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The Validity & Reliability of the Repetitions in Reserve Based Rating of Perceived Exertion Scale in Single Joint Exercise

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THE VALIDITY AND RELIABILITY OF THE REPETITIONS IN RESERVE BASED RATING OF PERCEIVED EXERTION SCALE IN SINGLE JOINT EXERCISE

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ABSTRACT

Introduction: Intentional regulation and individualization of resistance training schemes are imperative when structuring a resistance training program. Optimal adaptation cannot be expected without proper manipulation of training variables such as load and volume. Load is traditionally prescribed by testing a given exercise's repetition maximum and basing intensity from that load. This method of intensity regulation may be limited, considering it fails to recognize the day-to-day undulation of individual performance which can be impacted by several variables. A flexible method of regulating load and volume would be of use for those undergoing a resistance training program. The repetitions in reserve-based rating of perceived exertion (RIR-RPE) scale is a perception-based tool used to autoregulate the intensity of a lift. RIR-RPE allows for the user to govern programming variables such as load and volume on a day-to-day basis. **Purpose:** The aim of this study was to assess the validity and reliability of the RIR-RPE scale in single joint resistance exercise. **Methods:** 12 participants (7 male and 5 female) (age: 20.42 ± 1.98 years, training age: 5.83 ± 3.19 years, weight: 76.59 ± 16.74 kg, height: 1.72 ± 0.09 m) volunteered for this three-session study, each separated by a minimum of 48 hours. Session one included anthropometric assessments and 8RM tests for unilateral bicep curl and leg extension exercises. Participants were also familiarized to the RIR-RPE scale in session one. In session two, participants completed three sets at 70, 75, and 80% of predicted one repetition maximum for nine, seven, and five repetitions, respectively. After completing the assigned number of repetitions, participants were asked to pause and indicate a value on the RIR-RPE scale before continuing the set to technical failure. Velocity was measured on the repetition RIR-RPE was gathered and the final repetition before failure. Session three was the same as session two to assess reliability. Participants were randomized and blinded to the order in which they were exposed to the intensities. **Results:** Participants tended to underpredict RIR by approximately one repetition (1.02 ± 0.32) on average. Participants became more accurate in their predictions in session two (0.93 ± 0.44) compared to session one (2.78 ± 0.73). Calculations of intraclass correlation coefficients for absolute agreement revealed moderate to strong agreement between estimated- and actual-RIR in the bicep curl with a range of (0.51 – 0.91) and weak to moderate agreement in the leg extension with a range of (0.183 – 0.66). Reliability was low to moderate in the bicep curl with a range of (0.26 – 0.64) and low in the leg extension exercise with a range of (0 – 0.102). A negative relationship between RIR-RPE and velocity was at 70% (r = - 0.62, p = 0.023), 75% (r = - 0.86, p = 0.00017), 80% (r = - 0.42, p = 0.15) in the bicep curl and at 70% (r = - 0.8, p = 0.0016), 75% (r = - 0.77, p = 0.0021), 80% (r = - 0.67, p = 0.12) in the leg extension. **Conclusions:** The RIR-RPE scale is not perfectly accurate. The meaningfulness of an underprediction on one RIR has yet to be investigated. Individuals using the RIR-RPE scale tend to get more accurate over with experience. The RIR-RPE scale may not be reliable in single joint exercise until the individual using the scale has adequate experience. **Practical Applications:** Athletes and practitioners may consider using the RIR-RPE scale as a flexible way of autoregulating resistance training variables.

Key Words: RPE, Repetitions in Reserve, Single Joint Exercise

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CHAPTER I

THESIS INTRODUCTION

Physical activity is defined as the movement of the human body produced by skeletal muscle that requires energy expenditure above resting values. Physical activity can take many forms, such as work, recreation, and sport. The intensity in which individuals engage in physical activity will impact how long they can sustain the work as well as how difficult the work feels. Nearly all physical activity requires some form of strength, speed, power, or flexibility. These components are useful to the average individual for everyday activity as well as athletes seeking elite performance.

Resistance training is a method of increasing strength, speed, power, and/or flexibility. Individuals will typically identify a goal to serve as an outcome of the resistance training. This goal can be as general as improvements in strength, hypertrophy, and power, to specific improvements in athletic performance. Resistance training has also been shown to reduce body fat, increase basal metabolic rate, decrease blood pressure, improve blood lipid profiles and inulin sensitivity, attenuate muscle sarcopenia, reduce the risk of osteoporosis and colon cancer, and aid in the maintenance of long term independence and functional capacity (41,44,75,80,110). These benefits also play a role in an individual's quality of life. Overall, the incorporation of a regular resistance training program into a training regime can yield performance and health benefits.

Appropriately programmed resistance exercise can maximize individual progress. Professionals structure periodized programs designed to develop the individual and reach their health and fitness goals. Variables such as load, rest intervals, and recovery should be managed in order to deliver a stimulus that is specific to the identified goals. Assessments of performance (e.g., strength, speed, power) are completed at the beginning of a resistance training program and periodically throughout to evaluate the efficacy of the periodization design. However, these sporadic snapshots of function are prone to error as many factors external to the gym can influence an individual's daily abilities.

Autoregulation is the practice of daily load adjustment based on the lifter's abilities (134) so that they align more closely to athletes' competency on a particular day. Because autoregulation can be quantified without exhaustive or time-consuming testing, it may be an appealing evaluation tool for fitness practitioners. There are several ways to autoregulate a resistance training program, though two of the most popular are assessing movement velocity and the lifter's rating of perceived exertion.

Velocity based training (VBT) is a programming strategy that considers the lifter's movement velocity (typically during the concentric phase of a lift) as a variable to consider for exercise prescription. Data from VBT can be used to estimate 1RM values, allowing for load to be adjusted based upon an individual's daily performance. Furthermore, VBT can be used to quantify an individual's fatigue, which can be a useful marker of when load should be adjusted (e.g., lower than desired velocity is indicative of fatigue and need to reduce load). Monitoring velocity as a training tool can be an effective way of tracking and adjusting load or other programming variables based upon the performance of an individual on a particular training session. Unfortunately, the tools needed to monitor velocity are typically expensive and may not be available to some.

Rating of perceived exertion (RPE) is a tool used for exercisers to subjectively report how difficult an activity feels (23). This type of subjective scale has a growing body of literature supporting its use to manage the variables in a resistance training program as there is a clear relationship between perceived exertion and maximal lifting abilities (108). A recently developed perceived exertion scale, repetitions in reserve (RIR) based rating of perceived exertion (RIR-RPE), has been effective in adapting load so that it more precisely taxes the individual based on their ability that session (66). In practice, RIR-RPE is typically collected after the lifter finishes a set. It functions to evaluate how many more repetitions the lifter thinks they could have completed if the set were to have been conducted to failure. This scale is useful to both athletes seeking performance (7) and the average individual seeking to obtain health benefits (53,66) as it is simple to use, cost effective, and minimally invasive.

Overall Purpose and Study Significance

The purpose of this review is to explore resistance training and the ways in which it can be optimized, with a focus on the efficacy of using RIR-RPE to autoregulate resistance training variables. Secondary to the review, a study was developed to assess the validity and reliability of the RIR-RPE in upper and lower body single joint exercise. A secondary aim of the study was to determine if there is a relationship between movement velocity and RIR-RPE values. To the authors' knowledge, no study has validated the use of the RIR-RPE scale in single joint exercise. The use of RIR-RPE in accessory exercises, such as the bicep curl and leg extension, has the potential to better tune loading and progression in resistance training periodized programs.

Potential Limitations

- Participants may range greatly in training age
- Prior exposure to and ability to apply RPE or RIR-RPE
- Differences in performance determined by genetic variation

- Recovery status
- Different levels of familiarity with exercises tested

CHAPTER II

REVIEW OF THE LITERATURE

This literature review begins with an overview of resistance training. Next, a summary of periodized training is outlined. Components of a resistance training program such as assessments of strength and exercise selection are discussed prior to the components of a resistance training program and velocity. Factors that impact fatigue and recovery in a RT program are detailed next. Finally, methods of autoregulation and ratings of perceived exertion are reviewed.

Resistance Training

Resistance training (RT) describes the use of an external load to bring about desired muscular adaptations. Training outcomes can be realized as improvements in both health- and skill-related fitness (81). Trained individuals experience an array of adaptations, including improved muscular strength, flexibility, power, hypertrophy, and endurance. More related to sport, RT can improve speed, agility, balance, coordination, and other measures of motor performance (3).

Physiological systems in the body are highly plastic, capable of responding to any novel stimulus. Selye's general adaptation syndrome states that the body responds to stress in three phases: alarm, resistance, and exhaustion (122). The alarm phase is an accumulation of fatigue along with a reduction in performance. The body then moves to the resistance phase in which it adapts to the stimulus and performance is restored. If fatigue accumulates more rapidly than the body can recover, an individual will reach exhaustion rather than experience improved performance. The exhaustion phase is associated with an athlete who is unable to adapt to the stress placed upon them. A properly periodized RT program can help to avoid the exhaustion phase of Selye's general adaptation syndrome. In essence, periodization is a means of fine-tuning training overload to promote Selye's resistance phase. Program design backed by scientific evidence balances the need for a stress to stimulate adaptation without overtraining and exhaustion (131).

A specific and intentional RT protocol is necessary to optimally stimulate adaptation toward training goals. Characteristics of a balanced and effective training program include the use of concentric, eccentric, and isometric muscle actions, performance of uni- and bilateral movements, and single- and multiple-joint exercises (3). Notably, there are several additional principles that compose an RT program capable of continually eliciting specific training adaptations. Practitioners give special attention to the principle of progressive overload, the gradual increase in stimulus exposed to the working musculature. Methodically increasing stress on the body is important for continual adaptation; otherwise, a plateau would occur and progress would slow or stop (81). Progressive overload can be achieved via the manipulation of one or more of the following variables: exercise intensity (e.g., absolute or relative load for a given exercise/movement); total repetitions performed; speed/tempo of a repetition; length of rest periods (shortened to improve endurance or lengthened to support strength and power training); or training volume (total work = total repetitions performed x resistance) (3). While progressive overload is essential for the continuance of adaptation, an RT program must be designed specific to a training goal or goals.

The principle of specificity states that the adaptations realized from RT are "specific" to the stimulus applied. Particular physiological adaptations to RT are determined by multiple factors, including muscle actions involved (38), speed of movement (26,30), range of motion (76), muscle groups trained (78), energy systems involved (135), and training intensity and volume (113). Considering and manipulating these training principles into a systematic, cyclical, non-linear plan is often referred to as periodization.

Periodization

It is considered best practice for a periodized RT program to be structured around desired physiological adaptations. These periods or phases of training (preparatory, transition, competitive, second transition) are designed around a specific performance goal, often dictated by sport season (e.g., pre-season, in season, off season) (61,130,149). The preparatory phase describes when there is no competition for sport; the goal is to develop a base level of conditioning to allow for higher levels of work to be tolerated (61). The first transition phase is a shift toward strength and power development that will be later translated to sport-specific tasks. The competitive phase is meant to prepare the athlete for competitions by further increasing strength and power via an increase in intensity and a reduction in volume (61). Sport-specific skill training increases dramatically in this period, so volume in the weight room should decrease accordingly. Practitioners should take care to ensure that levels of fatigue do not exceed an athlete's recovery capabilities. The second transition period is often used to allow the athlete to recover from the competitive period by reducing training volume for a short time (61).

Periodization is considered a core component of the training process and provides the conceptual framework for designing a RT program (36). Evidence indicates that highly trained athletes use some form of periodization, as their bodies require more stimulus and variation than untrained individuals (36). The two core models of periodization are parallel (e.g. traditional models) and sequential models (e.g. block periodization) (149). The traditional model can be constructed from four consecutive phases: 1) preparation, 2) competition, 3) peaking, and 4) transition or active rest. Traditional periodization resembles the phases and transitions previously described.

Alternatively, block periodization concentrates training loads into "blocks" to develop specific physiological systems and motor abilities as opposed to following training seasons (13,71). For instance, block periodization may be separated into strength, speed, and endurance blocks that come one after another in an annual training plan (17). Unlike traditional, block periodization can be structured to allow for multiple peaks, which may be more applicable to sporting events with longer seasons or multiple tournaments.

The current literature suggests that a periodized RT program may yield greater increases in maximal strength when compared to non-periodized programs, regardless of age and sex (149). Some suggest that block style periodization may elicit superior training outcomes (36); however, others point out that the optimal style of periodization will vary depending on the individual (36,130). In order to tune in the loading schemes for periodization phases, practitioners need to have a valid and reliable mechanism to assess muscular strength.

Assessing Strength

Muscular strength is often defined as the ability to exert a maximal force on an external object or to overcome a resistance (72). Having a high level of muscular strength may improve performance in athletic events and reduce the risk of injury (130). Strength is much more than a sport-related metric; some level of muscular strength is essential for activities of daily life. For instance, greater strength in older adults increases their ability to function independently as well as improve their quality of life (74,85,128). Adequate lower body muscular strength is also associated with a reduced risk of mortality. (39) These factors bring to attention the importance of muscular strength to both athletes and the general public.

Strength can be assessed in several ways, such as in a laboratory via isokinetic dynamometers and free weights. Isokinetic strength assessments require equipment that may not be available to some (due to expense and physical space limitations) and is typically only used in single-joint assessments (72). An alternative muscle strength assessment is the one-repetition maximum (1RM) test. The 1RM test is defined as the maximal amount of weight that can be lifted once, while also maintaining the correct lifting technique (72).

1RM testing has several advantages compared to isokinetic testing. First, 1RM testing requires dynamic movements. Dynamic movements better reflect those performed in an RT program and daily living, as speed of movement and range of motion is rarely fixed in free living conditions. Furthermore, 1RM testing can be used to assess multiple joints at once, also known as compound movements. Because 1RM assessments require less expensive equipment, it is considered cost-effective. The 1RM test has been shown to be safe in a variety of populations including children, older adults, and clinical populations (21,42,84). It is also a useful tool to measure the efficacy of a strength-focused RT program by assessing progression of individuals across time (test-retest). 1RM assessments maintain a high level of test-retest reliability regardless of RT experience, the number of familiarization sessions, exercise selection, part of the body assessed, sex, and age of participants (72).

Practitioners may choose to implement a repetition maximum test rather than a 1RM. Multiple-repetition maximum testing (multi-RM) describes the gradual increase in load to find the greatest resistance a person can complete for a target number of repetitions. For example, an 8-repetition maximum (8RM) test will continue to increase load until only 8 repetitions can be performed. The goal repetitions for a multi-RM test can be determined based on the number of repetitions that will be performed in the training program (61). Multi-RM tests can be done on multi- and single-joint exercises. Practitioners must consider, however, that the multi-RM testing sets can become fatiguing, potentially diminishing the validity of the test (133). This may be particularly significant in exercises that use multiple joints and large muscle areas due to the high metabolic demand of such movements (61). The occurrence of delayed onset muscle soreness after strength assessments is a concern some researchers have shared (18,56). Fortunately, multi-RM testing does not seem to be associated with delayed muscle soreness (2). Though there is not a large sample of literature to evaluate, it does appear that the 8RM test is a valid measure of muscular strength, regardless of sex (133).

Multi-RM assessments are often considered a safer alternative to 1RM testing (though 1RM is relatively safe itself) (138). Single joint, or assistance exercises (exercises that assist in the development of muscles used in the core lifts), may not be suited for 1RM testing due to the isolative tension placed upon the involved joint and connective tissue (61). In this case, multi-RM testing is an option to minimize such stress. When evaluating single joints, multi-RM testing should be at or above an 8RM to reduce the risk of injury

(61). Multi-RM testing has been shown to be safe and reliable in both trained and untrained individuals (93). It has also been shown to be a valid assessment for knee extension, overhead press, and bench press exercises (19).

Similar to 1RM, the multi-RM test shares the advantages of the 1RM test in that it is a highly accessible and cost-effective means of determining strength, as well as useful in tracking athlete progress and efficacy of an RT program. Beyond this, multi-RM testing has the advantage of being safe for use in single-joint assistive exercises. Due to their safety, multi-RM tests allow lifters to measure performance and progress across a variety of exercise selections.

Exercise Selection

Exercise selection is an integral part of building an RT program. Practitioners should consider the goals of an RT program to guide which exercises are selected. Exercises can be varied in several ways: upper body, lower body, single- and multi-joint, machine-based, free weight, bilateral, variable load, and unilateral exercises (though others could be mentioned). Including a variety of exercises can assist in reaching the specific goals by avoiding plateauing performance.

Because most sports require high levels of muscle mass and skill, incorporating all areas of the body is needed to develop as a well-rounded athlete. Interestingly, a “transfer effect” has been reported between the lower and upper body. These studies suggest that individuals may experience greater increases in muscle size, strength, and power when upper and lower body RT interventions are performed in tandem compared to isolated upper or lower body RT (14,88). Others have reported greater isometric strength gains when upper is coupled with lower body RT compared to upper body RT alone (64). These studies highlight the importance of designing an RT program with upper and lower body exercises, as they have synergistic effects on one another.

Single- and multi-joint exercises are suitable for a RT program regardless of the training age of an individual (79). Both exercise types can increase strength of the muscle groups involved, regardless of modality (e.g. free weights, machines, cables, etc.) (3,31,79). Multi-joint exercises require a higher level of skill to perform (3) and elicit a greater neural response than single-joint exercises (24). It is generally agreed that multi-joint exercises are more effective in developing muscular strength due to an athlete's ability to lift greater loads across multiple joints (129). It is important, however, to consider the value of single-joint exercises. They are typically used as assistive movements to complement multi-joint exercises and are capable of targeting specific muscle groups. Furthermore, these lifts require less skill and technique to perform as compared to multi-joint exercise (3).

Multi- and single-joint exercises can be performed with free weights and weight machines. Weight machines are generally regarded as safer to use, easier to learn, and may allow the performance of some exercises that would be unrealistic to perform with free weights (e.g. leg extensions, leg curls) (3). Machines assist in stabilizing the body and limiting muscle and joint translation outside of a safe movement path. Machine-based training may be more appropriate for beginners as it has been shown to require less neural activation and inter- and intramuscular coordination than free weight exercises when intensity was matched (3,92).

Free weights may more closely mimic the movement requirements of specific tasks performed in a sporting event. It may be for this reason athletes regularly engage in free weight training to maximize performance. Both machine-based and free weight training are relatively specific, in that machine-based training results in better performance on machines, and free weight training results in better performance in training with free weights (18). It appears, from a neural perspective, that machine-based and free weight training result in similar improvements in strength (150).

Exercises can be further varied by performing movements unilaterally (single-limb) or bilaterally (both limbs). There exists cross-education between bilateral and unilateral training (54). Cross education is strength gain or skill improvement that is transferred to the contralateral limb following unilateral training or practice (54). Unilateral and bilateral training have been shown to result in similar adaptation in strength and power (54). A combination of both unilateral and bilateral training is likely optimal for strength development and transfer to athletic performance.

Unilateral and bilateral training may be considered for those dealing with a bilateral deficit which occurs often in trained individuals (125). A bilateral deficit describes when the force produced via simultaneous contraction of both limbs is lower than the sum of forces produced by the left and right limbs separately (69). Cross education is witnessed in unilateral training, wherein the training of a single limb increases strength of the contralateral limb, may reduce the presence of a bilateral deficit (125). Bilateral training may also reduce this bilateral deficit (125). Regardless of the attributes of a particular RT exercise, it remains important to select exercises specific to the movements involved in an athletic event.

Exercise selection should be done with purpose. Practitioners should consider the goals of an RT program, the ability of the individual, the movements of the sporting event, and the individual's training experience. Once a program is designed and implemented, professionals use many metrics to evaluate the efficacy of the design and progress of the athlete.

Training Outcomes

As discussed previously, RT programs are typically structured around training goals. These goals are typically measured in muscular strength, power, and hypertrophy through tests like 1RM and multi-RM testing, muscle biopsy, measures of velocity, and measures of electromyography (EMG).

Velocity of Movement

Practitioners most often use a percentage of 1RM or a rating of perceived exertion to identify a relative load that will achieve a given number of repetitions (52). An alternative method of prescribing intensity may be based upon movement velocity during the concentric phase of the lift. From this, coaches can create a velocity/load profile (58). Though prescribing intensity allows for training individualization and identifies an athlete's progression, it may not be optimal when used alone. Inter-daily athlete strength variability and the need to retest 1RM values for multiple movements pose as disadvantages (58). Basing intensity solely on 1RM testing can be time-consuming, making proper 1RM evaluations for large groups and teams impractical (86).

Velocity-based training (VBT) has gained popularity as a means of monitoring exercise intensity (50). VBT is the movement velocity of repetitions and has been utilized by practitioners to prescribe the intensity of an exercise (58). VBT allows for the estimation of 1RM from the mean concentric velocity of repetitions performed, without the need for an actual 1RM test (58). The principle behind VBT is the inverse relationship between velocity of bar movement and load lifted. It is this relationship that provides validity to the estimation of 1RM via velocity assessments (37,50). To implement VBT, practitioners need the concentric velocity of the fastest repetition for each respective exercise and the percentage of velocity lost across a set (58).

The inverse relationship between velocity and load allows for an accurate estimate of 1RM for any exercise where average concentric velocity can be measured. This method is considerably more time efficient compared to measuring 1RM and can be adjusted to account for variation in daily performance (58).

Velocity can also be used as a measure of fatigue (120). Fatigue can be characterized by velocity lost over multiple sets or repetitions performed in a set (105). Monitoring repetition velocity is a practical and non-invasive way to estimate the acute metabolic stress, hormonal response, muscle damage, autonomic cardiovascular response, and mechanical fatigue induced by RT (51,104,105,120). Repetition velocity loss can also determine the degree of effort in each set and equalize the level of effort for multiple lifters working at different loads (118). Velocity loss experienced during sets may serve as an objective measure to monitor the degree of fatigue and the lifter's daily performance (85).

In RT, barbell velocity is typically measured using a linear position transducer (e.g. (TENDO Sports Machines, Trencin, Slovak Republic) (58). This kinematic device is typically composed of a computer and a retractable cable that is attached to the object to be measured (e.g., barbell, dumbbell, gym equipment, athlete limb) (58). The computer directly measures the vertical displacement of the cable and sends live feedback to the display for real-time velocity monitoring (101). Linear position transducer assessment is valid and reliable for monitoring velocity during RT (49,101)

VBT has been incorporated into RT programs of recreational and elite athletes. The current literature suggests that incorporating VBT into a RT program can be an effective method of enhancing sport-specific performance (58). When considering the integration of VBT into a periodized RT program, movement velocities and velocity loss can be monitored to ensure that the desired adaptations are being met (e.g. power or strength adaptations) (58).

Investigations have shown that individuals completing VBT training have faster mean movement velocities compared to traditional 1RM training. (11). This training adaptation can translate directly into movements that require high levels of power (e.g., power clean, snatch, jerk). One study found more favorable outcomes in strength and power after VBT compared to 1RM, despite a reduction in total training volume when groups were compared (37). Despite its advantages, VBT's use may not be maximized by individual athletes in real-time as there is little feedback translated directly to the lifter amid performance. It may be prudent to identify a relationship between velocity and perceived exertion, similar to the relationship to 1RM. There are many factors to consider that impact the lifter's perceived exertion, such as fatigue, rest intervals and recovery.

Factors Impacting Fatigue

In order to make changes, the body must be exposed to a sufficiently tuned stressor to adapt while avoiding injury. Fatigue occurs secondary to stress of exercise within a set, session, or RT program. There are various factors to consider that contribute to fatigue, including neural fatigue, calcium (Ca^2+), blood flow, glycogen availability, and metabolic factors (140).

Fatigue

Fatigue can be managed through the proper structuring of rest intervals, and intersession recovery. For the purpose of this review, muscular fatigue is an exercise-induced decline in the ability of a muscle's maximal force production or power, despite continued effort *(16,40,126)*. Fatigue is a common symptom *(140)* that can be described as a sense of tiredness, lack of energy, and feeling of exhaustion experienced during exercise *(140)*. There are several mechanisms which may affect muscular fatigue, though none can fully explain the phenomenon.

Neural Fatigue

Neural contributions to fatigue can be separated into origins from the central or peripheral nervous systems. The central nervous system (CNS) produces various excitatory and inhibitory inputs on the spinal cord via neurotransmitters (140). These neurotransmitters arrive to downstream skeletal muscle, ultimately leading to activation of motor units to achieve muscular contraction. Over the course of a workout, the rate at which motor units are recruited is slowed, contributing to the loss of force output (140). Motoneurons also experience a reduction in firing rates as a result of fatigue (reduced rate coding). This onset of motoneuron fatigue comes from a decrease in their excitability secondary to repetitive firing, excitation from the motor cortex or other supraspinal areas, and firing of muscle spindles (133,139,140).

Calcium

Neural activation and $Ca^{2}+$ work hand in hand to produce muscular force. Stimulation from the somatic nervous system depolarizes the muscle's sarcolemma, passing the activation through the transverse tubules, leading to the release of $Ca^{2}+$ from the sarcoplasmic reticulum into cytosol, initiating cross-bridge cycling (87). The impaired release of $Ca^{2}+$ has been identified as a factor which may contribute to muscular fatigue. There are a few physiological justifications as to why $Ca^{2}+$ may play a role in muscular fatigue (1), but for the purposes of this review, simply reducing $Ca^{2}+$ release (regardless of etiology) results in less sites available for myosin to bind to actin, thus resulting in a reduction in force output.

Blood Flow

Blood flow works as a shuttle to bring oxygen and nutrients to and remove metabolic by-products from working muscles (140). Voluntary muscle contractions are associated with an increase in mean arterial blood pressure, which can result in a decrease in net blood flow to the working muscle and induces fatigue (33,140,151). However, this contraction-blood pressure relationship is dependent on the intensity of muscle contraction. For instance, high intensity RT can lead to blood flow occlusion due to musculature compressing the vasculature; this results in a reduction of time to exhaustion and the magnitude of force production's decline increases (27,34,82,109,132). Some have found that the decline in force production preceded significant changes in blood flow to the muscle (146) and that oxygen plays a significant role in fatigue at moderate to high intensity aerobic exercise (140). However, because RT rarely achieves such intensity, it is likely not a primary factor contributing to fatigue in RT exercise.

Glycogen Availability

A reliable supply of energy in the form of ATP is required for a muscle to contract and produce force. Glycogen is fundamentally accepted as the fuel used to recreate ATP during resistance-type exercise (103). Glycogen is stored in three distinct skeletal muscle subcellular locations: intermyofibrillar (between myofibrils near the sarcoplasmic reticulum and mitochondria), intermyofibrillar (within the myofibrils and most often in the I-band of the sarcomere) and subsarcolemmal (beneath the sarcolemma and primarily next to the mitochondria, lipids, and nuclei) (140). The majority of total glycogen (~ 75%) is stored as intermyofibrillar glycogen (97). Excitation-contraction coupling may be affected by glycogen levels via impaired release and reuptake of $Ca^{2}+$ and interference with function of the sodium-potassium pump(25,98,103). When glycogen stores are depleted, exercise cannot continue. Beyond the physiological ramifications of depleted glycogen, there appears to be an inverse relationship between muscle glycogen availability and rating of perceived exertion (RPE) (29).

Metabolic Factors

Exercise is fueled by a fine balance between energy (ATP) expenditure and its recreation. A consequence to accelerated activation of bioenergetics is the accumulation of intracellular metabolites such as hydrogen (H+), lactate, inorganic phosphate (Pi), and reactive oxygen species (ROS); all of which affect crossbridge activity (140). Excess H+ causes [1] pH to decrease and acidosis to occur; [2] impaired cross-bridge cycling due to interference with $Ca^{2}+$ release from the sarcoplasmic reticulum; [3] decreased troponin C sensitivity to $Ca^{2}+$ (106,140).

The concentration of Pi can rapidly increase during intense exercise. Elevated levels of Pi substantially impairs myofibrillar performance, decreases sarcoplasmic reticulum $Ca^{2}+$ release, and contributes to a reduction in myosin-actin binding (2,140,144). As aerobic or anaerobic work intensity increases, so does the rate of ROS production (124). ROS contribute to fatigue by interfering with the release of $Ca^{2}+$ from the sarcoplasmic reticulum, changing myofibrillar Ca^2+ sensitivity, and activating group IV muscle afferents (32,35,140). Metabolic related fatigue can be managed to some degree by properly structuring rest and recovery intervals between sets and sessions.

Rest

The rest interval granted between sets is an important training consideration that affects both the acute and chronic responses to RT (119). Recommendations concerning rest intervals are typically prescribed based on the training goals (e.g., strength, power, hypertrophy). Potentially more important than meeting these goals, however, is the individual's ability to maintain the number of repetitions across sets (147).

Several factors must be considered when selecting the rest interval duration movement being performed (e.g., multi-joint versus single joint exercises, upper versus lower body), age, sex, and training experience. The American College of Sports Medicine recommends rest intervals of two to three minutes in multi-joint exercises and one to two minutes for single joint exercises (3). Lower body musculature may possess greater endurance characteristics compared to the muscles of the upper body (119,148). Practitioners may consider selecting longer rest intervals for compound movements involving upper body musculature (e.g. bench press) and shorter rest intervals for compound movements involving lower body musculature (e.g. barbell back squat)0 if time is limited (119).

Age and sex may also play a role in selecting rest intervals for RT. The current literature suggests that younger individuals (19-39 years of age) require longer rest intervals than older individuals (≥ 65 years of age) to allow for adequate recovery (56). It appears that women have greater recovery capacity and reduced fatigue as compared to men, making it important for men to consider longer rest intervals compared to female counterparts (111). Practitioners should also consider an individual's training experience when prescribing rest intervals. Trained athletes likely have a higher resistance to fatigue as compared to recreational and novice lifters. Untrained individuals may need as much as five minutes of rest in order to keep repetitions consistent across sets (92).

Most literature supports a rest interval length between one and five minutes for strength training (119). Shorter rest intervals (i.e. one minute) appear to be insufficient for recovery as they significantly reduced the number of repetitions performed when compared to three minute intervals (77)(119). Still, others report that three and five minutes of rest may not be sufficient (115). This suggests that there is likely some interindividual variability (e.g., training age, sex) in time needed between sets. Rest intervals are subject to change with the intensity of the load being lifted and may vary depending on the proximity to concentric failure (119).

Recovery

Adequate recovery from RT is necessary to see adaptations and avoid injury. One variable of interest regarding recovery is training frequency. Training frequency refers to the number of RT sessions performed in a given time period, usually a week (107). Recovery periods, or the time between sessions, should be monitored to identify when it is appropriate for the athlete to train again, while avoiding overtraining (121). The American College of Sports Medicine recommends a recovery period of 48 to 72 hours before training the same major muscle groups previously trained for programs designed to elicit hypertrophy and strength adaptations in recreationally trained lifters (47).

Those interested in this vein of investigation implement several measurement techniques to evaluate RT response and recovery; these include external workload (e.g., volume-load), metabolic responses (e.g., blood lactate), EMG activity, and RPE (107) . A limited number of studies have assessed how different recovery periods (e.g., 24, 48, 72, 96, and 120 hours) impact repetition performance (73,94). In these studies, there was a large amount of interindividual variability as well as differences in the recovery of different muscle groups. Some have found that recovery periods of greater than 24 hours were needed to achieve greater training volume for upper body exercise and avoid the negative impact of fatigue on myoelectric activity in upper body muscles (107). It appears that recovery of 72 hours produced no difference in sEMG or session volume load compared to 48 hours, suggesting more rest may not necessarily be more beneficial (107). Because of such variability, the most accurate method of establishing proper rest periods is likely through individual testing (94).

There are many factors that impact fatigue, including those discussed as well as many more beyond the scope of this review. These factors not only impact the body physiologically, but also psychologically. As mentioned earlier, depleted glycogen is known to make exercise feel more difficult. Perceived exertion may be lower when rest is passive when compared to active, though blood lactate failed to differ between conditions (141). The interplay of physiological and psychological experiences to fatigue makes an interesting avenue for future investigations.

Feedback

Feedback in RT may provide an acute increase in performance (6,8,95,142). However, feedback may be a useful tool in aiding individuals in setting where maximal performance is the goal. Modes of feedback to regulate exercise include visual, verbal, and perceptual (8,143,145). Visual feedback, such as visual kinematic information (e.g. visualization of movement velocity), may enhance mean concentric velocity, motivation, and competitiveness (143). Visual kinematic feedback may be particularly useful when training quality is of importance (e.g. power development blocks) (143) and training sessions with high volumes. This feedback has been hypothesized to reduce levels of fatigue, which in turn may allow individuals to meet higher volumes (143).

Auditory feedback (e.g. practitioner provided kinematic feedback and verbal encouragement) can increase peak force, strength, and mean concentric velocity (95,95,142). Furthermore, the use of auditory feedback as both kinematic information and verbal encouragement appears to attenuate loss in mean concentric velocity across a set (142)**.** Increases in performance from visual and auditory feedback appear to be similar when the two are compared, indicating that practitioners may choose to provide either to lifters (142)**.** Perceptual feedback of intensity (e.g. RPE) allows for individuals to more closely adhere to a desired training intensity (145). Self-regulation through use of RPE allows individuals to avoid training at too high or low an intensity, therefore allowing for the appropriate training stimulus to be met. It should be noted, however, that verbal encouragement is the most cost-effective option as it does not require any additional equipment to provide information.

Autoregulation

Manipulating training variables based upon the perceptual or performance feedback of a lifter can be referred to as autoregulation (AR) (153). Autoregulation is defined as a sub-type of periodization, a design in which the training load and volume is matched with the lifter's rate of adaptation (89,153). Typically, AR is based upon performance or perceived capability to perform (55). There are currently two modes of AR implementation in the research literature. The most represented approach is to measure and manipulate training on a daily basis (e.g. RIR-RPE) (65). Daily manipulation of training allows for adjustments to be made that may be caused by both training- and non-training related stressors (55).

The second approach to AR is to measure and manipulate training less frequently (perception reviewed weekly, monthly, or per training block) (89). This use of AR is indicative of more chronic changes brought upon by training related stressors (55). Growing evidence suggests that the AR may be better than more traditional, predetermined loading strategies intended to improve strength and lean muscle mass (28,89,96,112). Traditional RT programs are prescribed using single baseline measures of performance (e.g. 1RM testing) that occur at the beginning of a training cycle (37). Some have hypothesized that this practice may lead to suboptimal loading schemes (123), as AR of load allows for loading to be flexible and individualized (63). Added benefits of AR include real-time adjustment to loading schemes as strength changes across time without the need for frequent retesting. Moreover, the training stimulus would more closely align with a lifter's current performance level and lead to outcomes more specific to training goals (55,67).

Rating of Perceived Exertion

The perception of physical exertion includes feelings of effort, strain, discomfort, and fatigue; these sensations may be experienced during exercise (117). The prolonged performance of exercise with a fixed load will eventually result in a reduction in a lifter's ability to meet the demands of the exercise (i.e. fatigue), thus a greater effort is needed to maintain performance (9). As fatigue builds, so also does the individual’s perceived exertion (70,99). A scale that measures rating of perceived exertion (RPE) was initially developed by Gunnar Borg in the early 1960’s (116), and it remains the primary tool used to monitor perceived exertion during aerobic exercise (66,116). This initial scale of 6-20 was developed to roughly match heart rate (116), thus applications to RT are limited. Other scales were later developed such as Borg’s category ratio scale (CR10) which provides RPE from 1-10 (116) and a visually aided 1-10 scale known as the OMNI scale (116). These scales have more recently been used to gauge perceived effort during RT exercise.

Many will prescribe RT loads based on a percent 1RM (46). Despite its popularity, several mechanisms for error exist in this method. Error is induced into 1RM testing in test administration or abnormal lifting performance (153). Other performance impacting factors include sleep (22), nutrition (68), recovery abilities (45,136) and stressful life events (12); these antecedents may influence strength on 1RM testing and daily performance (66).

There are a number of reasons why basing training load off of a percentage of a previously measured 1RM may lead to erroneous loading schemes failing to represent an individual's inter-daily performance capacity (66). Additionally, it is commonplace to use tables showing a range of repetitions allowed for a given percentage of 1RM (61). However, there is evidence to indicate that the number of repetitions that can be performed at a given percentage of 1RM varies between individuals (114). The use of a perceptual scale would compensate for the variation between individual capability relative to 1RM as well as accounting for daily fluctuations in strength (66).

The repetitions in reserve-based RPE (RIR-RPE) scale, first developed by Tuchscherer, incorporates an objective measure of repetitions in reserve (RIR) (or repetitions that could have been completed after the set and before fatigue) and the subjective measure of RPE (137). The validity of the RIR-based assessment tools was first explored by Hackett et al. (2012), who found that individuals were more accurate at gauging RT intensity by estimating their RIR in comparison to the traditional Borg scale (55,60). Hackett's team found that individuals tended to underestimate RPE when using the Borg RPE scale, even when sets were taken to momentary muscular failure (60). It was not until later that Zourdos et al. (2016) merged RIR values to correspond with an RPE scale; they were also the first to investigate the validity of Tuscherer's proposed scale (55,137,153). In the RIR-RPE scale, RIR values correspond to RPE values: RPE of 10 is equal to 0 RIR (maximal effort and no repetitions could be performed after the set); RPE of 9 is equal to 1 RIR; RPE of 8 is equal to 2 RIR, and so on (Table 1) (153). RIR-RPE appears to be most accurate at near maximal loading (60), consistent with recent findings indicating RIR-RPE accuracy improves as a lifter approaches failure (153). Experienced lifters may also be more consistent at accurately predicting RIR (102,153). Practitioners should not see RIR-RPE as the sole mode to prescribing intensity; rather, the RIR-RPE scale may be used in conjunction with repetition ranges or percent of 1RM to ensure that the intended stress matches what is actually experienced by the lifter (66).

Efficacy of RIR

AR using RIR would be a useful method of adjusting training variables throughout a RT program. However, there us limited research on the efficacy of the use of RIR over a training program. Graham and Cleather (53) compared two groups; one group used a fixed loading (FL) scheme based off a percentage of one repetition maximum, and the other group autoregulated load via RIR (AR). The study was designed to measure increases in strength of the front squat (FS) and back squat (BS) across a 12-week program. Experienced strength trained males (16 fixed and 15 autoregulated) participated in the study. They found that both groups had significant increases in strength. The group who AR load based on RIR had significantly greater increases in FS (FL +8.3%, AR +11.7%, p = 0.004) and BS strength compared to the FL group. When volume was matched between groups, however, the AR group trained at a greater weekly intensity. Due to adaptations of strength throughout a training program, it is likely that an initially gathered 1RM will quickly become inaccurate as the program and individual progress. These findings give support to the ability of AR via RIR to allow users to adjust adequately to such adaptations and obtain more favorable outcomes.

Table 1. The RIR-RPE Scale

Rating	Description
10	Maximal Effort
9.5	No more repetitions but could increase load
9	1 repetition in reserve
8.5	1-2 repetitions in reserve
8	2 repetitions in reserve
7.5	2-3 repetitions in reserve
7	3 repetitions in reserve
5-6	4-6 repetitions in reserve
3-4	Light Effort
1-2	Little to no effort

Note: adapted from Zourdos et al. (2016) with permission (153).

Familiarization to RIR-RPE

Introducing, revising, or combining perceptual scales, such as the case of RIR-RPE, practitioners may benefit by establishing anchor points (116). There are two primary ways to anchor an RPE scale, the memory procedure and the exercise procedure. It is important to note that the practice of setting anchor points requires an individualistic approach.

The memory procedure is considered more practical. In practice, an exercising individual is asked to estimate RIR-RPE by using memory of the levels of exertion equal to the desired anchor points on the scale. In the exercise procedure, an individual undergoes one to two minutes of very low intensity exercise, preferably the same mode of exercise that will be performed during the test or training session. The individual should be near the bottom of the scale at the end of this exercise bout. Next, the individual undergoes progressively more difficult exercise that escalates to maximal exertion. The client should be reminded to think of where they are in relation to the scale as they undergo the graded exercise test.

Factors Influencing RIR-RPE Prediction Accuracy

Measures should be taken to ensure that the prediction of RIR is as accurate as possible in order for RIR-RPE to be applied in RT. Factors that could reasonably influence RIR-RPE prediction accuracy include preconceptions of the load being lifted, proximity to failure, percentage of 1RM used, number of repetitions performed in a set, and the training status of the lifter. Though it was believed that knowing the load being lifted would impact RIR-RPE, evidence suggests that it does not have an impact on prediction accuracy (90). It is thereby reasonable to assume that preconceptions of the load being lifted before a set is unlikely to affect a lifter's ability to accurately predict RIR.

Proximity to failure appears to affect the accuracy of RIR predictions. Current evidence suggests the closer an individual is to failure, the more accurate RIR predictions become (i.e. RPE 9 was more accurate than RPE 7) (152). This suggests that RIR-RPE is best used in training that brings the lifter near failure. Evidence is available to suggest that the more repetitions in a set, the less accurate RIR prediction will be (153). Taken together, the most accurate predictions of RIR loading may be close to failure in moderate- to low-repetition sets (152). The literature is inconclusive regarding the impact training age has on prediction accuracy (60,152,153).

Conclusions

RT is an essential activity for those seeking strength related physical adaptations. An effective RT program is made up of many components that must be adjusted specific to the individual. RT is useful for a wide range of individuals from enthusiasts to athletes.

AR has recently gained attention in the literature allowing for some variables in a RT program to be better adjusted to the individual. The RIR-RPE scale poses a relatively new method to deliver an optimal stimulus based upon the lifter on a given day. Coaches, practitioners, and enthusiasts can all benefit by incorporating RIR-RPE into their training regime.

CHAPTER III

THESIS MANUSCRIPT

Introduction

Resistance training (RT) is beneficial to individuals ranging from athletes to recreationally active individuals to older adults. To meet training goals, a RT program should be made and structured around the individual's abilities. There are many variables that can be altered in an RT program, such as load and volume, to best meet goals. Traditionally these variables are largely based off a percentage of a previously performed 1 repetition maximum (RM). However, this method alone may not be representative of a lifter's ability in a given training session. Autoregulation (AR) is a method of altering some of these variables based on the individual's inter-daily abilities (55). AR can be implemented in RT using rating of perceived exertion (RPE) scales. Most RPE scales rely on subjective feedback from the individual, translating their perceptual feelings to a quantifiable value (e.g., 1-10).

An alternative to subjective-only perception scales is the recently developed repetitions in reserve (RIR) RIR-RPE (59). This tool differs from traditional RPE scales by measuring the number of repetitions that can be performed before failure of a movement (objective plus subjective). The scale is typically used at the end of a set to determine the level of effort given in that set given by a lifter anchored by how many repetitions that lifter believed they could complete before they could not continue the exercise. For example, a lifter seeking gains in strength performs 5 repetitions at 80% of their 1RM with an RIR-RPE of 6. The 1RM was gathered four weeks prior to the current session. Based off RIR-

RPE the lifter should likely increase the weight as it is probably too light to elicit strong adaptations for strength.

RIR-RPE has been shown to be relatively accurate in upper and lower body compound resistance exercise for novice and experienced lifters. Though it has potential to be universally applicable in the RT world, many questions remain regarding its efficacy of AR in single joint exercises. The purpose of the proposed study is to assess the validity and reliability of the RIR-RPE scale in upper- and lower-body single-joint exercise. A secondary purpose is to investigate the relationship between velocity and RIR-RPE in upper- and lower-body single-joint exercise. To the authors knowledge, only compound movements have been investigated in such a way (102,153). Determining the validity, reliability, and relationship to velocity of RIR-RPE can better inform practitioners and exercising individuals of the appropriateness of implementing RIR-RPE to autoregulate training sessions.

Hypotheses:

H_o: RIR-RPE will not be a valid tool to autoregulate single-joint resistance exercises.

H_a: RIR-RPE will be a valid tool to autoregulate single-joint resistance training exercises.

H_o: RIR-RPE will not be a reliable tool to autoregulate single-joint resistance exercise.

H_a: RIR-RPE will be a reliable tool to autoregulate single-joint resistance exercise.

H_o: There will be no relationship between RIR-RPE and average velocity in an upper body single-joint exercise.

H_a: There will be a relationship between RIR-RPE and average velocity in an upper body single-joint exercise.

H_o: There will be no relationship between RIR-RPE and average velocity in a lower body single-joint exercise.

H_a: There will be a relationship between RIR-RPE and average velocity in a lower body single-joint exercise.

Methods

Participants

Apparently healthy young adults (aged between 18-28) were recruited from the greater Bowling Green Kentucky community. Participants were recruited by announcements to students, and word of mouth. Individuals who participated in the study had a minimum of two years of experience in RT and had experience in performing the bicep curl and leg extension movements. Volunteers were screened for contraindications to exercise using the American College of Sports Medicine Physical Activity Readiness Questionnaire (PARQ+) (Appendix IV) (4); no volunteers were excluded based on existing contraindications. An a priori power analysis using data from past studies (60,102,153) indicated a needed sample size of eight to power the statistical analyses at 80%.

Session One: Anthropometrics and Strength Assessments

After eligibility was determined but before data collection, participants reviewed the procedures of the experiment, had the opportunity ask questions, and sign an institutional review board approved consent form (Appendix III). Once participants arrived, anthropometric measurements (height, weight, and body composition) were collected. Height was collected to the nearest 0.1 cm using a stadiometer (SECA, Hamburg, Germany). Body weight was collected on participants with no shoes and minimal skin tight clothing on a calibrated scale (COSMED, Concord, CA). Body fat percentage was assessed using air displacement plethysmography on each subject wearing no shoes and minimal skin tight clothing (BodPod, COSMED, Concord, CA) (5,10). Participants were asked to refrain from RT involving the biceps brachii and quadriceps muscles or strenuous aerobic exercise for a period of at least 48 hours prior to each session.

Participants were introduced to the RIR-RPE scale and how it was to be used in each session following the familiarization script established by Zourdos et al. (152) (Appendix I). After a general, self-selected warm-up, participants completed an 8RM bicep curl test followed by an 8RM leg extension test. Men and women can safely complete the 8RM test and researchers can anticipate reliable findings (133). Exercises were completed using a wall mounted pulley system (Titan Fitness, McLean, VA), as pictured in Figure 1. Before leaving the laboratory, participants were given the opportunity to take an informational sheet on RIR-RPE home with them to continue familiarization to the scale (Appendix II).

Figure 1. Visual of lifting equipment used for experimental design.

8RM Assessment Methods

The 8RM test is an assessment in which a participant performs sets of eight repetitions with load of each subsequent set increased until no more than 8 repetitions can be performed (133). This test was conducted on the campus of Western Kentucky University in Bowling Green, Kentucky. The 8RM test is a reliable assessment in both men and women that allows submaximal load to be used thus reducing the risk of injury (133). Assessments of 8RM strength followed the methods previously established in the scientific literature (61,133). Eight repetitions, representing approximately 80% of 1RM, were selected following the guidelines set by the National Strength and Conditioning Association (NSCA) for assistance exercises; maximal strength loading should meet a repetition zone at or above an 8RM to protect the connective tissues and joints used in such exercise (61). The test was conducted on an adjustable cable machine for each exercise. Before attempts began, participants completed a short familiarization session to the bicep curl and leg extension exercises to establish acceptable form, safety guidelines, and use of the RIR-RPE scale. The participant was then asked to identify a conservative estimate of a weight for which they had confidence they could complete only eight repetitions. A successful repetition required the participant to complete the movement through a full range of motion of the respective joint. The participants' upper arm rested on a bar across the chest so that only the elbow joint was mobile (Figure 1). The order of exercises was counterbalanced between the bicep curl followed by the leg extension. Rest periods between each attempt was set at two to three minutes (133). All attempts were observed by the same investigator trained in 8RM testing procedures. The tester ensured that all participants completed each repetition through a full range of motion with appropriate technique.

If the participant successfully completed eight repetitions, the weight increased approximately 5-10%. Load was increased in this manner until the participant could not complete eight repetitions. When this occurred, the last successful load was used as the participant's 8RM. The 8RM was gathered in six attempts or less for all participants. After the 8RM was obtained, 1RM was predicted from an equation developed by Brzycki (20) which was used for sessions two and three.

Session Two: Experimental

Participants returned to the lab for the first experimental session after a minimum of 48 hours, but no longer than two weeks from session one. Participants were familiarized to RIR-RPE using a planned script delivered by the principal investigator (Appendix I). Familiarization required that participants underwent a mental anchoring exercise in which they are asked to recall a time that they pushed a RT lift to local muscular failure. They were then be asked to associate that fatigue feeling with a value on the RIR-RPE scale (likely a score of "9" to "10").

After the anchoring process was complete, participants underwent a standardized warm-up before experimental testing. The warm-up consisted of five minutes of walking on a treadmill at a self-selected pace, followed by three sets of the bicep curl and leg extension at gradually increasing, but low intensities. The experimental design included a total of three sets per exercise, the set, repetition, and intensity prescriptions for the experimental design are outlined in Table 2. Participants were blinded to the intensity, load, and the order of exercise, which was counterbalanced between participants. Furthermore, the order in which the intensity was administered was randomized. Immediately upon completion of the repetitions in each set, participants were asked to briefly pause and indicate a value on the RIR-RPE scale. Immediately after indicating RIR-RPE, participants continued the set to failure. Failure was defined as when one of the following occurred:

proper technique was not maintained (technical failure), a full range of motion was not met (concentric failure), or the participant was unwilling to continue (volitional failure). Technical failure for the bicep curl was defined as an inability to maintain an upright posture and/or the excessive movement of the shoulder joint. For the leg extension, technical failure was defined as the inability of the participant to maintain contact between both hips and the seat and contact with their back and the back rest. During the set, if a participant did not maintain proper technique, they were given a verbal warning. If this occurred a second time the set was ended, and the final repetition was not counted.

Table 2. Experimental Lifting Design

Set	Repetition at which RIR-RPE was collected	Intensity based on estimated 1RM
1	9	70%
2	7	75%
3	5	80%

A Tendo Unit (TENDO Sports Machines, Trencin, Slovak Republic) was attached to the post on a pulley system where the weights were placed to capture velocity of movement. Mean concentric velocity was extracted from the same repetition that RIR-RPE was collected. In addition, the velocity of the final repetition performed before failure was collected. Because each set was performed until failure, the RIR-RPE after the final repetition was assumed to be 10. Velocity and RIR-RPE were compared to see if a relationship existed between the variables in single joint exercise.

Session Three: Experimental

Participants returned to the lab for the final experimental day after a minimum of 48 hours from session two. After the same warm-up from sessions one and two, participants repeated the experimental lifting design from session two to assess reliability of behavior. A visual representation of the study details is provided in Appendix V.

Statistical Analyses

An a priori power analysis using using G*Power (41) revealed eight participants were needed to yield an effect size of 0.72 (60,102,153) with 80% power. Data were evaluated using statistical program R (Vienna, Austria. URL https://www.R-project.org/) and are presented using means ± standard deviations. A two-way intraclass correlation coefficient ($ICC_{2,1}$) with random effects model were used to measure the absolute agreement (validity) of predicted and actual RIR for each session, intensity, and exercise.

Reliability was assessed in a non-traditional way due to the instrument being used. Because there was the potential for variability in the total amount of repetitions completed between sessions one and two due to AR, differences in RIR may have been due to both random error in RIR-RPE and true difference in possible repetitions completed. Consider that a participant reported an RIR-RPE of 8 (2 RIR) on repetition 9 during session one and an RIR-RPE of 7 (3 RIR) on repetition 9 during session two. Reliability analyses on RIR-RPE would indicate inconsistencies between session one and two; however, these should only be considered inconsistencies if the total number of repetitions completed were the same in each condition. If the total number of repetitions at a given intensity between sessions were not the same between sessions, then this inconsistency in the metric originally thought of as disagreement could actually be due to a true change in the number of repetitions completed before failure. Therefore, reliability in the current study was reimagined as the consistency in accuracy of RIR-RPE when comparing session one and session two. Reliability of the RIR-RPE scale was assessed using a two-way random effect model $ICC_{2,1}$ to measure the absolute agreement of the difference between the actual- and predicted-RIR between sessions one and two for each intensity and exercise.

Results

Participant demographics are presented in Table 3. Mean predicted RIR-RPE for the bicep curl (2.26 ± 0.43) and leg extension (3.67 ± 0.33) exercises was less than actual RIR (2.88 ± 0.61) (Figure 2) and (5.10 ± 0.65) (Figure 3). From a practical perspective, there was a tendency to underpredict repetitions to failure by approximately one repetition (1.02 ± 1.60) in single joint exercise. Participants became more accurate in their predictions in session two (0.93 ± 1.26) compared to session one (1.11 ± 1.88). The $ICC_{2,1}$ values measuring absolute agreement were low to moderate (0.45 – 0.55) for bicep curls (Figure 4) and low to high (0.3 – 0.82) for leg extension (Figure 5) in session one. In session two, $ICC_{2,1}$ values were moderate to excellent (0.74 – 0.92) for bicep curls (Figure 4) and low to high (0.42 – 0.8) for leg extensions (Figure 5). Reliability was low to moderate for the bicep curl with $ICC_{2,1}$ ranging from 0.15 – 0.74 (Figure 6) and low in the leg extension with $ICC_{2,1}$ ranging from 0 – 0.61 (Figure 7).

Table 3: Participant demographics

Height (m)	1.72 ± 0.094
Weight (kg)	76.59 ± 16.74
Fat Mass (%)	17.11 ± 9.31
Fat Free Mass (%)	82.89 ± 9.31
Age (yrs)	20.42 ± 1.98
Training Age (yrs; resistance training)	5.83 ± 3.19

Repeated measures correlations were calculated for each intensity of the two exercises to determine if a relationship between RIR-RPE and velocity existed. RIR-RPE and velocity were collected during the 9th, 7th and 5th repetition for 70, 75, and 80% of 1RM, respectively. In addition, velocity on the final repetition of each set was collected. Because participants were at a point of failure it was assumed that RIR-RPE was a 10 on the scale. The RIR-RPE and velocity values at estimated RIR-RPE and at failure were used in the calculations. A negative relationship between RIR-RPE and velocity was observed at all intensities (Tables 4).

Table 4. Relationship between RIR-RPE and Velocity

Intensity (% 1RM)	Bicep Curl		Leg Extension	
70%	r = - 0.62	p = 0.023	r = - 0.8	p = 0.0016
75%	r = - 0.86	p = 0.00017	r = - 0.77	p = 0.0021
80%	r = - 0.42	p = 0.15	r = - 0.67	p = 0.12

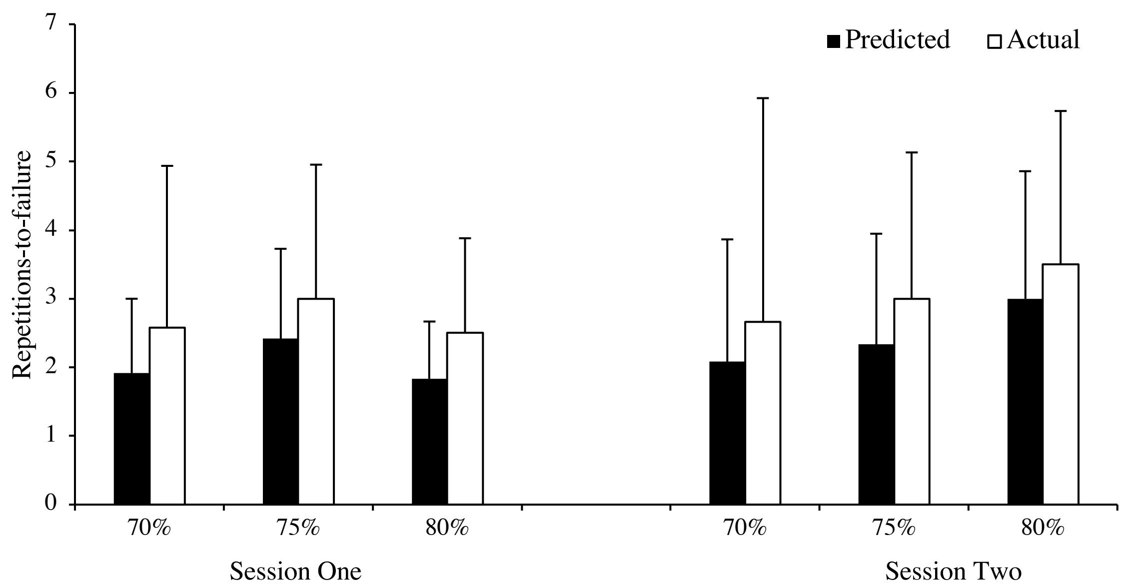


Figure 2. Predicted and actual RIR in the bicep curl.

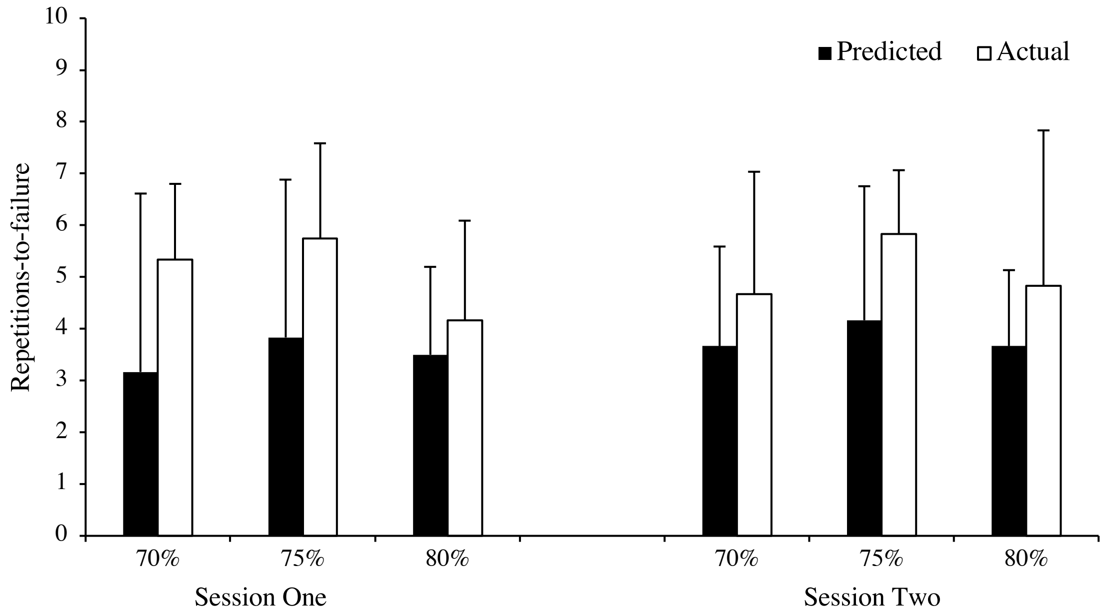


Figure 3. Predicted and actual RIR in the leg extension exercise.

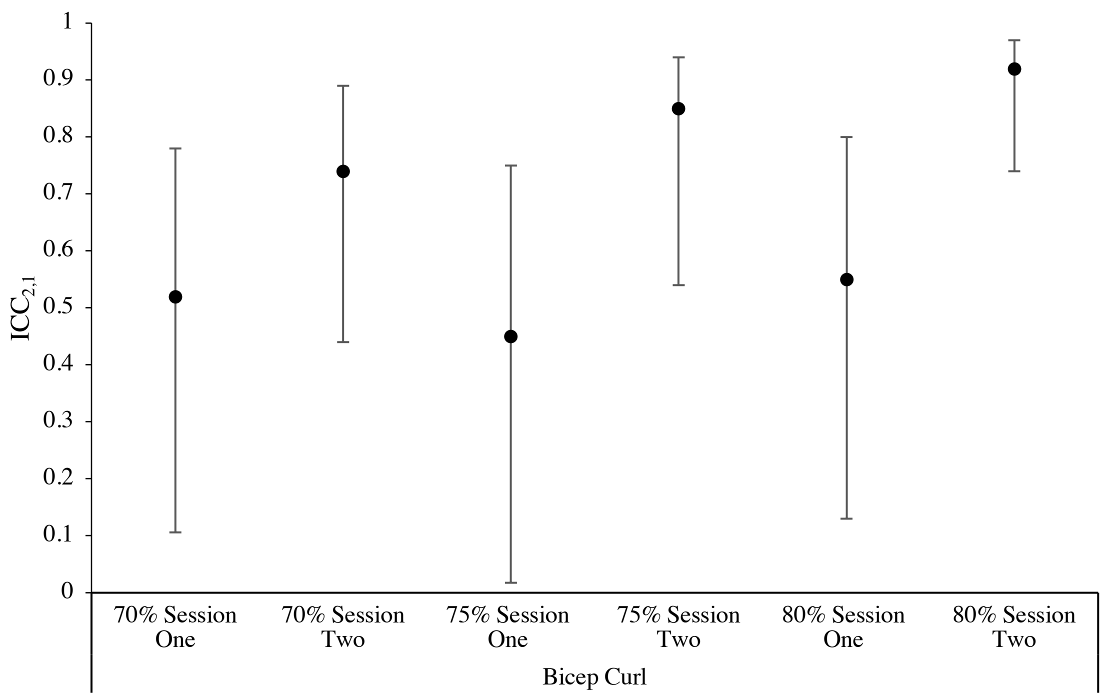


Figure 4. Agreement between the predicted- and actual-RIR in the bicep curl

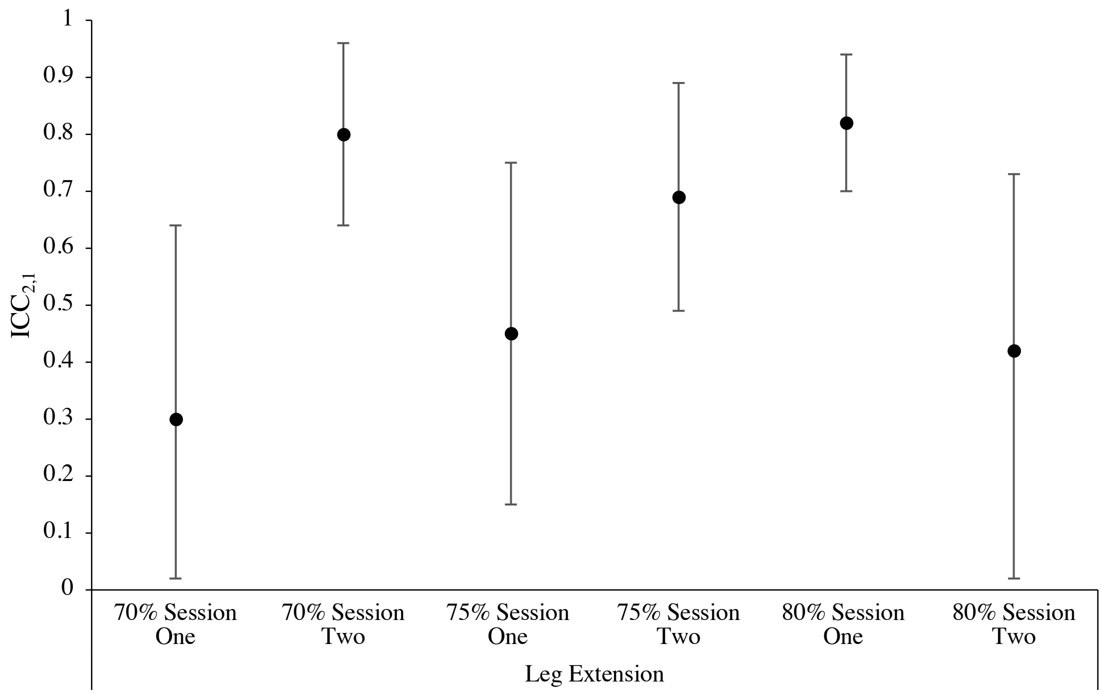


Figure 5. Agreement between the predicted- and actual-RIR in the leg extension

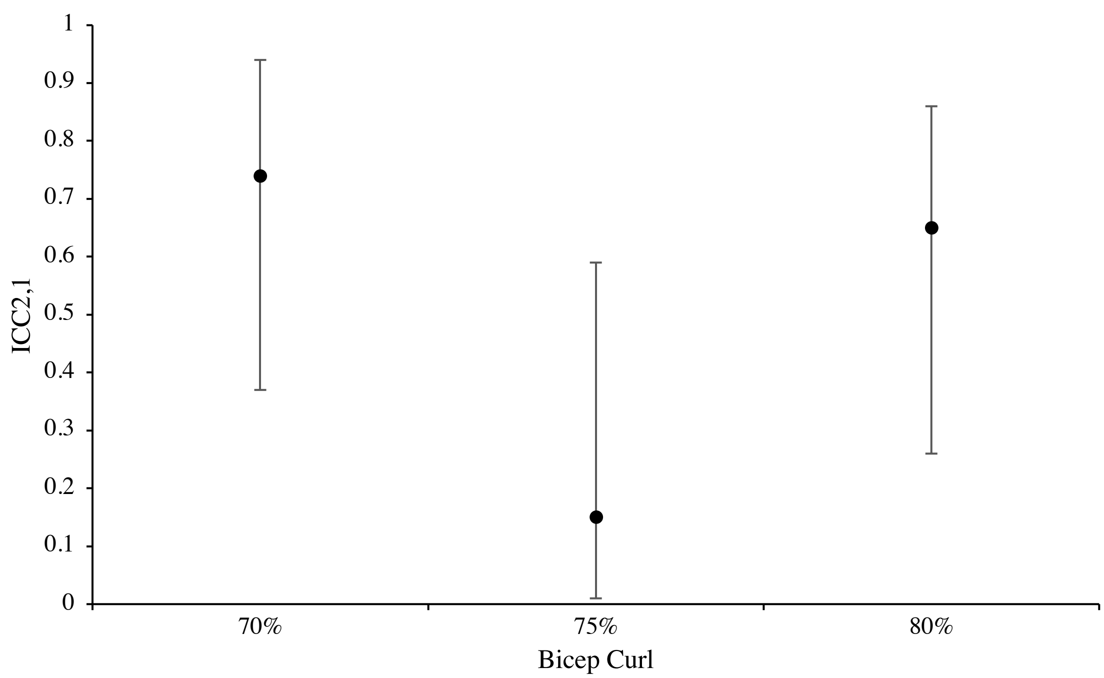


Figure 6. Reliability of RIR-RPE in the bicep curl.

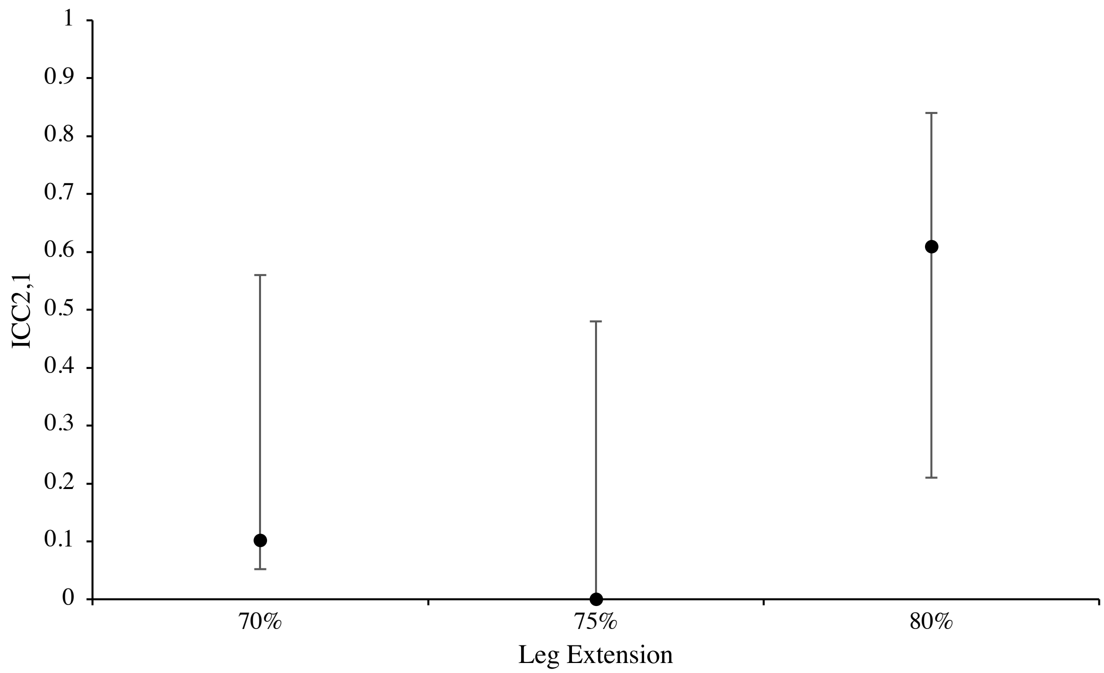
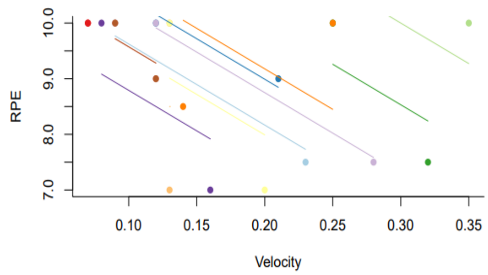
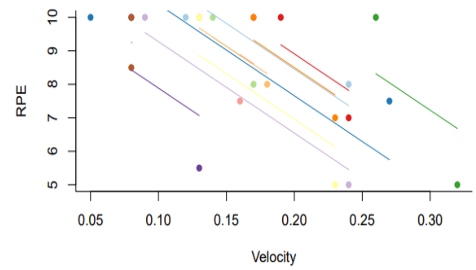
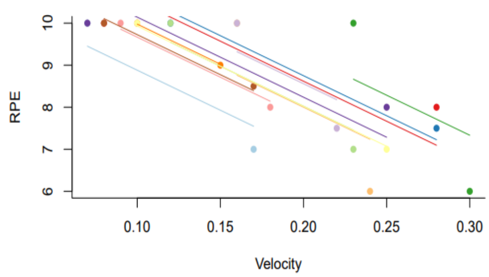
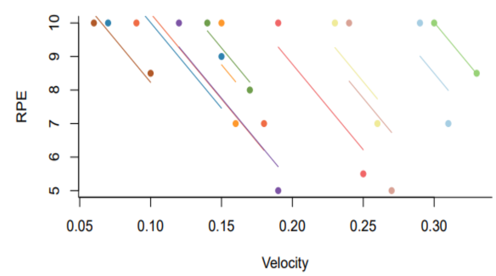
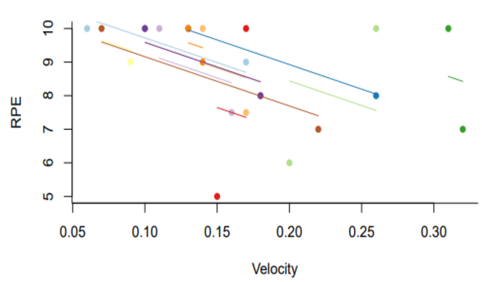
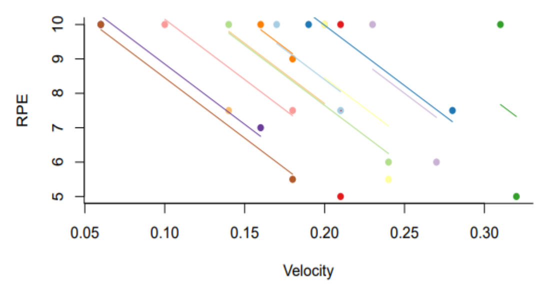


Figure 7. Reliability of the RIR-RPE scale in the leg extension

Table 5. Visual representation of the relationship between RIR-RPE and velocity

Intensity	Bicep Curl	Leg Extension
70%		
75%		
80%		

Discussion

The purpose of this study was to evaluate the validity and reliability of the RIR-RPE scale in single joint exercise. A secondary purpose was to investigate the relationship between the RIR-RPE scale and velocity in single joint exercise. Data on predicted-RIR, actual-RIR and mean concentric velocity were recorded across three sets per session over two sessions. The results revealed that the participants tended to underpredict RIR by an average of one repetition. Absolute agreement between predicted- and actual-RIR ranged from moderate to high in the bicep curl and low to moderate in the leg extension as indicated by ICCs (Figures 3, 4). Participants became more accurate in their predictions from session one to session two on average. These results indicate that the RIR-RPE scale is valid for predicting RIR in single joint exercise.

Reliability of the RIR-RPE Scale

The hypothesis that RIR-RPE would not be reliable in single joint exercise was supported, in that absolute agreement between predicted-RIR from sessions one and two ranged from low to moderate in the bicep curl and low for the leg extension. These results indicate that ratings of the RIR-RPE scale is subject to change across sessions. Changes in predicted values are likely due to learning effects. Participants became more accurate in their predictions from session one to session two. This indicates that the RIR-RPE scale is likely not reliable in individuals who have limited prior experience in using the scale. Participants had a minimum of two years of RT experience, however because the equipment used was likely novel to participants (arm bar for bicep curl and unilateral leg extensions) participants may have become more proficient with RIR-RPE by the final session. This is due to participants having experience from sessions one and two to reference in their predictions. Future studies should consider longer familiarization periods when investigating RIR-RPE.

Several factors are prone to influence RIR-RPE. These factors include, but are not limited to, fatigue from previous sessions, experience in performing repetition maximums, experience with the equipment used, RIR-RPE learning effects, amount of sleep, nutrition, and life stress (153). In this case, AR of RIR-RPE relies on internal feedback from the individual during the time RIR-RPE is collected. It is not yet clear to what extent these variables may influence reliability of the RIR-RPE scale from session to session. A longitudinal study that records these variables would contribute in answering such a question.

A potential limitation to the assessment of reliability is inconsistency in technique judgment between sessions. Technique was judged for every participant in every session by the principal investigator. Because technique was judged visibly, there was the potential for inconsistencies at which technique could not longer be maintained. Another limitation this study observed was low between-subject variability. Low between-subject variability can be cause for lower $ICC_{2,1}$ values. This observation of variability is likely because RIR-RPE was collected at the same repetition between participants respective of intensity, thus promoting homogeneity. This is a limitation of the research design however; it was a necessary component to best answer the research question(s).

Validity of the RIR-RPE Scale

The average under prediction of RIR by the participants is in alignment with previous research (62). The tendency for participants to underpredict RIR may be due to multiple factors such as inexperience with performing the movements, performing a repetition maximum, exposure time to the scale, proximity to failure, and anchoring bias.

Differences in prediction accuracy were observed both between participants and within participants between sessions. One explanation for differences between participants is prior experience in performing the bicep curl and leg extension. Those who have more experience with a given movement typically report predicted-RIR values closer to their actual-RIR when compared to novices (102,127,153). This finding could be due to the more experienced lifters possessing a greater capacity to use feedback from the trained muscles. While participants performed an 8RM test for each exercise at baseline, it is not clear if participants had previous experience with the performance of repetition maximums in the observed exercises. The RIR-RPE scale relies on internal feedback as repetitions approach failure. Due to this, experience in completing repetitions maximums may give reason to differences in predicted-RIR values between participants.

Proficiency with monitoring feedback likely lies on a continuum. Therefore, it is possible that the number of exposures to repetition maximums beyond this study played a role in prediction accuracy (127). Research has shown that those individuals who are more experienced in RT tend to more accurately predict RIR (60). This is also a factor for the within subjects, between session prediction accuracy as each participant gained more experience as they progressed through the study. Similar trends in accuracy are consistent with previous research on the RIR-RPE scale (60).

Learning effects may be another possible mechanism for the increase in prediction accuracy. The trend of an increase in accuracy from session one to session two leads to the consideration that experience in using the RIR-RPE scale may play a role in the accuracy of predictions. The scale was explained in detail to participants at the beginning of each session; however, participants indicated that they did not have prior experience with the RIR-RPE scale outside of the study setting. ICC values increased from session one to two in the 70 and 75% intensities. This could be due to one or a combination of the variables discussed previously. Conversely, ICC decreased in the 80% condition which may have been influenced by error in technique judgement or random variability.

Participants in the current study underpredicted repetitions by an average of one on the RIR-RPE scale. Halperin et al. (62) identified that the error between predicted- and actual-RIR is largely influenced by the total number of repetitions performed in the set. For example, a difference of one repetition in a set of ten would be a 10% error, while an error of one repetition in a set of four would be a 25% error. It is important to establish a dose-response relationship that considers both volume and load to determine an acceptable range of error.

The accuracy of predicted-RIR increases as the individual approaches failure, or toward the end of a set (152). Previous studies found that accuracy improved when RIR-RPE was collected on multiple sets in the same session (60,90). One mechanism that may explain this is an accumulation of fatigue from previous sets, effectively increasing the relative intensity of the remaining sets and reducing the number of repetitions performed. Performing a set to failure reduces the number of repetitions completed in following sets regardless of recovery (115). This would mean that over the three sets, participants were closer to failure at the point of prediction compared to the prior set. As repetitions are completed throughout a set, the sensation of fatigue becomes stronger. This sensation may have indicated to participants that they were nearing failure. The accumulated fatigue may have aided in predicted-RIR accuracy over multiple sets as participants had memory of those sensations in later sets (100). The current methodology was constructed so that predicted-RIR was gathered approximately three repetitions before anticipated failure using predictions provided by Haff and Triplett (2016) (61). This anticipated failure point was based off of each individual's 1RM calculated from an equation using 8RM performance (20). The current study observed a wide range of repetitions completed for each intensity. Because of this interindividual variability, future studies may be better served by choosing a repetition to gather predicted-RIR on an individual basis.

The current investigation may have been exposed to anchoring bias when estimating participants' RIR (62). Anchoring bias is the theory that the predicted-RIR indicated before continuing the set to failure impacts the number of repetitions performed. It is possible that participants set the predicted-RIR as a goal of repetitions to complete which may have impacted the completed number of repetitions (62). Some studies have tried to reduce this bias (83,127) by collecting a predicted-RIR and discontinuing the set with several other exercises injected between the failure attempt. This method may reduce an anchoring bias as the participant has the opportunity to forget the predicted-RIR value for a given exercise, however it loses environmental validity in the process as this is not how RIR-RPE would be used in a real-world setting.

Velocity

There was a similar, negative relationship between RIR-RPE and velocity in upper (r = - 0.42 to - 0.86) and lower body (r = - 0.67 to - 0.80) single joint exercise. These findings indicate that a reduction in the velocity of repetitions throughout the set may have indicated to the participant that they were approaching failure, thus guiding predicted-RIR.

A negative relationship between RIR-RPE and velocity can be corroborated in the literature (102,118,153). Several factors may have impacted the observed negative relationship in this study. As previously discussed, experience with the bicep curl and leg extension, RM, exposure time, proximity to failure, and anchoring bias may have impacted predicted-RIR values. Many of these variables may have influenced velocity as well. There was the potential for variation in the data for velocity, likely due to differences in experience with each exercise and repetition maximum. There was a large range of training experience (2 – 13 years) indicating that some participants may have had a greater capacity to complete repetitions at lower velocities. It has been previously demonstrated that individuals who are more trained have a higher rate of force development which may be due to neuromuscular adaptations leading to greater recruitment of high-threshold motor units (15,91). Based on the size principle of motor unit recruitment, muscle fibers are recruited in order from smallest to largest (61). The larger type II fibers are required for high force and high velocity outputs. Under high load or fatigued conditions, velocity becomes slower despite recruitment of high velocity motor units (52,120). More trained individuals may have adaptations that allow them to better recruit these larger fibers in fatigued conditions. This allows for the completion of repetitions at slower velocities which may have allowed for more repetitions to be completed in individuals who were more trained.

This study identified a few concerns for future investigators to evaluate. The acceptable error between predicted- and actual-RIR is absent from the literature. It is difficult to determine if chronic underprediction of RIR makes a meaningful impact on training outcomes. When testing the same movement or muscle group over multiple sets, it is important to take the effects of fatigue into account in later sets when constructing methodology. Learning effects have the potential to impact rating, thus future studies may consider including multiple sessions dedicated to ensuring all participants fully understand the RIR-RPE scale and have an equal amount of experience in using it. Finally, future studies may consider recruiting participants with more homogenous training experience with the specific exercises being performed in the study.

Practical Applications

It is commonplace to perform a 1RM test and base intensity off a percentage of a maximal load. While this method has been shown to be effective (61), it may not be the best representation of performance on a day-to-day basis. The RIR-RPE scale is a tool that accounts for daily variability in physical preparedness and is easily used by practitioners, athletes, and RT enthusiasts. Furthermore, with adaptation occurring across time, the initially gathered 1RM will becomes less relevant as the current ability level becomes increasingly distant from the level of ability initially gathered. The RIR-RPE scale can be used in conjunction with other measures such as 1RM and velocity to allow for comprehensive individualization of a RT program. These factors make the RIR-RPE scale an easy to access and cost-effective method of regulating load and volume. Although the underprediction of RIR-RPE was consistent with previous literature, practitioners and lifters should take caution in using RIR-RPE as an independent method of regulation. Additionally, many participants reached technical failure before concentric failure. The strict enforcement of technique is likely not realistic in many resistance training sessions. Thus, this factor should be taken to account in the implementation of RIR-RPE.

CHAPTER IV
THESIS CONCLUSIONS

The current study expanded upon the previous RIR-RPE literature. While other authors have previously investigated the RIR-RPE scale in upper and lower body compound resistance exercise, there are no other studies, to the authors' knowledge, observing the RIR-RPE scale in single joint exercise. The primary purpose of this study was to identify the validity and reliability of RIR-RPE in single joint exercise. The findings of the current study suggest that the use of the RIR-RPE scale in single joint exercise may be viable as they are similar to what was previously found in multi-joint movements (62). While the findings of this study suggest the scale in unreliable from session to session, these findings are likely due to learning effects. Thus, in future studies involving and when implementing the RIR-RPE scale adequate time for familiarization should be allowed. A secondary purpose to this study was to assess the relationship between RIR-RPE and velocity. Although findings are similar to previous research (102,153), there are several factors such as difference in technique and equipment used that may limit these findings.

Based on the observations of this study, athletes and practitioners may stand to benefit from incorporating the RIR-RPE scale in the regulation of RT. Although the scale is not always perfectly accurate, is provides an option of AR that considers the lifters readiness to train. Compared to the traditionally used RPE scale, RIR-RPE offers feedback that is specific to RT. Used alongside other methods, such as regulating RT variables based off a percentage of 1RM or velocity, the RIR-RPE scale can add another level of feedback for lifters and practitioners. It is cost effective and relatively easy to record, allowing for a simple means of tracking the progress of a RT program.

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Appendix I

Script: "This RPE scale will measure repetitions in reserve. For instance, a 10 RPE represents 'max effort' or no more repetitions could be performed. A 9.5 RPE means you could not do another repetition but could add more weight. A 9 RPE means you could do one more repetition. An 8.5 RPE means you could do between 1 and 2 more repetitions. An 8 RPE means you could do 2 more repetitions. A 7.5 RPE means you could do between 2 and 3 more repetitions. A 7 RPE means you could do 3 more repetitions, a 5–6 RPE means you could do 4–6 more repetitions, a 3–4 RPE indicates that the set was of little effort, while an RPE of 1–2 indicates that the set was of little to no effort."

Appendix II

Repetitions in Reserve based Rating of Perceived Exertion

Informational Sheet

This RPE scale will measure repetitions in reserve. For instance, a 10 RPE represents ‘max effort’ or no more repetitions could be performed. A 9.5 RPE means you could not do another repetition but could add more weight. A 9 RPE means you could do one more repetition. An 8.5 RPE means you could do between 1 and 2 more repetitions. An 8 RPE means you could do 2 more repetitions. A 7.5 RPE means you could do between 2 and 3 more repetitions. A 7 RPE means you could do 3 more repetitions, a 5–6 RPE means you could do 4–6 more repetitions, a 3–4 RPE indicates that the set was of little effort, while an RPE of 1–2 indicates that the set was of little to no effort.

Table: 1 RIR-RPE

Rating	Description
10	Maximal Effort
9.5	No more repetitions but could increase load
9	1 repetition in reserve
8.5	1-2 repetitions in reserve
8	2 repetitions in reserve
7.5	2-3 repetitions in reserve
7	3 repetitions in reserve
5-6	4-6 repetitions in reserve
3-4	Light Effort
1-2	Little to no effort

Appendix III

INFORMED CONSENT DOCUMENT

Project Title: Validity and Reliability of the Repetitions in Reserve-Based Rating of Perceived Exertion Scale in Single-Joint Exercise

Investigator: Grant Malone Faculty Advisor: Whitley Stone School of Kinesiology, Recreation, and Sport

Email: grant.malone877@topper.wku.edu

You are being asked to participate in a project conducted through Western Kentucky University. The University requires that you give your signed agreement to participate in this project.

You must be 18 years old to 40 years old to participate in this research study.

The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may ask any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have.

If you then decide to participate in the project, please sign this form in the presence of the person who explained the project to you. You should be given a copy of this form to keep.

1. **Nature and Purpose of the Project:** The purpose of this project is to assess the use of a scale that measures how many repetitions you think you will be able to complete after a single joint lifting set is over. We are also going to see if there are any relationships between this scale and movement velocity as well as muscle activity.

2. **Explanation of Procedures:** As a part of this study, you will complete multiple resistance training protocols over three sessions. These sessions will include exercises for your upper arm and upper leg. These protocols will consist of an 8-repetition maximum test on day one, and two sessions of three sets of five repetitions at low, moderate, and high loads based off your performance on day one. Upon completion of each set of five repetitions, you will report how many repetitions you think you could complete before fatiguing using a perceptual scale. After giving us a number, you will continue the set to momentary muscular fatigue. The order you will complete these

exercises will be at random and you will not know which load you are lifting before you start.

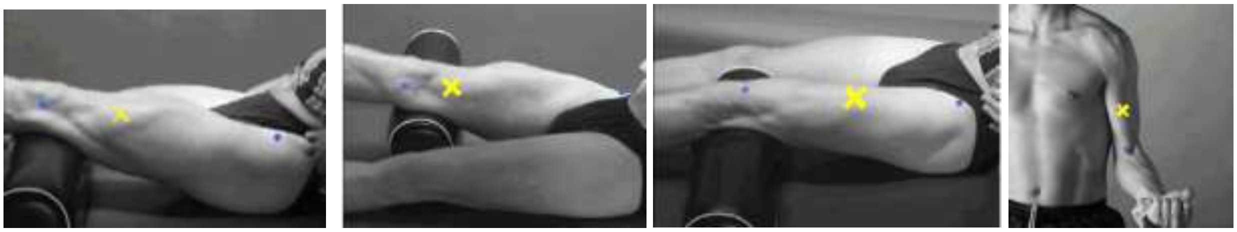
You will be asked to make sure you have eaten enough food and drank enough water to participate in exercise, but you should not consume any substances that may impact your exercise capacity (e.g., pre- workout, coffee). During your first visit, you will be asked to fill out a pre-exercise participation form (called a PARQ+) and review an informed consent form. We will ask about your exercise history and review your PARQ+ to determine if you are eligible to participate.

We will ask you to remove your shoes so that we can measure your weight on a digital scale and height on a stadiometer. Next, we will measure your body composition in the BodPod (pictured below). We ask that you wear skintight clothing (compression shorts, dry fit shirt, sport bra, etc.) and a head cap to cover your hair. You will sit in the BodPod chamber for approximately 3-5 minutes. You can exit the BodPod at any time if you feel uncomfortable.

WKU IRB# 22-079
Approved: 1/10/2022
End Date: 5/15/2022
EXPEDITED
Original: 10/11/2021

Visualization of BodPod device.

Before exercise, we will show you the equipment that will measure your movement velocity. This equipment will be attached to the weight machine and will not interfere with your movement in any way. Next, we will introduce you to the equipment that collects your muscles' electrical activity. This equipment, known as EMG, will be placed on the surface of your skin where it will collect information about your muscles' activity. To make sure the EMG devices stay in place and collect clear data, we will need to remove the hair using a razor and any loose skin using an abrasive wipe. To know where to place the devices, we will need to feel for specific boney landmarks near your hip, shoulder, elbow, and knee. Places we will feel for are pictured by "circles" and the devices will be placed where you see "x"s.



You will be introduced to the repetitions in reserve-based rating of perceived exertion scale (RIR-RPE) and perform an 8-repetition maximum test for your biceps (front, upper arm muscle) and another for your quadriceps muscles (front, upper leg muscle group). These tests will start at low intensities and will gradually get more difficult until we find the load you can lift only eight times. You will get several minutes of rest between each attempt.

You will return to the lab a minimum of 48 hours after the first visit. We will reintroduce you to the RIR- RPE scale. You will then complete five repetitions at low, moderate, and high loads (calculated based on your performance during the first session). Upon completion of each set of five repetitions you will indicate a value on the RIR-RPE scale and then continue the set to momentary muscular fatigue. We will be measuring your RIR-RPE, repetitions completed, movement velocity, and muscle activity during each repetition. You'll be given three to five minutes between lifts. You may choose to discontinue exercise at any point with no penalty.

You will return to the lab a minimum of 48 hours after the second visit to repeat the exercise from session two.

3. **Discomfort and Risks:** Likely/Common: Feelings of fatigue and soreness will typically dissipate after a few days. Furthermore, because you are familiar with resistance training, soreness and fatigue are likely to me minimal.

Less Likely/Less Common: Though the risk of injury is present anytime we engage in activity, we anticipate the risk for injury to be low as you have a minimum of two years of resistance training experience. This inclusion criterion was crafted so that our intervention is considered commonplace in your lifting habits, limiting the potential negative consequences that accompany novel exercise.

You may become uncomfortable while sitting in the BodPod while it is closed. You may exit the BodPod at any time with no penalty. Your skin will be lightly abraded for EMG, which may cause a low level of irritation to this skin.

Though rare and highly unlikely, high intensity exercise can be responsible for life threatening arrhythmias (irregular heart rhythms). The principal investigator is certified in CPR and AED use in case of emergency. An AED is nearby the lab as well as First Aid certified personnel. The researcher is aware of emergency procedures for exiting Smith Stadium as well as where the AED and emergency phone are located.

Literature cited by the American College of Sports Medicine indicates that those with greater levels of muscular fitness (such as those we are recruiting in this study), have better cardiometabolic health, are at lower risk for all-cause mortality, have fewer cardiovascular events (such as dangerous arrythmias), and are at lower risk for nonfatal diseases.

4. **Benefits:** You will gain experience in the use of perceptual scales, which you may then utilize in your own training. You will also be given information on your muscular strength including your 8- repetition maximum and predicted one-repetition maximum. Furthermore, you will be tested under the supervision of certified personnel.

You will also receive $30 cash for participation ($10 each visit) after completing all three sessions. If all three sessions are not completed, you will not receive any cash.

5. **Confidentiality:** To help protect your confidentiality, we will do everything we can to keep your information private and protected. Your information will be assigned a Patient ID# and will be protected in a locked document on a locked computer. All hardcopy data records are stored in locked file cabinets. If we write a report or article about this study or share the study data set with others, we will make sure that you cannot be identified. If any photos are taken (with your consent), all identifying information will be removed.

6. **Refusal/Withdrawal:** Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty.

You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks. If a medical emergency does occur, you understand that you are responsible for any costs incurred, including but not limited to the services of Emergency Medical Technicians, emergency room care, hospitalization, etc. We strongly encourage you to ensure that you have adequate health insurance coverage or other means of satisfying any costs for which you will be liable.

____ ______________

Signature of Participant Date

____ ______________

Witness Date

- I agree to the audio/video recording of the research. ***(Initial here)*** ______

THE DATED APPROVAL ON THIS CONSENT FORM INDICATES THAT THIS PROJECT HAS BEEN REVIEWED AND APPROVED BY
THE WESTERN KENTUCKY UNIVERSITY INSTITUTIONAL REVIEW BOARD
Robin Pyles, Human Protections Administrator TELEPHONE: (270) 745-3360

WKU IRB# 22-079
Approved: 1/10/2022
End Date: 5/15/2022
EXPEDITED
Original: 10/11/2021

Appendix IV

2021 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	**YES**	**NO**
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

✔ **If you answered NO to all of the questions above, you are cleared for physical activity.**
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______________________ DATE ______________

SIGNATURE ______________________ WITNESS ______________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________

● **If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.**

⚠ **Delay becoming more active if:**

- ✔ You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- ✔ You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- ✔ Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

2021 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ______________________

____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:
You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______________________________ DATE ______________________

SIGNATURE __________________________ WITNESS ____________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
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The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References
1. Jamnik VK, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-S298, 2011.
3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

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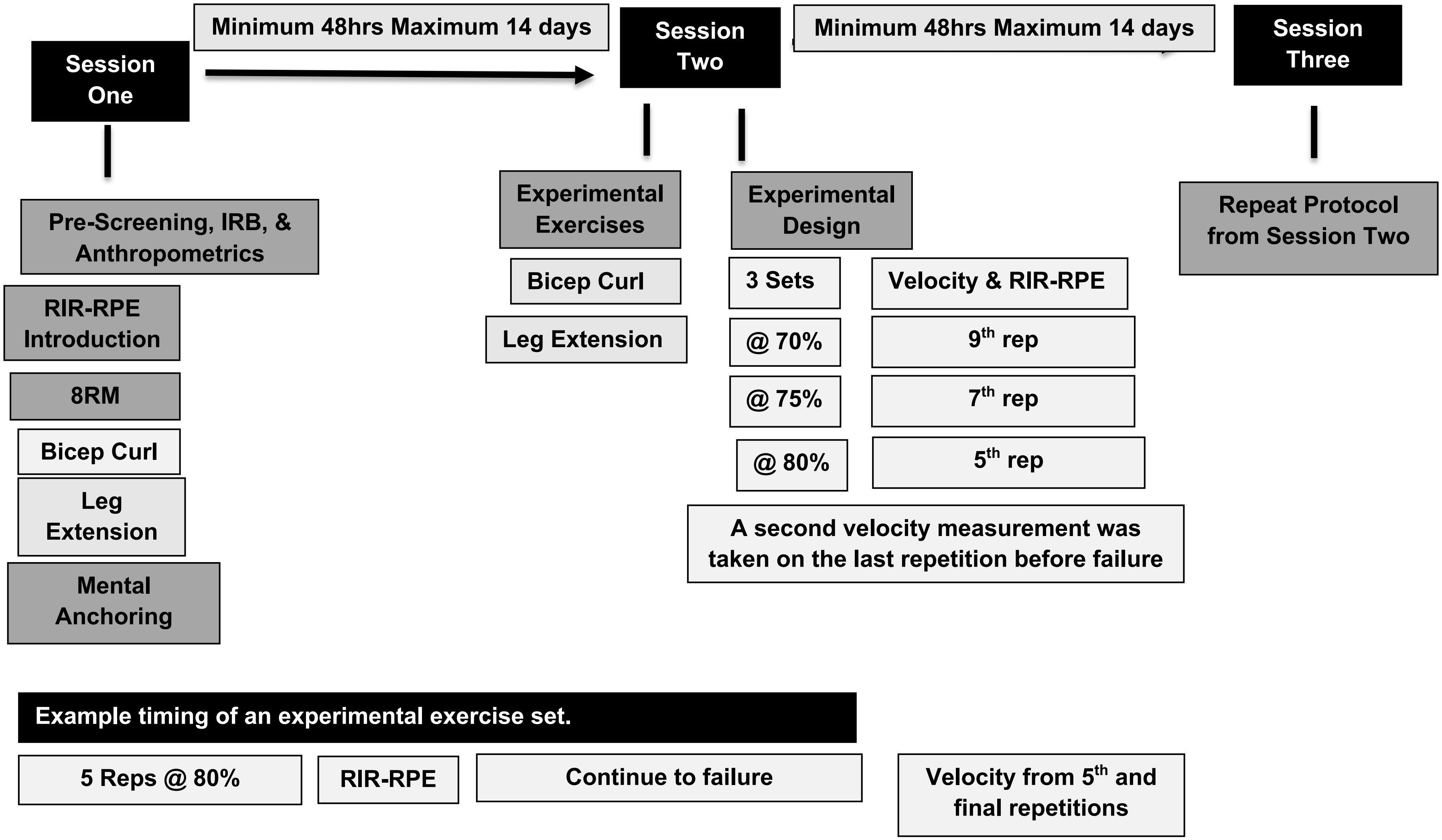
Appendix V


Session One
Minimum 48hrs Maximum 14 days
Session Two
Minimum 48hrs Maximum 14 days
Session Three
Pre-Screening, IRB, & Anthropometrics
RIR-RPE Introduction
8RM
Bicep Curl
Leg Extension
Mental Anchoring
Experimental Exercises
Bicep Curl
Leg Extension
Experimental Design
3 Sets
@ 70%
@ 75%
@ 80%
Velocity & RIR-RPE
9th rep
7th rep
5th rep
A second velocity measurement was taken on the last repetition before failure
Repeat Protocol from Session Two
Example timing of an experimental exercise set.
5 Reps @ 80%
RIR-RPE
Continue to failure
Velocity from 5th and final repetitions

Seguin, Todd

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