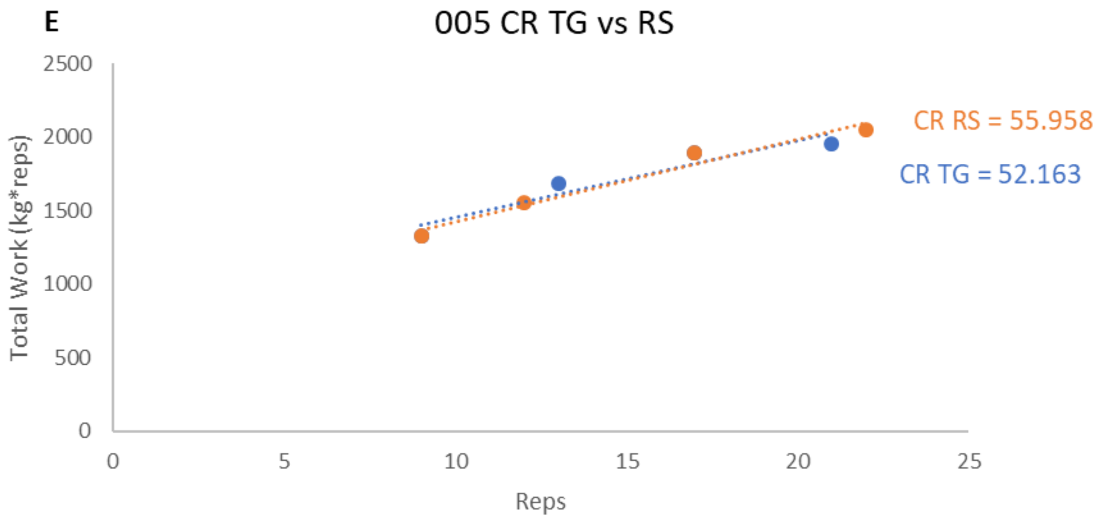
4.3 Individual Responses

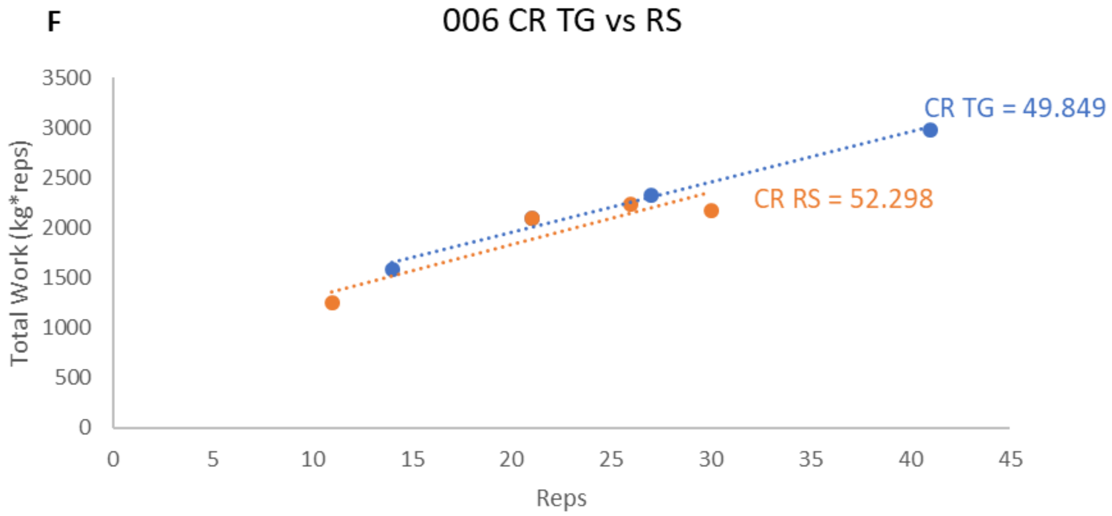
The slope of the relationship (CR) between the total amount of work (kg x reps) and the number of repetitions completed for the reset and the touch-and-go methods for each subject are presented in Figure 4.



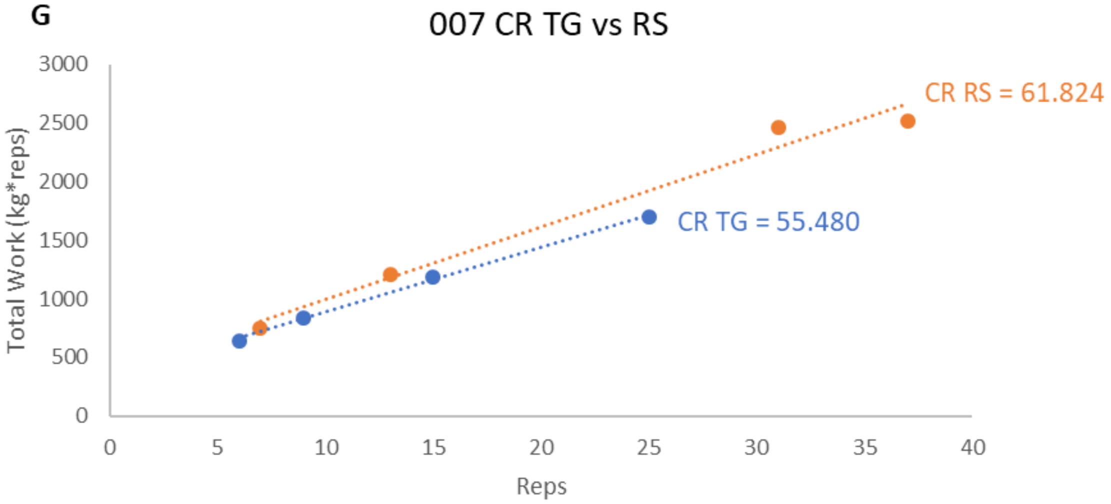

C
003 CR TG vs RS
Total Work (kg*reps)
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
Reps
CR RS = 26.071
CR TG = 32.734


D
004 CR TG vs RS
Total Work (kg*reps)
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
Reps
CR RS = 39.136
CR TG = 46.477

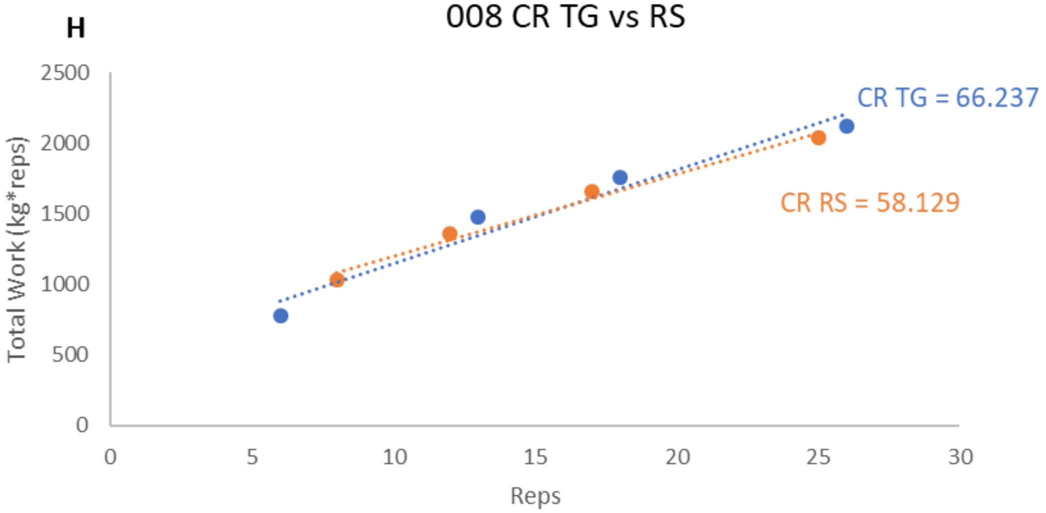

E
005 CR TG vs RS
Total Work (kg*reps)
2500
2000
1500
1000
500
0
0
5
10
15
20
25
Reps
CR RS = 55.958
CR TG = 52.163

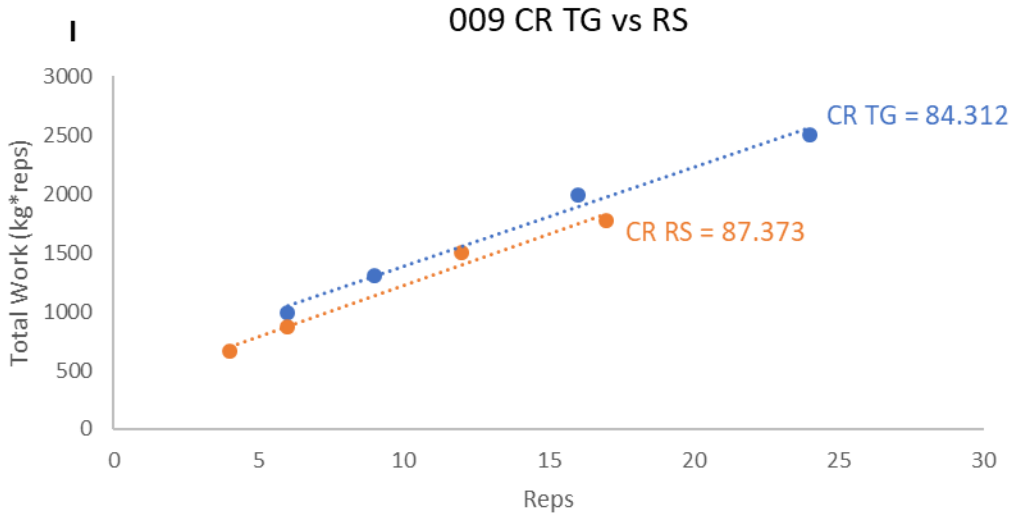

F
006 CR TG vs RS
Total Work (kg*reps)
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
45
Reps
CR TG = 49.849
CR RS = 52.298

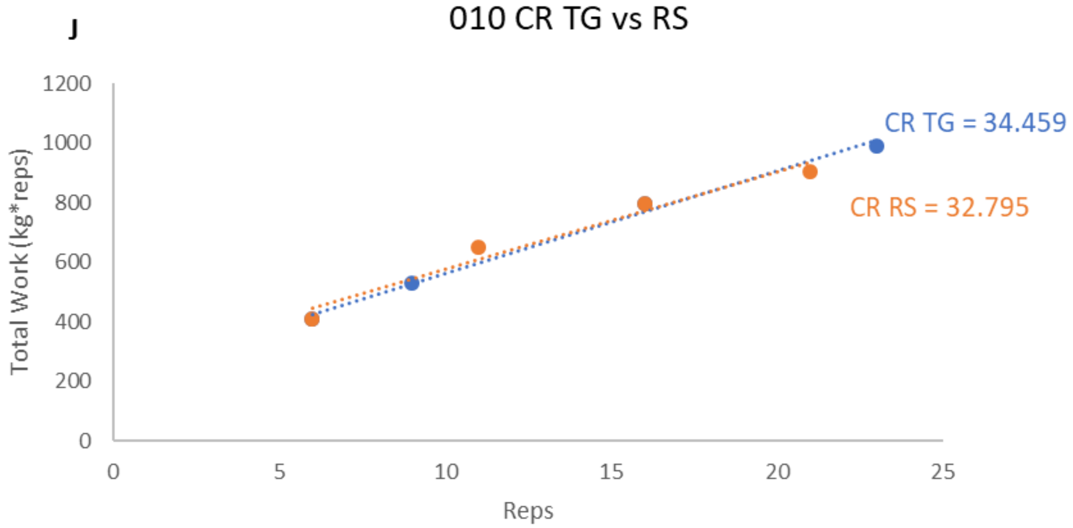
G

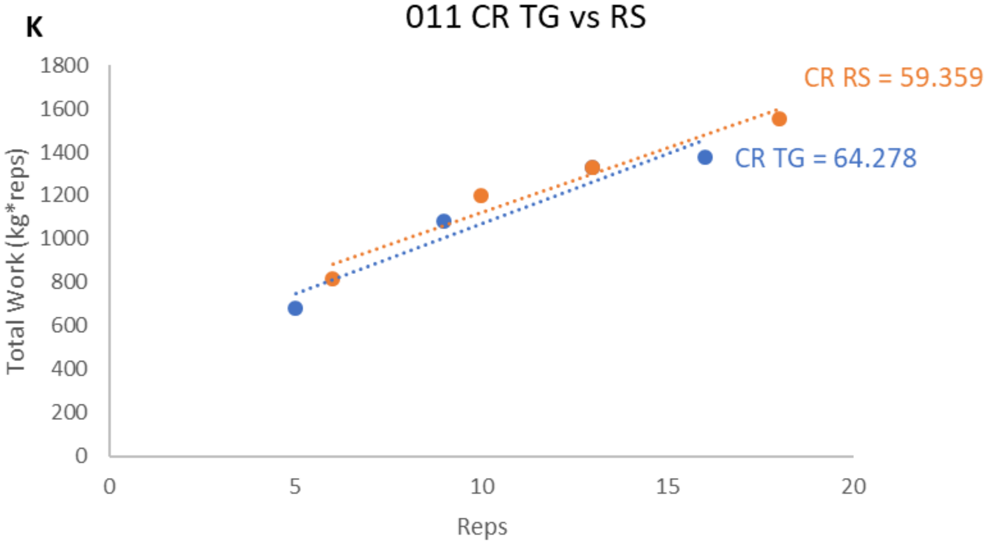

007 CR TG vs RS
Total Work (kg*reps)
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
Reps
CR RS = 61.824
CR TG = 55.480

H


008 CR TG vs RS
Total Work (kg*reps)
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
Reps
CR TG = 66.237
CR RS = 58.129


I
009 CR TG vs RS
Total Work (kg*reps)
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
Reps
CR TG = 84.312
CR RS = 87.373


J
010 CR TG vs RS
Total Work (kg*reps)
1200
1000
800
600
400
200
0
0
5
10
15
20
25
Reps
CR TG = 34.459
CR RS = 32.795



Figures 4.1A-K. The total work versus the number of repetitions completed for each subject used to determine the critical resistance (CR) for the reset (RS) and touch-and-go (TG) methods. The CR value is the slope of the relationship. The kg value for the CR_{RS} is denoted by the orange text and the CR_{TG} is denoted by the blue text.

CHAPTER 5. DISCUSSION

5.1 Summary

This study examined whether plate movement during conventional deadlifting affected estimates of the critical resistance (CR) derived from the linear relationship between W_{lim} (work limit) versus the total number of repetitions completed, by comparing the reset (CR_{RS}) and touch-and-go (CR_{TG}) methods of deadlift cadence. The relative (%1RM) as well as absolute (kg) values for the CR_{RS} (52.9kg, 36.9% of 1RM) and CR_{TG} (53.3 kg, 38% of 1RM) in this study were consistent with those previously reported (56 kg, 40% of 1RM) for CR values derived from the reset deadlift methodology (15). There were no mean differences between the estimates of CR_{RS} and CR_{TG}, and they were highly correlated (r = .888). Therefore, the initial hypothesis that the CR_{TG} method of conventional deadlifting would elicit a higher CR than the CR_{RS} method was not accepted. In addition, there were no differences in the total number of repetitions completed between the RS and TG methods for the four intensities (50, 60, 70, and 80%) used to determine the CR_{RS} and CR_{TG} or in the total number of repetitions completed at the CR_{RS} and CR_{TG}. These findings indicated that plate movement did not affect the mean estimation of CR or the number of repetitions completed at submaximal loads. Thus, the current findings indicated that the estimates of CR from the modeling of total work versus repetitions are relatively robust to variations in deadlifting methodologies.

It has been suggested the CR reflects the highest sustainable resistance that can be lifted for an indefinite number of repetitions (≥ 30 repetitions) and has been hypothesized to identify the point where blood flow becomes compromised during DCER exercise (15, 35) and may reflect a threshold for peripheral fatigue development (9). Previously, investigators (9) have provided evidence of a critical threshold, that is demonstrated by a rate of fatigue development during exercise that does not increase proportionately with torque requirements (i.e., torque-duration curve). Specifically, it was proposed that this critical threshold differentiates central from peripheral factors of fatigue (9). Central fatigue refers to a central nervous system decline in voluntary activation, while peripheral fatigue occurs within the contracting muscle (3,6,18,19,40). According to Burnley et al. (2012), central fatigue increases proportionately in relation to the torque requirement. However, peripheral fatigue develops more abruptly for torque values above a certain "critical" value. Thus, a critical threshold can be established at the point in which peripheral fatigue begins to disproportionately increase, as reflected by an increase in performance fatigability (% decline in maximal voluntary contraction [MVC] torque from pre- to post-test) and motor unit activation (9). It was demonstrated that exercise performed below this threshold resulted in slow peripheral fatigue development (reduced torque in response to stimulation) where subjects exercised for up to 60 minutes and presented with motor unit activity reserves (MVC > end fatigue test torque) (9). Exercise performed above the critical threshold, however, resulted in sharp increase of peripheral fatigue (increased muscle activation over time and decreased stimulated muscle torque production) to the point of maximal motor unit activation and subsequent task failure (9). The underlying premise of this critical threshold is the theoretical foundation for the CR examined in the present study. In this study, the subjects were able to complete 43 ± 15 and 46 ± 15 repetitions for the CR_{RS} and CR_{TG}, respectively. Previously, investigators have reported an average of 49 repetitions were completed at the CR for the deadlift (reset method) (15). Investigators (15) have suggested a sustainable resistance is defined by completing ≥ 30 repetitions, a value typically achieved during low-load (30-50% 1RM) resistance training (15). Thus, the mean repetitions completed to failure at CR_{RS} and CR_{TG} in this study were consistent with the number of repetitions previously reported at the CR (reset method) (15) and indicated the CR may provide an estimate of the highest sustainable resistance for DCER exercise, that reflects a threshold for peripheral fatigue development. Future studies should examine the performance of repetitions to failure above and below the CR and measure performance fatigability, motor unit activation, and voluntary activation to determine if the CR defines a threshold for peripheral fatigue development for the deadlift.

5.2 Inter-Individual variability

Although the mean CR_{RS} and CR_{TG} were not significantly different, there was a large range in the individual difference scores for kg values and the number of repetitions completed at each estimate of CR (RS and TG). Specifically, the difference scores for resistance completed at CR_{RS} compared to CR_{TG} ranged from -8.8kg to 17kg, which likely resulted in the wide range of difference scores (-15 to 37 repetitions) and the moderate ($r = .452$), but non-significant correlation in the number of repetitions completed at CR_{RS} compared to CR_{TG}. The ranges of kg values and repetitions completed between methods suggested that, though the two methods (RS vs. TG) were similar in mean responses (i.e., no significant bias), the subjects performed decidedly better in one method versus the other. This may relate to the fact that a slightly different set of skills and muscle group specific fatigue resistance was required for performance of each method.

Anecdotally, fatigue leading to volitional exhaustion appeared to be muscle group specific and dependent on the lifting method (RS or TG). After the TG testing, most of the subjects volunteered that they felt their grip and forearms were the most fatigued, while most subjects indicated that the low back was the most fatigued muscle group following the RS testing sessions. The deadlift exercise is used to fatigue and strengthen the posterior chain (i.e., hamstrings, gluteus maximus, erector spinae, trapezius), and grip strength is usually a secondary factor (4). Therefore, it appears the CR_{TG} method may be contrary to the purpose with which the deadlift exercise is typically associated when muscular strength is the primary goal. The RS method, therefore, may be more suitable for this purpose. However, both methods may be valid to measure performance if the test matches the intended action. Previous research indicated that continuous repetition deadlifting (like the touch-and-go) may be more appropriate for muscular endurance or high intensity interval training because of the utilization of the stretch-shortening cycle and the increase in impulse power (32). Whereas, the pause between repetitions using the RS method has been shown to increase concentric time under tension and, thus, is hypothesized to elicit better strength and hypertrophy development because of an increase in stimulus (32). Theoretically, the TG method puts more constant time under tension upon the hands/grip than the reset, which allows for a 1.3s pause between reps with the weight grounded. Despite the weight being grounded, some tension may still be created upon the lower back muscles created by gravity acting on the position of the torso as the subject paused at the bottom, with the torso flexed, before completing the next repetition. This would imply that both plate movement and the stretch-shortening cycle could still impact CR determination, should the confounding factors of time under tension be mitigated. This may be done through the use of a weight belt (for the low back) and wrist straps (for grip) (12). Although both methods appear to robustly calculate CR, further studies should investigate the difference in anatomical fatigue between these two methods by either attempting to eliminate grip fatigue using wrist straps or by examining it further with a grip strength dynamometer. This would shed light on the potentially confounding variable of grip fatigue for the CR_{TG} method. Also, future studies should determine how use of a weight belt impacts results across both methods. It should be noted that neither method in its current state is necessarily “wrong”. The CR formulation has been designed as a measurement of individual performance. Therefore, whichever method best corresponds to the way an athlete will be lifting in competition should theoretically be used to assess their performance.

One limitation of the current study was that failure was defined by volitional exhaustion and the inability to maintain proper form throughout the ROM. The trials were terminated once a subject could not maintain the cadence, but there were no physiological markers to verify maximal effort. Therefore, the validity of the measure relied upon the honest effort and volition of the participant. It may be possible to measure metabolic byproducts such as inorganic phosphate, phosphocreatine, and H+ concentration throughout exercise in such a way that it does not interfere with the exercise. Previously, investigators (27) have shown, using a 31P-MRS device with single-leg knee-extensions, that exercise above the critical threshold corresponded to a subsequent decline in phosphocreatine and a drastic increase of metabolites like inorganic phosphate and H^+ concentration. The ability to determine and correlate these substrates in some fashion throughout testing may allow for a more meaningful determination of true maximal exhaustion.

5.3 Conclusions

The RS method of deadlifting was not significantly different from the TG method in CR determination. These results depict the reliability of this CR mathematical determination across deadlifting methods. Though not significantly different, the RS and TG methods of deadlifting for determination of CR may differ in anatomical region of fatigue. Individual variability in repetition counts at CR values for each method implicate the need for further research involving the confounding variables of volitional exhaustion, performance enhancing equipment, and grip strength fatiguability. This variability suggests that neither method is inaccurate but should not be used interchangeably for comparisons of athletic performance. Future studies should examine: 1) the efficacy and impact of potentially performance enhancing equipment (i.e., weight belts and wrist straps) on CR determination for the deadlift and, 2) the impact of grip strength fatiguability on both RS and TG methods of deadlifting.

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