Using the Repetitions in Reserve-based Rating of Perceived Exertion Scale to Autoregulate Powerlifting Training

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PhD

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Abstract

Autoregulation is a training approach where adjustments are made based on the recovery, performance and readiness of the individual. By providing greater individualisation, autoregulation may optimise muscular adaptations. This thesis investigates the practical implementation of autoregulation in strength training to answer the question: "can autoregulation, through the use of the novel rating of perceived exertion (RPE) scale based on repetitions in reserve (RIR), improve the efficacy of powerlifting training?". First an introduction to powerlifting and the training concepts common to it is undertaken. Then, the history of RPE in powerlifting is detailed, establishing the thesis framework. In Chapter two the body of knowledge on methods of monitoring and regulating resistance training is reviewed. Those methods with strong ($r \geq 0.68$) relationships to resistance training performance are highlighted and the need for further investigation into the use of the RIR-based RPE scale in autoregulation is identified. Chapter three is a narrative review of the history of RPE scales in resistance training and the utility of the RIR-based RPE scale. In Chapter four, this scale's utility when conducting one-repetition maximum (1RM) tests in competitive powerlifters is assessed. Specifically, while similar, near-maximal RPE at 1RM among the powerlifts (9.7-9.8 RPE; $p > 0.05$) was found, average concentric velocity (ACV) among the squat (0.23 ± 0.05 $m \cdot s^{-1}$), bench press (0.10 ± 0.04 $m \cdot s^{-1}$) and deadlift (0.14 ± 0.05 $m \cdot s^{-1}$) differed ($p < 0.05$). The relative training volume of powerlifters, when using three levels of the 'RPE stops' method to regulate number of sets performed, over a 3-week training period is reported in Chapter five. Briefly, this method sets an RPE-threshold whereby if reached, sets are no longer performed, after a percentage reduction from the first set's load is implemented. Specifically, 2, 4 and 6% RPE stops were investigated. Weekly combined relative volume load (squat + bench press + deadlift), expressed as sets x repetitions x percentage 1RM differed between weeks ($p < 0.001$): 2% = 74.6 ± 22.3; 4% = 88.4 ± 23.8; 6% = 114.4 ± 33.4. Chapter six is an analysis of the same cohort of powerlifters' ability to accurately select loads based on RPE targets during this 3-week period. Overall, post-set RPE scores differed minimally (0.33 ± 0.28 RPE) compared to target RPEs. In Chapter seven, the effectiveness of training with self-selected loads based on a target RPE range versus using a traditional percentage 1RM-based approach for the bench press and back squat was tested in two parallel groups of resistance-trained males for 8 weeks. While both groups increased 1RM and muscle thickness ($p < 0.05$), differences between groups were non-significant. However, probabilistic analysis of effect size (ES) indicated a greater likelihood (57-79% probability) that RPE-based loading provided small (ES = 0.28-0.50) advantages for improving 1RM strength compared to percentage 1RM-based loading. Additionally, average percentage of 1RM, relative volume and RPE differed during training, as well as subjective recovery. Chapter eight is a summary of the findings, their applications, and future research directions in powerlifting and strength training as a whole.

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List of Commonly Used Abbreviations

RPE: Rating of perceived exertion

RIR: Repetitions in reserve

1RM: One-repetition maximum

RM: Repetition maximum

CL: Confidence limit

SD: Standard deviation

ES: Effect size

DUP: Daily undulating periodisation

RPEDIFF: RPE difference (actual RPE – target RPE)

IPF: International Powerlifting Federation

APRE: Autoregulatory progressive resistance exercise

PRS: Perceived recovery status

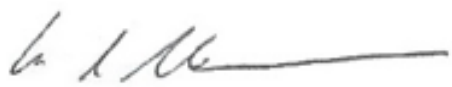
HRV: Heart rate variance

ACV: Average concentric velocity

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Chapters 2 to 7 of this thesis represent separate papers that have either been published or have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contributions by the various co-authors to each of these papers are outlined at the beginning of each chapter. All co-authors have approved the inclusion of the joint work in this doctoral thesis.



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Co-Authored Works

Table 1. Co-authored works.

Chapter publication reference	Author %
Chapter 2. Helms ER, Cronin J, Storey A, Zourdos MC. Methods for regulating and monitoring resistance training. Sports Med. 2017:[in review].	ERH: 87.5% JC: 5% AS: 5% MCZ: 2.5%
Chapter 3. Helms ER, Cronin J, Storey A, Zourdos MC. Application of the repetitions in reserve-based rating of perceived exertion scale for resistance training. Strength Cond J. 2016:38(4):42-49.	ERH: 82.5% JC: 5% AS: 5% MCZ: 7.5%
Chapter 4. Helms ER, Storey A, Cross MR, Brown SR, Lenetsky S, Ramsay H, Dillen C, Zourdos MC. RPE and velocity relationships for the back squat, bench press, and deadlift in powerlifters. J Strength Cond Res. 2016:31(2):292-297.	ERH: 80% AS: 2.5% MRC: 2.5% SRB: 2.5% SL: 2.5% HR: 2.5% CD: 2.5% MCZ: 5%
Chapter 5. Helms ER, Cross MR, Brown SR, Storey A, Cronin J, Zourdos MC. Rating of perceived exertion as a method of volume autoregulation within a periodised program. J Strength Cond Res. 2017:[accepted].	ERH: 80% MRC: 5% SRB: 5% AS: 2.5% JC: 2.5% MCZ: 5%
Chapter 6. Helms ER, Brown SR, Cross MR, Storey A, Cronin J, Zourdos MC. Self-rated accuracy of RPE-based load prescription in powerlifters. J Strength Cond Res. 2017:[in review].	ERH: 80% SRB: 5% MRC: 5% AS: 2.5% JC: 2.5% MCZ: 5%
Chapter 7. Helms ER, Byrnes RK, Cooke DM, Cross MR, Cronin J, Storey A, Zourdos MC. RPE and percentage 1RM loading in periodised programs matched for sets and repetitions. Med Sci Sports Exerc. 2017:[in preparation].	ERH: 80% RKB: 5% DMC: 2.5% MRC: 2.5% JC: 2.5% AS: 2.5% MCZ: 5%

We, the undersigned, hereby agree to the percentages of participation to the chapters identified above:

Supervisors

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influences. Even more, I could not have completed my PhD without coming to FAU for my final study. You created something amazing and unique there. It was an honour to work in that environment for the 10 weeks I was there. You opened your home to me, trusted me with your lab, your students, your classroom and even your dog! I can't thank you enough.

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Ethics Approval

Ethical approval for the thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 19th February 2015 for a period of three years:

- 15/06 Practical auto-regulation in resistance training

Additionally, ethical approval for Chapter 7, which was conducted at Florida Atlantic University was granted by the Florida Atlantic University Health Sciences Institutional Review Board on 15th July 2016 for a period of one year:

- [918291-2] Percentage Based Versus Autoregulated Resistance Training for Muscle Strength and Hypertrophy in Trained Males

Chapter 1: Introduction

The sport of powerlifting

Competitive powerlifting is a weight class-based strength sport in which competitors attempt to lift a maximal weight on three lifts: the squat, bench press and deadlift. Three attempts are given for each lift, in order, and the winner within each weight class is determined by who achieves the heaviest combined total weight, among the three lifts. Each of the lifts must be completed to a certain technical standard to count towards an athlete's total. The squat must be performed to a certain depth, the bench press requires the bar to be motionless on the chest before the command to begin the concentric phase is given, and the deadlift must be performed without the thighs being used to support the load once the bar has passed the knees. Three referees determine whether lifts conform to these (and additional) movement requirements. For a lift to be deemed legal, at least two of the three referees must pass it [1].

Powerlifting is not an Olympic sport, but it has been a part of the World Games since their inception in 1981 [2]. Additionally, the bench press has been represented in Paralympic powerlifting since the 1984 Summer Paralympic Games [3]. The International Powerlifting Federations (IPF) is the governing body recognised by the International World Games Association [4].

Training for powerlifting

The competition lifts and variations of them, including squatting to a box, placing a board on the chest to alter bench press range of motion, adding elastic band or chain tension to the barbell to change the force curve, and also supplemental use of Olympic weightlifting-style movements, make up the bulk of training among elite powerlifters [5]. Additionally, given that strength is the sum of various adaptations including muscle size, motor skill, muscle architecture, and neuromuscular efficiency [6], it is perhaps unsurprising that the overwhelming majority of elite powerlifters periodise their training [5, 7, 8], likely in an attempt to maximize all paths to strength enhancement.

Simply put, periodisation is the planned manipulation of training variables to maximise adaptation to training [9]. In a 2004 meta-analysis, the authors reported that periodised resistance training plans produced superior strength gains compared to non-periodised; primarily through the organisation of training volume and intensity [10]. Furthermore, authors of a recently published meta-analysis reported undulating periodisation specifically resulted in superior strength gains compared to linear models [11]. Undulating periodisation models systematically manipulate training variables on a more frequent basis than traditional models e.g. daily undulating periodisation (DUP) models elicit variations in load, repetitions and sets day to day within a microcycle. Additionally, in weekly undulating periodised models, resistance training variables are manipulated on a week to week basis. In contrast, traditional linear models require athletes to spend months at a time training in a singular repetition-intensity range before entering a phase where training occurs in a new repetition-intensity range. In theory, these more frequent variations inherent in undulating models prevent the decay of adaptations attained during previous blocks of training by including some form of work in all repetition-intensity ranges at all times [12].

Arguably, as training age advances and a greater stimulus is required to prompt further adaptation, fatigue management and preventing the decay of previous adaptations would be more important to optimise the training process. Indeed, in studies where undulating models of periodisation outperform linear models, the participants are often reasonably well trained [13-16]. For this reason, there is growing interest in research on DUP models in powerlifting [17]. Furthermore, there is interest in the integration of different periodisation strategies for powerlifting; for example, a DUP strategy within a week, while a mesocycle (or macrocycle) follows an overall linear pattern (i.e. volume decreasing as intensity increases) to peak maximal strength for competition [17, 18].

Autoregulation

One critique of periodisation literature is that there has been too much emphasis on models that assume predictability and stability of time frames and progression, while leaving out the critical component of individualisation [19]. 'Autoregulation' is a systematic approach of incorporating elements of individualisation into a periodised plan. Autoregulation is described as training that adjusts to the athlete's performance to allow improvement at an individualised pace to optimize adaptation [20]. Unlike an approach whereby a coach simply adjusts training based on the observed outcomes, autoregulation embeds the adjustment of a specific variable (or variables) that automatically responds to performance (e.g. an RPE guideline for load prescription or a progression model based on the performance of a previous set or day) or, that is user selected.

However, autoregulation can take many forms based on this definition. A strategy whereby the lifter selects the difficulty of a training session based on their readiness to train could be said to be autoregulated [21, 22]. Likewise, a training strategy whereby load progression is based on individual, ongoing performance criteria, rather than pre-set amounts could be considered autoregulated [20]. Finally, one could label an approach to training where the prescribed load is based on perceived exertion, rather than a percentage of a pre-test 1RM as autoregulated [18].

The history of RPE in powerlifting

This purpose of this thesis is to examine the use of a novel RPE scale as a tool for autoregulating powerlifting training. Specifically, powerlifting author, athlete and coach, Michael Tuchscherer, conceptualised a modified version of the Borg 1-10 RPE scale [23], whereby scores are determined by how many RIR remain at the completion of a set (see Figure 1 below), in his book The Reactive Training Manual [24]. While this book was published in 2008, the scale was only recently introduced into the scientific literature [18].

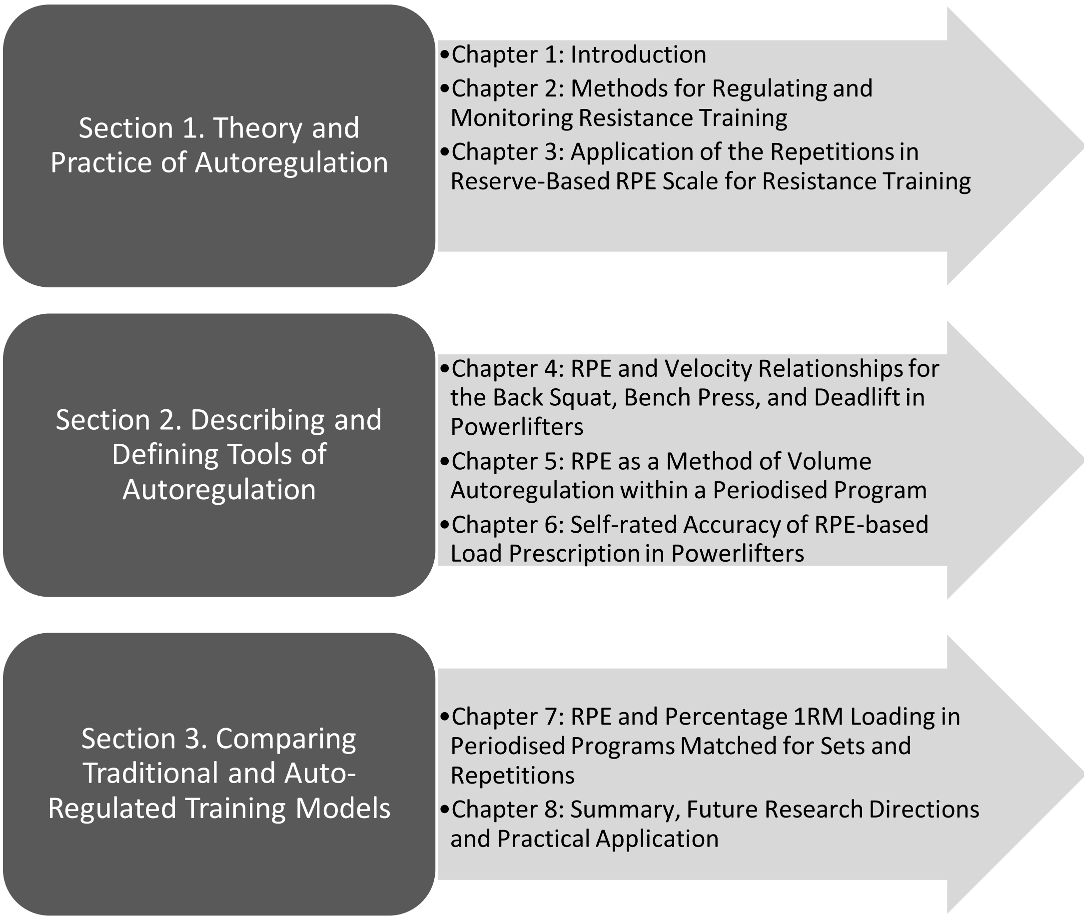
Figure 1. The resistance-training specific RPE scale based on RIR.

Rating	*Description of Perceived Exertion*
10	*Maximum effort*
9.5	*No further repetitions but could increase load*
9	*1 repetition remaining*
8.5	*1-2 repetitions remaining*
8	*2 repetitions remaining*
7.5	*2-3 repetitions remaining*
7	*3 repetitions remaining*
5-6	*4-6 repetitions remaining*
3-4	*Light effort*
1-2	*Little to no effort*

Structure of the thesis

This PhD was conducted using quantitative research methodology to answer the overarching question, "Can autoregulation through the use of the RIR-based RPE scale improve the efficacy of powerlifting training?" As a Pathway Two thesis at AUT, all chapters excluding the first and final were written in the format of a published journal article. Additionally, Chapters 2-7 begin with a preface explaining how each of the chapters are linked and build upon each other to ensure that the thesis is a cohesive whole. The eight chapters of this thesis are divided into three thematic sections outlined below in Figure 2:

Figure 2. Thesis structure.



The present chapter serves to detail the structure of this PhD and to introduce the primary concepts and frameworks used throughout this thesis (e.g. the sport of powerlifting, periodisation, DUP, autoregulation and RPE) to answer the overarching question. Chapter two is a broad review of the literature on methods of regulating and monitoring resistance training. In this initial review of the first thematic section, a broad view of the literature is taken; identifying multiple areas of potential utility in strength and conditioning. It concludes by highlighting the need for further investigation of the RIR-based RPE scale in resistance training autoregulation. Chapter three is the second review of this thematic section, which narrows the focus of the thesis. It acts as a targeted, practically focused review of the current literature (at the time) on RIR-based RPE (and RIR is isolation).

The first experimental chapters of this thesis are introduced in section two. Chapter four serves as a validation study. In it, the relationship between concentric barbell velocity and RPE in powerlifters is established. Additionally, comparisons are made between the velocity and RPE at which competition-lift 1RM attempts are performed. In Chapter five, a novel form of volume autoregulation known as "RPE stops" is introduced. In this chapter, the differences in relative volume performed when using this system were analysed. In the final chapter of this section, the ability of powerlifters to self-select loads using a repetition and RPE target for each of the competition lifts was determined. Specifically, the difference between the target RPE they attempted to reach and the final RPE values they reported under various conditions was compared.

The final section of this thesis consists of Chapter seven, a parallel group trial in which two groups of resistance-trained males performing the squat and bench press over an 8-week period were compared. Groups followed training protocols matched for sets, repetitions, exercise selection, and rest periods; the only difference being load assignment in one group was based on a percentage of 1RM, while in the second group, an ostensibly equivalent RPE range was provided and participants self-selected load. Finally, in Chapter eight a discussion of the data reported throughout the thesis is provided. The final chapter provides context on how the findings in this thesis relate to the larger body of research and finishes with conclusions, practical applications and future research directions for the field.

Chapter 2: Methods for Regulating and Monitoring Resistance Training

This chapter comprises the following paper submitted to *Sports Medicine.*

Reference:

Helms ER, Cronin J, Storey A, Zourdos MC. Methods for regulating and monitoring resistance training. Sports Med. 2017:[in review]

Author contribution:

ERH: 87.5%, JC: 5%. AS: 5%, MCZ: 2.5%

Preface

This initial broad review of the literature sets the stage for the following chapters on autoregulation by identifying the potential methods of regulating and monitoring resistance training performance. Specifically, the potential utility of the RIR-based RPE scale is highlighted, along with the need for further research on its use.

Introduction

The primary goal of monitoring and regulating resistance training is to more closely match the intended training stress with readiness and recovery to optimize adaptation on an individual basis. However, there is a paucity of research that has addressed the principle of individualisation and subsequently the understanding in this area is rudimentary [19, 25]. This can in part be attributed to the large inter-individual differences in response to exercise and the single-subject study design specifically used to evaluate these differences is arguably underutilised [26]. Individuals recover from resistance training at different rates [27] and genetic [28], biological age [29], menstrual cycle phase [30], and training age [31] differences result in muscular adaptations occurring at different magnitudes. In fact, those beginning the same resistance training program may experience no increase in maximal strength or hypertrophy while others may increase muscle size by ~60% and increase maximal strength by as much as 250% after a 12 week period [32]. However, despite the fact that genetic differences are immutable, there is evidence that adaptation to training can be improved when program-design is tailored to the individual [33-35].

An effective resistance training approach needs to be customised to an individual based on their dynamic state of recovery and performance needs. According to Selye's

General Adaptation Syndrome [36], a stressor is required for adaptation. However, to adapt to stress, an individual must be able to recover, which can be impacted by outside stressors putting additional strain on their system. In the context of exercise, if a stressor is beyond the capacity for adaptation (defined by Seyle as "exhaustion"[36]), improvements in performance can cease or regress. The amount of time it takes for positive adaptations to return and continue, determines whether the maladaptation was considered non-functional overreaching (shorter and less severe) or overtraining (longer and more severe) [37]. Factors such as sleep [38], nutrition [39] and psychological stress [40] can all impact adaptation. In fact, those who experience more negative life stress appear to gain less strength in response to resistance training in comparison to their lower-stress counterparts [41-43]. It is no wonder that numerous strength and conditioning authors recommend that some form of athlete monitoring occur alongside a training plan to ensure that the predicted response to training occurs, and if an unpredicted response occurs, training should be adjusted [25, 37, 44-49].

Arguably, adjusting a plan based on how the individual responds, how their needs change, and how their ongoing states of readiness and recovery shift over time should be a continual process in order to optimize adaptation [19, 26, 33, 34, 50, 51]. Thus, a cornerstone skill of the strength and conditioning practitioner is the ability to make training adjustments in an effective manner such that the frequency and severity of injury is reduced and the rate and magnitude of adaptation is optimised. However, this subjective aspect of athletic training largely falls under "the art" rather than the science of strength and conditioning and there is a learning curve for novice practitioners. For this reason, "autoregulation" is an intriguing area of study. Autoregulation is described as training that automatically adjusts to the athlete's performance to allow improvement at an individualised pace to optimize adaptation [20]. While it is unlikely (and not necessarily desirable) that coaching input will ever be divorced from training, if certain aspects of training regulation can be automatically embedded in an objective and systematic manner, this reduces the chance of human error and allows for greater focus on the elements of coaching requiring subjective decision making.

With this preamble in mind, this review is a brief treatise of the various methods that have been employed to monitor the state of the athlete for the purpose of regulating resistance training. Such methods include physiological, performance, and psychological monitoring measures that provide information before, during and after training. It is hoped by the end of the article that the reader understands the utility of the various methods available to enhance their training prescription. Additionally, this review identifies novel practices in resistance training regulation that are deserving of future exploration.

Methods

PubMed, Medline, SPORTDiscus, Scopus and CINAHL electronic databases were searched online in addition to hand searching. Subject area in the Scopus database was limited to "medicine" and "health professions" with only "articles", "reviews" and "articles in press" included in the search parameters. The search string: (resistance OR strength OR weight) AND training AND (autoregulat* OR auto-regulat* OR auto regulat*) OR monitor* AND athlet* was used for initial selection of manuscripts while limiting database results to peer reviewed studies of human subjects in English.

Once all manuscript records were obtained, initial screening consisted of: (i) screening for duplicates; (ii) screening titles for relevance; (iii) screening the abstracts for relevance; (iv) screening the full paper for inclusion criteria; and, (v) reviewing the references of the included papers to find any additional relevant publications that were not included previously. For a study to be included, the researchers must have: either investigated methods of athlete monitoring which were or could be used for resistance-training regulation, or investigated a training system or periodisation paradigm in which training was autoregulated; and/or, defined as an approach in which ongoing adjustments of a training variable (i.e. frequency of training, load selection, load progression, etc.) were systematically embedded into a protocol. If any papers were added that were found through reference checking or manual searching, they were subjected to the same screening process as if they had been found in the initial database search. Manuscripts that were not from peer reviewed journals or that were not completed theses or dissertations were excluded. Additionally, only manuscripts that added new knowledge to the review were included (repeated information was excluded).

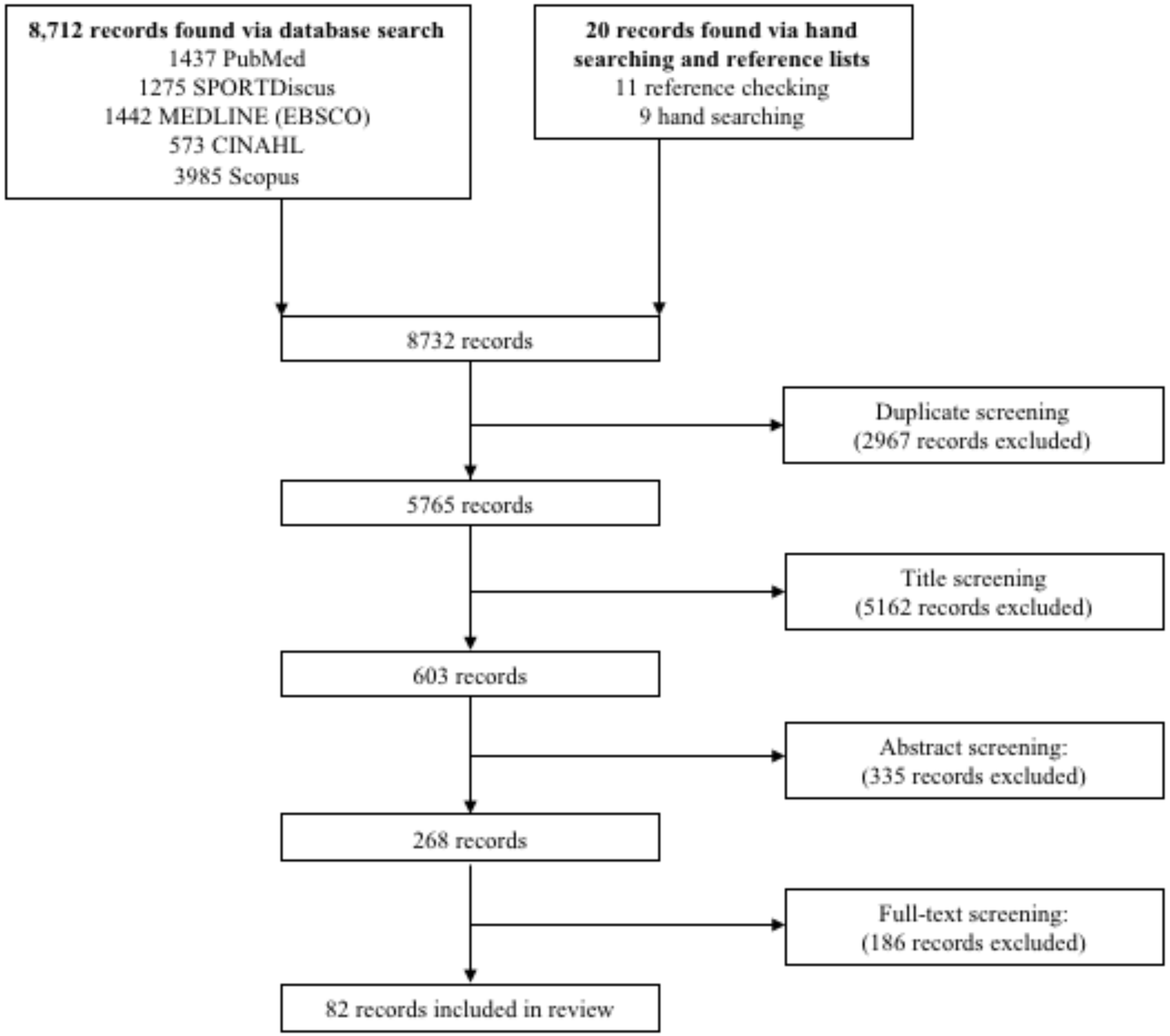
Correlations between measures of resistance training performance and monitoring variables were tabulated if the correlations were of a "strong" value of 0.68 or higher [52]. Pearson correlation coefficients (r) were calculated by determining the square root of coefficient of determination scores (r^2) when they were reported rather than r scores. If r or r^2 scores were presented at multiple time points between the same variables, the correlation was presented as ≥ to the lowest score. When correlational data was presented in a case series, the mean correlation from all participants was reported only for relationships that were significant across all participants.

This review is presented in a narrative format as it is not an attempt to provide guidelines for best practice or compare variables across studies. The purpose of this review is to provide an overview of the body of knowledge, avenues for future research, new perspectives in training theory, and to establish a framework for future experimental studies on autoregulation in resistance training.

Results

A flow chart diagram of the search selection process and articles included in this review can be observed in Figure 3. Upon viewing the included articles, certain themes emerged which are represented in the major sections within the discussion of this article. The major sections are organised by monitoring method to include; physiological, perceptual, and performance based measures. For each major section Tables 2, 3 and 4 respectively, display *r* scores denoting the strong relationships between the monitored variable/s and resistance training performance (1RM, volume performed, maximum repetitions performed, etc.) reported in all manuscripts. Additionally, sub-sections in each major section are organised by specific categories of physiological, performance and perceptual monitoring variables where appropriate.

Figure 3. Search and selection process.



Discussion

Physiological

Measuring the physiological status of an athlete is a commonly recommended approach to optimize future training [46, 51, 53, 54]. Additionally, monitoring of physiological markers is a proposed method of detecting the presence of non-functional overreaching or overtraining [37, 44, 55-60]. Depending on the time needed to analyse the data collected, physiological markers can theoretically be used to predict readiness to train. Likewise, the data can be analysed retrospectively to assess the effectiveness of training, and the results can be used to modify subsequent micro (e.g. daily - weekly), meso (e.g. weeks - months) or macrocyles (e.g. months – years) of training. The following section contains a review of hormonal biomarkers, muscle damage biomarkers, and heart rate variance.

Table 2. Physiological correlations with resistance training performance.

Study	Population	Correlating variable	Resistance training variable	*r* score
Cook et al. (2013) [61]	12 Elite F netball players	Salivary T	Bench press VL	0.84
Crewther et al. (2010) [62]	4 M Olympic weightlifters	Salivary T	SN 1RM	0.70
Fry et al. (1994) [63]	17 Trained M	Post-exercise E %Δ	ISO leg extension %Δ after RT	≥ 0.90
		Post-exercise NE %Δ	ISO leg extension %Δ after RT	≥ 0.94
		Post-exercise NE %Δ	Smith squat 1RM %Δ after OT	-0.72
Fry et al. (1998) [64]	11 Trained M	T, free and total T/C ratio Δ	Smith squat 1RM Δ after OT	-0.72
Fry et al. (2000) [65]	8 Elite M Olympic weightlifters	Pre-exercise T/C ratio %Δ	SN + C&J 1RM %Δ after NV RT	0.92
	14 M Olympic weightlifters	Pre-exercise T/C ratio %Δ	SN + C&J 1RM %Δ after NV RT	-0.71
González-Badillo et al. (2016) [66]	9 Trained M	T %Δ	Smith squat % velocity loss	0.70

M = male; F = female; T = testosterone; C = cortisol; E = epinephrine; NE = norepinephrine; ISO; isometric; SN = snatch; C&J = clean and jerk; RT = resistance training; 1RM = 1-repetition maximum; VL = volume load; OT = over training; NV = normal volume.

Hormonal biomarkers

Assessing the exercise-induced hormonal response of an individual is a commonly used method to quantify training stress in a research setting. However, there are inherent difficulties associated with using serum and/or plasma hormones and other biochemical markers to monitor and predict performance. The use of such physiological indices requires expert laboratory analysis that can be prohibitively costly if used on a regular basis, and depending on how the biological samples are collected, can be inappropriately invasive for regular use. In addition, due to the sample collection and processing time, no immediate modification of training variables can be performed based upon the obtained results. Thus, while biochemical analysis is a potential method of athlete monitoring, these issues draw into question the practicality of taking blood samples to assess markers for recuperation and readiness to train. That being said, one potential method that avoids some of these issues, is salivary hormone analysis [53].

Cook and colleagues [61] reported the relationship between pre-training salivary testosterone levels and performance in 12 national female netball players with at least 3 years of structured and progressive strength training experience. They reported that salivary testosterone levels were significantly related to relative voluntary workload in the back squat ($r^2 = 0.45$, $p = 0.02$) bench press ($r^2 = 0.70$, $p < 0.001$), and medicine ball throw distance ($r^2 = 0.50$, $p = 0.01$). Nunes et al. [67] reported moderate correlations ($r = 0.58$ to 0.65, $p = 0.02$ to 0.05) between the change in salivary testosterone and the change in half squat, bench press and biceps curl 1RM among elite female basketball players. Crewther and Cook [62] observed a similar trend in four male Olympic weightlifters, noting their pre-workout salivary testosterone concentrations significantly related to the snatch, clean and jerk and Olympic lift total ($r = 0.62$ to 0.70, $p < 0.01$ to 0.05). However, in the four female lifters in this study there was no significant relationship observed between pre-workout salivary testosterone and performance in the snatch or clean and jerk ($r = 0.01$ to 0.09) [62]. Similar research has also been performed with elite rugby players by Crewther and colleagues [68]. However unlike the aforementioned studies, significant relationships between testosterone and 1RM strength and allometrically scaled strength were not observed [68]. A potential reason strong relationships between salivary testosterone and strength are shown in some studies while others show no relationship at all, are differences in strength. It appears that when segregated by squat strength (those ≤ 1.9x bodyweight and those ≥ 2x bodyweight), stronger athletes display a much higher correlation ($r = 0.92$, $p < 0.01$) between salivary testosterone and 1RM than weaker athletes ($r = 0.35$, $p > 0.05$) [69].

Beyond differences due to subject characteristics, there is conflicting evidence regarding the validity of salivary testosterone analysis. While some reviews have concluded that salivary testosterone is a valid and reliable representation of serum free testosterone levels [53], not all research in this area is in agreement. Cadore and colleagues [70] reported very weak and non-significant correlations between salivary and blood testosterone ($r = 0.22$ to 0.26, $p > 0.05$). In another study the authors reported free testosterone to be very well represented by salivary testosterone measures in men ($r = 0.92$, $p < 0.001$) [71]. However, Youssef et al. [72] reported that this relationship was substantially weaker in females ($r = 0.52$, $p < 0.001$). The inconsistent findings on the validity of salivary testosterone may be another reason for the reported discrepancies for performance prediction in the literature.

Unlike testosterone, salivary measures of cortisol appear to be more consistently representative of serum levels [53, 70, 73]. As previously mentioned, while Crewther and colleagues observed no relationships between salivary testosterone and strength in elite rugby players, relationships between allometrically scaled box squat 1RM and salivary cortisol ($r = 0.69$, $p < 0.05$) and allometrically scaled and unscaled box squat 1RM with testosterone to cortisol ratio were observed ($r = -0.62$ to -0.73, $p < 0.01$ to 0.05). However, these relationships appeared to be movement and position dependent as they only reached significance in backs but, not in forwards and only in the box squat and not the bench press [68]. McGuigan and colleagues found that while volume load was not related to salivary cortisol, the percentage change in salivary cortisol levels was moderately correlated ($r = 0.54$, $p = 0.08$) to squat 1RM relative to bodyweight in resistance-trained males and females [74]. In contrast, changes in salivary cortisol had a moderate negative relationship ($r = -0.63$, $p = 0.08$) with front squat 1RM among male and female weightlifters as reported by Crewther [62].

Beyond training, there are mixed results as to the ability of salivary cortisol for predicting competition performance in strength athletes. Passelergue et al. [75] found a moderately strong correlation ($r = 0.67$, $p < 0.05$) between competition performance and salivary cortisol levels in male weightlifters, while Crewther [76] reported moderate correlations ($r = 0.48$ to 0.49, $p < 0.05$) for the competition lifts in male and female weightlifters during simulated competition, which disappeared in actual competition.

Similarly, Le Panse [77] found no correlation between cortisol and competition bench press results among male and female elite powerlifters.

Overall, there appears to be a high level of variability and inconsistency regarding the use of pre and post workout levels of, changes in, and the ratio between testosterone and cortisol as a predictive tool to monitor and regulate performance. In many cases disparate results between males and females [62], athletes of different competitive levels [65], athletes of different 1RM strength level [69], positions within a sport [68], actual versus simulated competition [76], exercises [68] and correlational direction (positive or negative) [62, 74] are reported. Therefore, while the invasiveness associated with blood collections can be avoided by salivary measurements, the time spent and expertise needed for analysis and the variability between and within studies, draws into question the practical utility of hormonal analyses as a training monitoring tool.

Heart rate variance

Another potential non-invasive method of physiological monitoring, is measuring heart rate variance (HRV). Measuring cardiac parasympathetic reactivation via HRV, determined in the immediate post exercise period, has been identified as a potential tool for; 1) monitoring the physiological strain experienced from training and, 2) adjusting the training loads of subsequent sessions [50, 51]. In endurance training studies, HRV guided training has been successful i.e. HRV guided training has either shown to be as or more effective than a 'traditional' training program [78, 79]. Additionally, with the validation of easy to use, low cost smart phone applications that can quickly and accurately monitor HRV data [80], this area of study is becoming increasingly attractive in the strength and conditioning community.

With that said, to the authors' knowledge no HRV guided resistance training interventions have yet been performed. However, there do appear to be differences in 24 hour HRV kinetics between strength athletes and endurance athletes [81]. But, these differences due to training modality are not found during acute HRV testing [54], as used in guided-training interventions. With that said, a number of studies have examined the time course of parasympathetic reactivation via HRV in response to various resistance training protocols [82-85]. Overall, acute parasympathetic activity is suppressed (e.g. reduced vagal activity; lower blood pressure and stroke volume) while heart rate remains elevated in response to resistance training [51]. Parasympathetic response seems related to the interaction of volume, relative intensity and effort per set (i.e. distance from muscular failure), and at 20-60 minutes post-exercise parasympathetic activity can be suppressed by 15-44% [82, 84, 85]. However, if the relative intensity is low and sets are completed far from failure (i.e. sets of 20 repetitions at 30% 1RM) there may be no suppression of parasympathetic activity at all [84].

While the use of post-training HRV measurements to guide subsequent training is an intriguing area, until resistance training interventions guided by the individual HRV response are implemented in a similar fashion to the endurance training studies that have been performed [78, 79], the benefits remain theoretical. Given that the time course of parasympathetic reactivation is thought to mirror recovery of central fatigue, but not necessarily peripheral factors such as muscle damage [83], it may be that HRV alone would not be an appropriate tool for monitoring recovery in strength trained athletes. Future research should investigate the use of HRV guided training in resistance training, potentially with easy to capture adjunct measurements of muscle damage, such as ratings of soreness [51].

Muscle damage biomarkers

Likewise, muscle damage has been proposed as a relevant biomarker for monitoring training [45, 55, 57, 86]. However, just as HRV may be inappropriate for resistance training monitoring in isolation because it provides data solely on central and not peripheral fatigue [51, 83], markers of muscle damage may also be inappropriate in isolation as they cannot provide information on a global scale [45, 55, 57]. For example, creatine kinase (CK) is one of the most commonly used biomarkers for muscle damage; however, it is not truly representative of exercise induced muscle damage as CK levels may be influenced by various factors such as ethnicity, hydration status and CK clearance rate within the muscle itself [86]. While CK does moderately correlate (r = 0.45 to 0.55, p = 0.01 to 0.05) to the amount of resistance training volume performed [87], this correlation may not be indicative of how much volume can or should be performed. Specifically, the causative relationship between adaptive skeletal muscle remodelling and muscle damage is disputed [88, 89]. Additionally, the repeated bout effect attenuates the muscle damage response to exercise and is impacted by the volume, contraction type, familiarity with the exercise and frequency of its performance [90]. Therefore, the muscle damage response may not be appropriate for determining an optimal training dose, as some of these factors are not necessarily related to workload or adaptive capacity.

There are a large number of muscle damage biomarkers which can be measured [91]. However, variability between studies, non-standardised procedures, measurement confounders, an unclear relationship between muscle damage and performance, and the fact that cheaper and easier to implement methods of subjective monitoring appear to better mirror training loads, suggests muscle damage markers at best have utility for regulating resistance training only when used alongside other monitoring methods [45, 55, 57, 86, 92].

Performance

Performance in and of itself can be a useful tool for monitoring resistance training. Unlike team sports, in strength sports such as Olympic weightlifting, powerlifting and strongman, the competition lifts can be directly replicated and tested in training. Typically, maximal strength testing is performed at the end of a training cycle to assess its effectiveness [93]. However, this approach only allows for retrospective analysis and may not provide feedback frequently enough to optimise training. While well-trained lifters can perform 1RMs with a high degree of reliability (CV = 1.7-3.6%) [94], novice lifters can increase their 1RMs quite rapidly due to neuromuscular adaptations and the learning effect of testing and thus, tests may not be representative of their true maximal strength [95, 96]. This draws into question the validity of basing training on a percentage of 1RM in these populations. Additionally, regularly testing competition 1RMs can be problematic even in well trained lifters. Strength gains may be optimised in trained populations when relative load, on average, reaches 80-85% of 1RM [97, 98]. However, there is data indicating that as the proportion of lifts exceeding 90% of 1RM increases, strength gains attenuate [99], potentially caused by increased fatigue from heavy loading. Additionally, there is some evidence that if form breakdown occurs the risk of injury is higher when lifting heavy (≥ 90% 1RM) loads [100]. While repetition maximum (RM) testing (i.e. maximal load capacity when performing 3, 5 or 10 repetitions, etc.) allows for a reduction in the peak mechanical strain on the body compared to 1RM testing, training to failure on a regular basis can be counterproductive as it can induce unnecessary fatigue and metabolic strain without an added benefit to performance when compared to a submaximal approach [95, 101, 102]. Therefore, there is interest in studying less taxing forms of performance that could be tested more frequently that are thought to reflect improvements in competition lifts [103, 104].

Table 3. Physical performance correlations with resistance training performance.

Study	Population	Correlating variable	Resistance training variable	*r* score
Carlock et al. (2004) [103]	38 M Olympic weightlifters	CMJ and SJ PP	SN and C&J 1RM	≥ 0.90
		1RM squat	SN 1RM	0.93
		1RM squat	C&J 1RM	0.95
	26 F Olympic weightlifters	CMJ and SJ PP	SN and C&J 1RM	≥ 0.76
		1RM squat	SN 1RM	0.79
		1RM squat	C&J 1RM	0.86
Channell et al. (2008) [105]	21 M high school athletes	Vertical jump height	PC 1RM/BW	0.75
		PC 1RM/BW	Squat 1RM/BW	0.88
Cronin et al. (2004) [106]	12 F netball players	Chest pass distance	Smith bench maximal strength	0.71
González-Badillo et al. (2010) [107]	56 Trained M	Mean velocity 30-95% 1RM	1RM	0.99
Murphy et al. (1995) [108]	13 Trained M	Bench press ISOPF 90°	Bench press 1RM	0.78
Shetty (1990) [109]	23 M/F Olympic weightlifters	Leg MVIC	SN 1RM	0.76
		Leg MVIC	Jerk 1RM	0.84
		Back MVIC	SN 1RM	0.72
		Back MVIC	Jerk 1RM	0.84
Vizcaya et al. (2009) [104]	21M Olympic weightlifters	DSJ height	SN 1RM	0.75
		DSJ height	C&J 1RM	0.78
		DSJ height	Sinclair total	0.83
		SJ height	SN 1RM	0.69
		SJ height	C&J 1RM	0.73
		CMJ height	SN 1RM	0.75
		CMJ height	C&J 1RM	0.78
		CMJ height	Sinclair total	0.75

M = male; F = female; CMJ = counter movement jump; SJ = squat jump; DSJ; deep squat jump; SN = snatch; C&J = clean and jerk; PC = power clean; 1RM = 1-repetition maximum; BW = body weight; PP = peak power; ISOPF = isometric peak force; MVIC = maximum voluntary isometric contraction. Sinclair total is a relative strength score in Olympic weightlifting to compare performance across weight classes [110].

Predictive performance measures

A number of research groups have investigated whether or not jump performance can predict the performance of the Olympic lifts and their derivations [103-105]. While Carlock et al. [103] reported strong relationships ($r \geq 0.76$) for peak power in the counter-movement and squat jump with Olympic weightlifting performance in both male and female Olympic weightlifters (Table 3), measuring jump height also appears to predict performance [104, 105]. Additionally, measuring jump height requires less expensive equipment and technical expertise than kinetic variables. While strong correlations are reported between counter-movement, deep squat and squat jump height with snatch and clean and jerk performance [104], the highest correlations within individual studies are typically found when taking bodyweight into account. Specifically, Vizcaya and colleagues [104] found that out of all tested correlations, the deep squat jump correlated highest ($r \geq 0.76$) with the Sinclair total (an equation for strength relative to bodyweight used in Olympic weightlifting [110]). Likewise, Channell et al. [105] reported their highest correlation ($r = 0.88$) for jump height with power clean 1RM relative to body mass. Limited study of the predictive ability of other peak power tests on exercise performance has occurred outside of jumps and Olympic weightlifting. For example, medicine ball chest pass distance was reported to strongly correlate ($r = 0.71$) with maximal Smith machine bench press strength [106].

Other lab-based kinetic measures have also correlated to resistance training performance. Maximum voluntary isometric contractions of the leg and back musculature are predictive ($r = 0.72$-0.84) of snatch and jerk 1RM [109] and 90 degrees isometric bench press peak force can predict ($r = 0.78$) bench press 1RM [108] in well trained lifters (these relationships may be weaker without technical proficiency in the exercises in question). While electromyography and force measurements are typically prohibitive due to the cost and expertise needed, measuring barbell velocity is an emerging possibility for field use. Mean concentric velocity is highly predictive of strength (Table 3) as per the load-velocity relationship. As a lifter approaches the maximal number of repetitions they are capable of performing during a set, velocity will slow until they reach failure or zero velocity [107]. Thus, it has been proposed that volume could be regulated by the maintenance of velocity or mechanical power or that load could be individually prescribed based on a velocity profile [107, 111, 112]. Indeed, authors of a review on velocity based training describe how an individualised velocity profile can be conducted with 5 sub maximal sets between 30-85% of 1RM without the need to test the individual's 1RM. This profile can then be used to prescribe load based on velocity as opposed to using a percentage of 1RM. This approach allows for load autoregulation on a session to session basis because it avoids the potential for acute arousal or fatigue to make a load prescribed by percentage 1RM too easy or difficult, respectively [96]. Furthermore, recently researchers investigated a system by which volume could be autoregulated based on thresholds for velocity decay. Specifically, two groups were compared, one which ceased performing repetitions within a set when the initial velocity decreased by 40% and another which ceased repetitions after a 20% velocity decay. More volume and subsequently greater hypertrophy was generated in the 40% group, while less volume and greater improvements in jump height occurred in the 20% group [113]. The linear position transducers utilised to track velocity in the field are easy to use, and as they become more affordable and with the advent of smart phone applications which can reliably measure velocity [114], velocity based training will likely become more accessible to athletes and practitioners.

Individualised load progression

Another performance based method of autoregulating training, is to implement individualised load increases based on variations in performance instead of using set increases in load from week to week [20]. In one such study, Mann investigated "autoregulatory progressive resistance exercise" (APRE), a system in which each exercise is performed for four sets, with the repetitions in the third and fourth sets performed until failure. A chart is consulted that dictates the load adjustment to the fourth set based on the number of repetitions achieved during the third set. If greater or fewer repetitions are performed than expected, the load for the fourth set is either increased or decreased according to the chart, respectively. This same process is then repeated based on the number of repetitions achieved on the final fourth set to determine the load to be used in the next training session [20]. Interestingly, when comparing APRE to a linear periodised (LP) approach with Division I American football players during a 6-week training period, Mann and colleagues found that APRE resulted in greater improvements in 1RM bench press strength (APRE: 93.4 ± 103 N vs. LP: 20.40 ± 49.6 N; $p = 0.02$), estimated 1RM squat strength (APRE: 192.7 ± 199 N vs. LP: 37.2 ± 155 N; $p = 0.05$) and number of bench press repetitions performed to fatigue with a weight of 225 lb (APRE: 3.17 ± 2.86 vs. LP: -0.09 ± 2.40 repetitions; $p = 0.02$), compared to LP [20].

Based on the same concept, in a speculative review Fairman and colleagues proposed the use of an APRE inspired, RPE modified, individualised load progression approach. The authors recommended that increases or decreases in load could occur when sets were performed at a lower or higher RPE, respectively, than prescribed [115]. Likewise, in a study comparing volume matched, moderate-load, high-repetition resistance training to high-load, low-repetition training, Klemp et al. [116] implemented an individualised approach to load increases in both groups based on the completion of the prescribed training from the previous week. Specifically, load increases scaled to the ability of the individual to complete prior training with smaller increases occurring when prescribed repetitions were missed [116]. While both approaches are inspired by the APRE model, these modifications allow the same concept to be applied without the requirement of training to failure.

Perceptual

Psychometric questionnaires and rating scales have long been used to assess readiness [117] and recovery [118] in athletes. Their ease of use, negligible cost, and versatility make them attractive options for training monitoring [92]. Simple scores for rating perceived exertion can be obtained after sets [119], or after entire sessions [120], and ratings for readiness can be recorded prior to sessions to predict performance [121] or even to alter training schedules [22]. Additionally, tracking fatigue and depression with psychometric questionnaires is one of the only methods of monitoring overtraining which is almost universally suggested due to its validity in mirroring training loads, ease of use and reliability [37, 44, 45, 55-60, 122, 123].

Table 4. Perceptual correlations with resistance training performance.

Study	Population	Correlating variable	Resistance training variable	*r* score
Hackett et al. (2012) [124]	17 M competitive bodybuilders	Estimated RIR	Actual RIR	≥ 0.93
		Mean CR-10 RPE	Actual RIR	≥ −0.94
Testa et al. (2012) [119]	80 Trained M/F	Mean CR-10 RPE	VL relative to MNR capacity	≥ 0.81
Zourdos et al. (2016) [18]	15 Trained M/F	RIR-based RPE	Mean squat velocity	-0.88
	14 Novice M/F	RIR-based RPE	Mean squat velocity	-0.77

M = male; F = female; RIR =repetitions in reserve; CR-10 = Category ratio one to ten; RPE = rating of perceived exertion; VL = volume load; MNR =maximum number of repetitions.

Perceived recovery status

One such scale introduced by Laurent and colleagues called the perceived recovery status (PRS) scale is a way of monitoring athlete readiness [117]. The PRS scale is essentially an inverted RPE scale from 0-10 whereby 10 signifies "very well recovered" and 0 signifies "very poorly recovered". PRS scores of 0-2 indicate that the athlete or coach can expect reduced performance, with scores of 3-7 normal performance is expected, and with scores of 8-10 improved performance is expected. In this study, PRS scores were applied to repeated sprint training over 72 hours and the authors found that PRS scores taken post warm up were inversely associated with change in sprint times, i.e. faster sprints were moderately correlated with higher subjective ratings of recovery (r = -0.63, $p < 0.01$). When PRS scores were taken prior to warming up, this correlation fell to -0.41. While not a study of resistance training, this study opened the door for Sikorski and colleagues to examine the relationship between PRS scores and biomarkers of recovery and readiness 48 hours after a high volume bout of resistance training in trained participants [121]. The authors reported that 58.6% of the variance in the muscle damage marker creatine kinase was explained by PRS scores (r^2= 0.59, $p < 0.05$) and overall, moderate coefficients of determination were observed between muscle soreness in the legs, chest and arms respectively (r^2 = 0.53, 0.29, 0.12, $p < 0.05$).

Questions remain however, as to the utility of the PRS scale to predict acute performance. In a recent case series of two well-trained powerlifters and one Olympic weightlifter, it was reported that their daily PRS scores were moderately correlated with daily 1RM performance in two out of three lifters. However, in one lifter this correlation was positive (r = 0.53, $p < 0.05$) as one might expect, while in the other lifter the correlation was actually negative (r = -0.39, $p < 0.05$) [125]. In contrast to the inconsistent relationship between PRS and 1RM in this case series of well-trained lifters, significant relationships were reported for all participants between the RPE score of their final warm up set at 85% 1RM and 1RM performance (r = -0.35-0.70, $p < 0.05$) [125]. In this study, a relatively new RPE scale based on RIR was utilised, in which RPE scores are defined by how many additional repetitions the user believes they could have performed had they taken the set to failure (i.e. 7 RPE corresponds to 3 RIR, 8 RPE to 2 RIR, 9 RPE 1 RIR, etc.) [18]. Thus, it seems that RIR-based RPE may be a more accurate predictor than PRS for acute force production.

Borg and RIR-based RPE

The "resistance training specific" RPE scale based on RIR [18] is a validated objective measure for intensity of effort [95, 96, 107, 126, 127] as shown by the strong inverse correlations with barbell velocity as load increased in novice and well trained lifters (r = -0.77-0.88, $p < 0.001$) [18, 128]. Additionally, it may be a more accurate scoring system for resistance training than the Borg category ratio 1 to 10 (CR-10) RPE scale [23]. This notion is based on the fact that lifters using the Borg scale have been shown to report submaximal RPE scores (6.8 to 8.1) even when taking sets to failure [129, 130]. In one study, bodybuilders reported submaximal CR-10 scores when taking bench press and squat sets to failure (8.9-9.0 ± 0.7-0.8), yet their estimated RIR was within 0.63 repetitions from actual RIR (95% limits of agreements) [124]. Also, the ability to accurately gauge exertion using the traditional Borg RPE may be influenced to a greater degree by biological sex and athletic experience [131, 132]. Specifically, the more experience an athlete has the more accurate ratings become [132]. Furthermore, in one study inexperienced female athletes rated Borg RPE less accurately than inexperienced males however, athletic exposure seemed to override these differences [131]. In contrast, authors of a recent study found when trained and untrained males and females performed the machine chest and leg press within 0 to 3 repetitions from failure, their predicted RIR error (i.e. the difference in the number of repetitions between predicted and actual) was less than one and did not significantly differ based on biological sex or experience [133]. However, some minor differences related to biological sex and experience do exist when using the RIR-based scale. In the same study, when more than 3 repetitions from failure remained, males gauged RIR slightly more accurately than females [133]. It also appears novice lifters are less accurate when selecting back squat 1RM loads using the RIR-based scale compared to experienced lifters. However, this is likely caused by novice lifters' inability to maintain neuromuscular control of heavy loads versus markedly poorer rating ability [18].

Overall, the greater accuracy observed when using RIR-based versus Borg RPE may be due to the differing definitions for scores between scales. Exercise "anchoring" (which is often not performed), whereby the researcher has the participant perform exercises at varying intensities and then verbally anchors RPE scores to each intensity, improves the accuracy of subsequent Borg RPE ratings [134]. Arguably, the Borg RPE scoring criterion such as "very hard" or "somewhat hard" are more reliant on anchoring because individuals of different demographics and with different backgrounds (i.e. athletic experience, biological sex etc.) may have differing perceptions of what constitutes these descriptions. However, the RIR-based scale may have less variability as scores are more objectively anchored based on the specific number of repetitions the user believes they can perform at the end of a set.

Athlete-adjusted training configuration

Another use for subjective rating scales, is for altering training scheduling. In a study that more or less applied the PRS for daily load selection, McNamara and Stearne implemented a flexible non-linear model of training whereby members of a university weight training class could select either 10, 15 or 20RM loads for the day after rating their energy level on a 1 to 10 scale [22]. The flexible training group made significantly greater strength improvements on an estimated 1RM leg press test when compared to a volume-matched group that performed a predetermined loading order (62 kg vs 16 kg; $p = 0.02$). Thus, while PRS was not explicitly studied, a 1 to 10 scale of readiness was used to guide daily training. Therefore, although it is unclear whether the PRS scale can accurately predict force production in trained lifters, based on the findings of McNamara and Stearne [22], it still may be a viable method of assessing readiness to train.

Supporting this notion, in a recent study resistance trained males were split into two groups, one performing an undulating protocol in a pre-set daily order of hypertrophy, power, and strength (HPS), while participants in a 'flexible' group were given the option to choose the order in which they wanted to perform the sessions each week. Unlike McNamara and Stearne [22], the flexible and HPS groups gained similar ($p = 0.63$) amounts of strength (increase in powerlifting total by 9.3% and 9.2%, respectively) [21]. This lack of difference is potentially explained by a recent investigation, in which participants using the HPS model performed more volume on strength days and increased 1RMs to a greater degree than a group performing sessions in the order of hypertrophy, strength and then power [17]; suggesting that there is little room to improve the HPS model when only intra-week adjustments are made (McNamara and Stearne allowed for adjustments throughout an entire mesocycle [76]). With that said, even though performance was similar between groups, all participants in the flexible group completed the protocol while only 11 of 16 did so in the HPS group. Thus, it appears that a training protocol with a flexible schedule may improve adherence and will at least result in similar [21], if not potentially greater strength gains [22], compared to a pre-set protocol.

Session RPE

Another application of RPE in resistance training is the use of 'session RPE' [120] which was originally introduced by Foster and colleagues in the study of endurance athletes [135]. Session RPE is calculated by providing a 1-10 RPE rating using the Borg CR-10 scale 30 minutes after training to encapsulate the global perceived difficulty for the session. This rating can then be used as a representation of internal training stress by itself [118, 120], or it can be multiplied by the total repetitions [48, 74] or sets performed in a session [74]. When using the session RPE rating in isolation, the score tends to mirror the load used in training without respect to the volume performed [118, 120]. Thus, it is recommended to multiply session RPE by the number of repetitions performed, and optionally to divide that by the amount of time the session took, to provide a measurement for internal training load that represents volume, intensity and density of training [118].

Furthermore, McGuigan and Foster [136] propose that the use of session RPE can be extended for more in depth resistance training monitoring. Specifically, session RPE is multiplied by the number of sets (in the case of aerobic exercise, session duration would be used) to represent 'training load' for the day. Then, 'training monotony' (defined as the variability of training over a given time period) is determined by dividing the mean training load over a week by its SD. Finally, the product of training load and monotony is used to calculate 'training strain' [58], which represents the overall stress experienced by the athlete. Importantly, higher levels of monotony and strain are associated with overtraining in athletes [58], however, little research exists examining overtraining relationships with these variables when performing resistance training [137].

The original and CR-10 Borg RPE scales [23, 138], modified scales that include a visual component [139] and the session RPE [135] methods all appear to be reliable, representative of both training load and physiological stress markers and have thus, been suggested for use in training monitoring [48, 58, 74, 118-120, 136, 140-143]. However, largely the application of RPE has been as a post-set or post-session method of ensuring the prescribed external stress is matched internally with the experience of the athlete. Only recently has RPE, specifically the RIR based scale, been suggested as a method for load prescription to embed autoregulation within a programming strategy

[18, 115]. While this is an intriguing proposition, future research is required to assess the effectiveness of this approach to load prescription.

Conclusions

A great deal of research has been conducted which examines methods of monitoring and regulating resistance training. Many of the biochemical monitoring methods are currently only appropriate for use within a research setting due to cost, time course for analysis, expertise required, and sample size needed for reliability. Other physiological monitoring methods, such as HRV, side step these issues, however, their application for resistance training has not yet been adequately studied. In contrast to the often difficult to use physiological methods, practical performance based approaches to individualising training exist. Autoregulating load progression based on previous performance may result in greater strength gains than pre-determined progression models; and selecting an acute session-focus based on perceived readiness may also result in greater strength gain compared to rigid scheduling. Some field based performance measurements appear to have utility for predicting competition lift 1RM strength. Specifically, bodyweight or light weight implement (such as a medicine ball chest pass) tests of maximal power may be usable as testing surrogates to avoid the fatigue and high mechanical loads associated with testing 1RM or repetitions to failure, if the athletes have a high technical proficiency and if a high test-retest reliability is established. Additionally, as the accessibility of velocity measurement technology improves, velocity-based autoregulation for both load and volume may become increasingly attractive approaches to individualising training. Given the ability of athletes to accurately gauge RIR and the high correlations between velocity and RIR-based RPE, this novel RPE scale may also have similar utility. While Borg and session RPE are useful for post-hoc monitoring, future research may reveal the RIR-based scale to have unique applications for autoregulatory training prescription much like velocity.

Chapter 3: Application of the Repetitions in Reserve-Based RPE Scale for Resistance Training

This chapter comprises the following paper published in the *Strength and Conditioning Journal.*

Reference:

Helms ER, Cronin J, Storey A, Zourdos MC. Application of the repetitions in reserve-based rating of perceived exertion scale for resistance training. Strength Cond J. 2016:38(4):42-49.

Author contribution:

ERH: 82.5%, JC: 5%, AS: 5%, MCZ: 7.5%.

Preface

At the completion of the previous chapter it was identified that further study of the RIR-based RPE scale was required. Therefore, this chapter serves as a targeted review specifically on the application of the RIR-based RPE scale. At the time of this chapter's publication in the *Strength and Conditioning Journal*, only two studies had been published in this area [18, 124]. These studies are the key focus herein. In this chapter, the limitations and the broad potential applications of the RIR-based scale are discussed, which provides a platform for the subsequent investigations that are presented in the experimental chapters.

Introduction

An RPE scale is a tool used to monitor the perceptual response to training, which has been well established as a method of determining exertion during exercise [144]. The original RPE scale was developed by Gunnar Borg over forty years ago [138] and has been primarily used to monitor aerobic exercise. The original scale rated exertion from 6-20 to roughly match heart rate, and therefore its application to resistance training may have been limited. Its creation was followed shortly by the development of Borg's CR10 scale. The Borg CR10 Scale was the first scale to provide exertion ratings from 1-10 and it was followed by the creation of a visually aided 1-10 RPE scale known as the OMNI scale [145]. However, more recently RPE has been utilised, via these three aforementioned scales, to gauge effort during resistance training [146]. While there are slight differences in the nomenclature and numerical ranges of these scales, all have been determined valid methods of quantifying perceived exertion [145].

There are different ways to utilize RPE scores in resistance training. Scores can be obtained from the lifter after each exercise or group of exercises, or alternatively using the session RPE method, whereby 30 minutes after a session is completed an RPE score for the entire training bout is obtained [147]. Session RPE can be used to prescribe intensity for an entire training session or to monitor the global response to training over time to make adjustments to a periodisation plan [120]. However, if a strength and conditioning practitioner wishes to prescribe intensity using RPE on a set to set basis, the traditional RPE scale has limitations. Arguably the most important limitation is that less than maximal RPE scores are often reported even when the maximal number of repetitions are performed at a given load [124, 129, 130].

In fact, Hackett and colleagues [124] explored this limitation by measuring both the estimated repetitions remaining, actual repetitions remaining and the RPE in bodybuilders performing the bench press and squat. To do so, the researchers had the participants perform five repeated sets at 70% of 1RM for 10 repetitions (or to failure if 10 repetitions could not be completed) with five minutes rest between sets. At full extension in both the squat (standing at full extension) and bench press (arms extended with elbows locked), upon completion of the tenth repetition of each set, participants verbalised either how many more repetitions they believed they could perform before reaching failure or a 1-10 RPE score (whether remaining repetitions or RPE was reported was randomised). Then, while receiving verbal encouragement from spotters they continued the set to muscular failure to determine actual repetitions remaining.

Hackett and colleagues discovered that not only did participants report RPE ratings that fell short of maximal (less than 10) even when sets were taken to volitional failure (no further repetitions could be performed), but that the participants had a high degree of accuracy in estimating their number of repetitions remaining on a set. The actual and estimated number of repetitions performed by the lifters were highly related for both the bench press (r = 0.95) and squat (r = 0.93). Additionally, with each subsequent set the participants were able to more accurately gauge the number of repetitions remaining. Meaning, that as fatigue mounted from prior sets and the closer to failure a set was taken, the more accurate the estimation of repetitions remaining became [124]. However, a disconnect remained as Hackett et al. [124] had athletes utilize two different scales to assess RPE and repetitions remaining, thus it may be more appropriate to present one scale to athletes for feasibility and ease of use.

For this reason, Zourdos and colleagues recently investigated the use of a 1 to 10 scale in which RPE value corresponds to a number of RIR (i.e. 10 RPE = 1 RIR, 9 RPE = 2 RIR, and so forth) in experienced (those who had > 1 year experience performing the barbell back squat) and novice (those who had < 1 year experience) squatters [18]. Because Hackett et al. [124] found athletes' estimates of repetitions remaining were more accurate when a set was closer to failure, this scale was developed using RIR descriptors for scores of 5 to 10 and descriptors of perceived effort to describe scores from 1 to four. Additionally, scores of 5-6 were grouped as 4-6RIR as it is easier for athletes to give a range of RIR when RIR is greater than 3. Zourdos and colleagues also found substantial differences between novice and experienced squatters which have important implications for the use of this scale. The scale introduced by Zourdos and colleagues can be seen in Figure 1. It must be noted that even though Zourdos et al. have introduced an RIR based scale into the scientific literature, a scale of this type was originally created in "The Reactive Training Systems Manual" in 2008 to be used in powerlifting-type training [24]. Based upon these recent studies it seems that a scale based on RIR has a number of potential applications in resistance training, which this review will examine.

Benefits of using an RIR-based scale for prescribing intensity

While it may be a more accurate method of determining near-limit loads for resistance training compared to the traditional RPE scales [124], the RIR-based scale also shares many of the beneficial traits associated with traditional RPE. There is inherent variation in human performance due to normal biological and psychological variability and factors such as sleep [38], nutrition [39], and life stress [43] all may affect strength during training or during testing. Additionally, rates of progress and recovery are highly individual [28, 148]. Methods of determining intensity such as percentage of one 1RM and RM are based on a previous performance that may not be representative of an athlete's current status. 1RM is not stable in novice populations [149] and can be suppressed by fatigue from prior training mesocycles [150]. Thus, if a 1RM or RM test happens to be reflective of an abnormal performance, positive or negative, subsequent training loads would be lighter or heavier than intended. Likewise, even if a test does accurately reflect current strength, subsequent percentage 1RM loading does not account for day to day fluctuations in performance. Also, despite the common use of tables showing "repetitions allowed" at different percentages of 1RM in professional texts [151], there are inter-individual variations in how many repetitions can be performed at the same percentage of 1RM [152]. To conclude, the RIR-based scale not only shares the benefit of putting all individuals on a "level playing field" that traditional RPE enjoys, but also has the unique advantage of being more valid than traditional RPE for sets performed with near-limit loading [124].

If a practitioner decides to use an RIR-based scale to prescribe intensity, care must be taken to ensure it is properly implemented. The ability to accurately gauge traditional RPE is greater in those experienced with resistance training compared to novices [119, 153], and this appears to hold true when using an RIR-based scale as well. In Zourdos and colleagues' recent study comparing the use of an RIR-based scale in experienced and novice squatters, not only were experienced squatters more often able to provide accurate scores at 1RM (9.80 ± 0.18 versus 8.96 ± 0.43, p = 0.02), but the inverse association between scores and velocity was stronger in experienced compared to novice squatters (r = -0.88 versus r = -0.77) [18]. This relationship between RIR and velocity is important; as per the load-velocity relationship, as intensity increases the speed of movement decreases. For example in competitive powerlifting, a sport where one of the goals of the competitor is to squat as heavy a load as possible for a single repetition, it has been said that an attempted lift that is just barely completed at the slowest speed possible is indicative of the best performance capable by that lifter [154]. This is not to say that loads are intentionally moved slow, but rather that experienced lifters due to their extensive neuromuscular adaptations and their ability to hold form at very heavy loads, can "grind" through heavier attempts than novice lifters at slower speeds without failing. For this reason, the ability to complete maximal lifts at very slow speeds can be viewed as a sign of neuromuscular efficiency, with regards to maximal strength, and indicative of an experienced lifter [18]. Thus, for this RIR-based scale to be seen as a valid measure of assessing intensity, final-repetition velocity should decrease as the score of a given set increases. Therefore, the stronger inverse relationship observed in experienced squatters seems to indicate that experienced lifters are more accurate in gauging RIR.

Similar to previous data [124], Zourdos and colleagues also observed that experienced lifters are more consistent at gauging RIR as they approach failure. This is indicated by a decrease in the variability of scores as lifters performed single repetitions at increasing intensities. The standard deviation (SD) of the scores reported for single repetitions at 100, 90, 75 and 60%, of 1RM were 0.32, 0.92, 0.97, and 1.18, respectively for the experienced squatters [18]. The data from Zourdos and colleagues clearly suggests experienced lifters to record more accurate scores than novice lifters. Therefore, novice lifters should practice recording RIR, but likely not base training intensity or progression solely on the RIR-based scale until increased accuracy is achieved. A possible way to gauge this is to take a submaximal set short of failure and record a score followed by a subsequent set at the same load that is taken to failure to test if the score was accurate. Once accuracy is established, RIR scores should primarily be used for training goals that require sets to be completed near, or a few repetitions short of volitional failure (RPE 7 to 10). Therefore, the use of the RIR-based scale should primarily be relegated to training goals such as strength, hypertrophy, muscular endurance or heavy power training.

To conclude, implementation of the RIR-based scale with novice and experienced lifters for various training goals is possible. However, the RIR-based scale should be implemented only as an additional variable to be tracked alongside normal training data with novice lifters. This serves to increase the awareness of how close each set is performed to failure, and to therefore familiarize the user with the scale. Once the lifter has advanced past the novice stage, the use of this scale for intensity prescription can be considered. However, before implementing the scale in this manner, a session dedicated to testing the lifter's rating accuracy with the scale should be performed.

Furthermore, prescribing intensity using an RIR-based scale is not mutually exclusive with prescribing intensity using percentage 1RM or RM values. If a practitioner wishes to use these arguably more objective measures of intensity, they can also use RIR in conjunction with a RM or percentage 1RM prescription to ensure the intended stress matches the experienced stress of the lifter. For example, if a practitioner prescribes three sets of three repetitions at 90% 1RM, they might expect on a good day for the lifter to be able to complete the initial two sets with one repetition remaining, and for the final set to be near maximal. To ensure that this intended intensity is what is experienced, they can concurrently prescribe "0 to 1 RIR on all sets" so that the lifter knows to reduce the intensity if they are unable to complete three repetitions, or to increase the intensity if they are able to complete sets with more than one RIR. This approach could also be used with an RM prescription if the practitioner wishes for the lifter to stop short of muscular failure. For example, a "5RM with 1 RIR" could be prescribed so that the lifter knows to use the heaviest load they can lift for five repetitions, while stopping the set with one RIR.

Relationship of percentage 1RM, repetitions performed and RPE

For practitioners used to prescribing intensity based on percentage 1RM (and RM) and its relationship with repetitions allowed, we direct them to Table 5 which is a conversion chart based on the mean RIR-based RPE scores reported by the experienced squatters for the single repetition sets at 90 and 100% 1RM, and the eight repetition set at 70% 1RM in the publication by Zourdos and colleagues [18]. This chart is not without limitations as it is based on the mean scores specific to the trained lifters in this study only. Values for percentage 1RM-repetition combinations besides single repetitions at 90% and 100% 1RM and eight repetitions at 70% 1RM are estimations. Additionally, as previously stated, there are significant differences in how many repetitions can be performed at the same percentage of 1RM by different individuals [152]. Furthermore, this chart is based on the barbell back squat, and this relationship may change with machine-based, single joint or upper body exercises. Lastly, this chart is based on the mean scores from Zourdos and colleagues [18]. Statistically, this is important to note due to individual differences in the ability to perform repetitions at different percentages of 1RM. For example, the SD reported at eight repetitions at 70% of 1RM was 1.2. Meaning, that roughly two thirds of lifters when performing a set of eight repetitions at 70% of 1RM may report an RIR between 2-4, while some lifters may report an RIR as low as 1 or as high as 5. Therefore, this chart should be primarily used to conceptualize the relationship between repetitions performed, percentage of 1RM and RIR scores in trained lifters. It should not be viewed as an absolute conversion tool, due to individual differences and day to day variations in strength that were discussed earlier in this review.

Table 5. Relationship with percentage 1RM, repetitions performed and RPE.

RPE	Repetitions performed							
	1	2	3	4	5	6	7	8
10	**100%***	95.0%	91.0%	87.0%	85.0%	83.0%	81.0%	79.0%
9.5	97.0%	93.0%	89.0%	86.0%	84.0%	82.0%	80.0%	77.5%
9	95.0%	91.0%	87.0%	85.0%	83.0%	81.0%	79.0%	76.0%
8.5	93.0%	89.0%	86.0%	84.0%	82.0%	80.0%	77.5%	74.5%
8	**91%***	87.0%	85.0%	83.0%	81.0%	79.0%	76.0%	73.0%
7.5	89.0%	86.0%	84.0%	82.0%	80.0%	77.5%	74.5%	71.5%
7	87.0%	85.0%	83.0%	81.0%	79.0%	76.0%	73.0%	**70%***

*Mean values from sets in Zourdos et al. [18]

Incorporating the scale into programming

Once an athlete is determined to be adequately experienced with resistance training and has been familiarised with the use of the scale, it can be integrated into any training plan designed to maximize hypertrophy, muscular endurance, strength or power at relatively heavy loads. Due to the inaccuracy of gauging RIR when a set is completed far from volitional failure, it would not be appropriate to use this scale for low to moderate intensity, high velocity power training (under 80% 1RM) if the goal is to have an accurate gauge of RIR [151]. However, the development of power in the high-force portion of the force-velocity curve could be targeted using this scale [155]. That said, a potential use for this scale for low to moderate intensity, high velocity power training may exist by setting an "intensity cap" on sets performed. Since the scale has subjective descriptors of effort for values below 5 (1-2 RPE = "little to no effort", 3-4 RPE = "light effort"), it could be used to determine if high-velocity power training is being performed in an explosive enough manner, by limiting sets to loads that can be performed at an RPE no higher than 4. Thus, this illustrates the additional advantage of a combined RPE/RIR scale rather than solely focusing on one or the other.

As previously mentioned, intensity can be prescribed using percentage 1RM or as a RM with a reference RIR value, or if the lifter is appropriately familiarised with this scale a practitioner can prescribe only a repetition target (or range) and a target RIR (or RIR range). For example, if the practitioner wishes for the lifter to perform three sets of 10 repetitions one or two repetitions short of failure, they would prescribe: "3 x 10 at RPE 8-9 (i.e. 2 or 1 RIR)." The lifter would then select a load with which they believe they could complete 10 repetitions, 1-2 repetitions short of failure (based on prior training experience, perceived readiness on the day of, and RPE scores on warm up sets). To further aid practitioners who wish to prescribe intensity using RIR, the following sections cover how the scale functions for different training goals.

Muscular hypertrophy

Recent investigations into the determinants of muscular hypertrophy have revealed that total volume of training is of primary importance for stimulating muscle growth rather than a specific repetition range [156-160]. While low intensities (~20RM or higher) can produce appreciable hypertrophy [160], if the intensity is too light it may not completely optimize muscle growth. Even when low intensity (30% 1RM) training is performed until volitional failure, the same degree of muscle activation that occurs with heavier intensities (75% 1RM) is not attained [161]. Campos and colleagues observed that when a matched volume of moderate (9-11RM) and high intensity (3-5RM) training is performed, a similar magnitude of hypertrophy occurs, which is greater than hypertrophy induced by low-intensity training (20-28RM) also performed at a matched volume [162]. This may be because light loads, even when forcefully accelerated and matched for volume, do not produce the same force output over the course of a session as moderate loads as indicated by a lower average impulse [163]. However, the utility of high repetition low intensity training for hypertrophy should not be completely dismissed. Recent research compared an equated number of sets at 25-35RM to 8-12RM and found similar levels of hypertrophy [164]. Unlike Campos' research, volume (resistance x sets x reps) in the 25-35RM group was approximately twice that of the 8-12RM group, so the comparative utility of high repetition low intensity training is still in question. However, given the recommendation of some researchers to use a mixture of high, moderate and low repetition training to optimize not only global, but fibre-specific hypertrophy [157], a direct comparison between RM training zones might not be the appropriate research question. Rather, future research should examine the utility of a combination of high, moderate, and low RM training zones within a periodised plan as it could prove optimal for maximising hypertrophy.

To summarize, loads that are "heavy enough" (< 20RM) and are performed with an adequately high volume appear to optimize hypertrophy. Thus, for the majority of training both heavy and moderate loads can be used to effectively stimulate muscle growth. However, it appears that the repetition range typically associated with hypertrophy of six to 12 may not be inherently superior to heavier training for hypertrophy for any mechanistic reason [116]. Rather, the six to 12 repetition range could potentially have an advantage from a time efficiency stand point. Specifically, data has shown 3RM training to yield similar biceps hypertrophy to 10RM training [157], and undulating periodisation of a low repetition group (2-6 repetitions) versus a high repetition group (8-12 repetitions) to result in similar hypertrophy of the chest and quadriceps [116]. Importantly, in both cases high repetition training took less total time per session. Performing sets with very heavy loads (3RM) requires substantially longer to perform than matched-volume training with moderate intensities (10RM) [157]. Therefore, we advise primarily (but not exclusively) utilising repetitions in the range of six to 12, with an RIR-based RPE of 8-10 (RIR 0-2) depending on phase of training. Training at an RIR of 0 (to failure) should be implemented in a manner so as not to potentially reduce volume on subsequent sets due to fatigue, and therefore limited to the final set performed for a given body part and primarily relegated to exercises with a low biomechanical complexity and risk of injury (i.e. isolative assistance movements) [156]. Thus, for main movements (squats, bench press, etc.) primarily performing sets within the RPE range of 6-8 (i.e. 2-4 RIR) may be an appropriate strategy to avoid excessive muscle damage and reductions in intensity can be implemented as needed on subsequent sets. Likewise, to avoid decrements to volume performed on subsequent sets, rest periods should not be restricted for hypertrophy training despite the common recommendation to do so. With only one exception [165] the majority of research has not supported the hypothesis that restricted inter-set rest periods provide an advantage for hypertrophy [156, 157, 166-168]. In fact, in one study a significant increase in hypertrophy was reported only in the group using a longer versus shorter rest interval [169]. Indeed, short rest intervals can compromise the volume performed on repeated sets [170], which some authors have theorised could harm hypertrophy and thus subsequent sets should be performed when the athlete is ready [166].

Muscular endurance

Muscular endurance in the context of resistance training, is often represented by the ability to perform as many repetitions as possible at a given absolute load, such as seen in the bench press combine event in professional American football. Also, it is often measured as the ability to perform as many repetitions as possible with a low or moderate percentage of 1RM. However, this could also be viewed simply as one's specific strength capacity with lower relative loads. Muscular endurance training is performed in a similar manner as hypertrophy training except with a focus on developing fatigue resistance rather than training to maximize volume at a moderate intensity. In this case, and in contrast to hypertrophy-type training, rest periods can be purposely restricted to promote the adaptation of faster inter-set recovery if desired [170]. Higher repetition training (25-35RM) has been shown to result in a greater number of repetitions performed than hypertrophy training (8-12RM) on the 50% 1RM bench press to failure test [164]. Very high repetition training (100-150RM) can also be used to develop muscular endurance, depending on the training goals of the individual, as shown by seminal research by Anderson and Kearney [171]. Also, while training to failure is not always advised for hypertrophy due to the potential to harm performance on subsequent sets, training to failure does seem to more effectively enhance local muscular endurance than stopping short of failure [101]. Therefore, sets of 12 repetitions and higher [151] performed with shorter rest intervals (< 2 minutes) at an RIR-based RPE of 9-10 (RIR 0-1), with rest periods and repetition ranges specific to the needs of the athlete, should constitute the majority of a session targeting muscular endurance.

Maximal strength

For the development of strength, it appears that training intensities of 80-100% of 1RM provide the largest mean effect for those with resistance training experience [97, 172]. For this reason, it is recommended when training athletes to use intensities in the 1-6RM range for sessions with the goal of maximising muscular strength [151]. When using RIR-based scores, this could translate into a large number of RPE-repetition combinations. As displayed in Table 5, 83% of 1RM is roughly equal to 6RM, therefore 6 repetitions with 0 RIR, 5 repetitions with 1 RIR, 4 repetitions with 2 RIR or 3 repetitions with 3 RIR would all be roughly equivalent in load and representative of the lower end of the intensity threshold for maximal strength development. However, it is worth repeating the limitations of Table 5 as it is based on the mean values of trained lifters performing the barbell back squat, and thus a perfect relationship between percentage 1RM and RIR should not be expected.

Inherently, the term 'maximal strength' is indicative of a performance representative of an athlete's maximal force output. Therefore, per the principle of specificity some training at an RPE 10 (RIR 0) should occur to acclimate an athlete for this goal, especially if a training cycle is concluded with RM testing. However, caution is advised when training to failure regularly as it may cause alterations in resting hormone concentrations consistent with overreaching in the absence of superior strength enhancement versus submaximal training (i.e. 2 or 1 RIR) [101]. Additionally, when a large portion of an athlete's training volume is performed to near maximal intensities (i.e. > 90% of 1RM), increases in strength may be compromised compared to performing only a moderate amount of volume in this range [99]. Thus, training at the higher end of the intensity spectrum should be carefully planned and cycled into a periodised program.

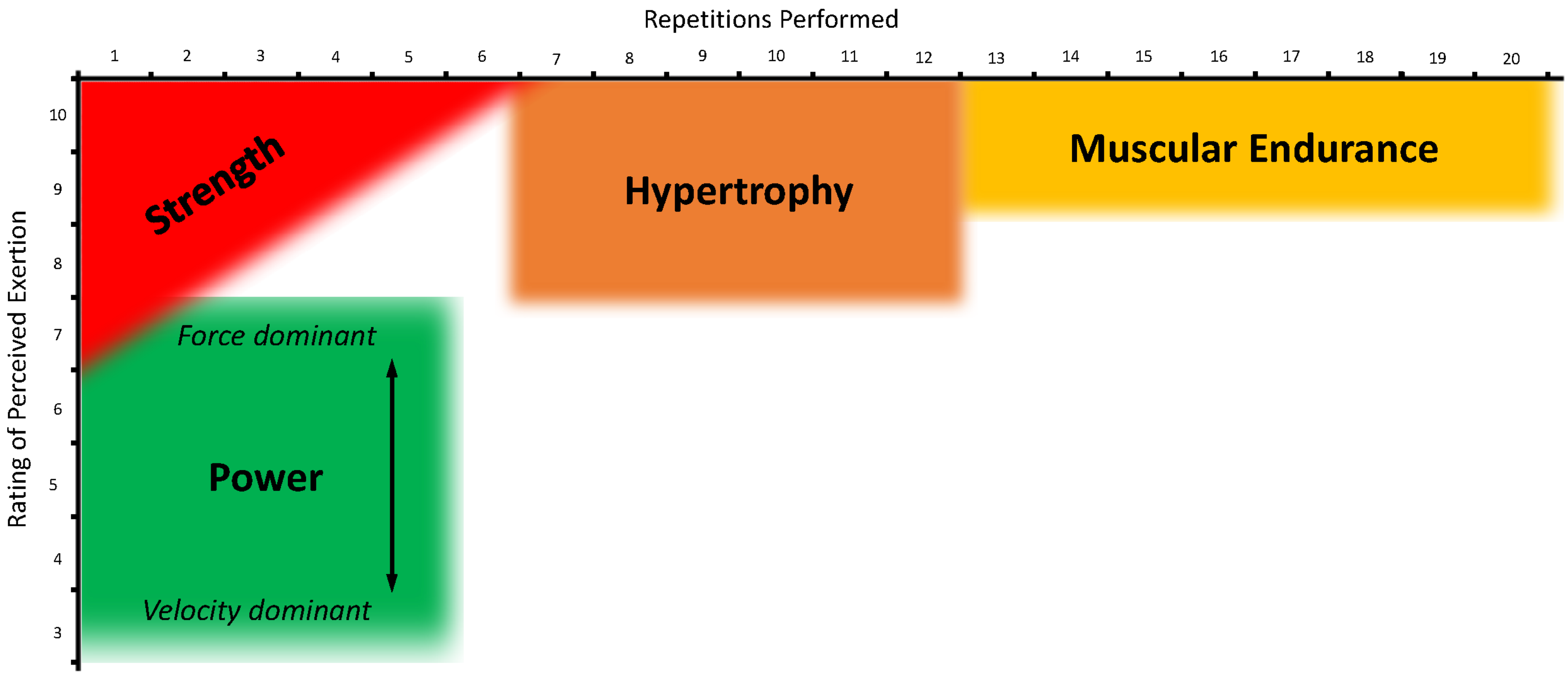
Power

As was previously stated, determining actual RIR for low intensity high velocity power training is most likely not possible due to the inability to determine RIR far from failure. However, using an "intensity cap" of RPE 4 could be implemented for low intensity high velocity power training to ensure movement speed remains appropriately high. Meaning, that if the lifter can accurately estimate RIR, the load is likely inappropriately heavy for this type of training and should be reduced to maintain velocity.

For power training with the goal of developing the high force end of the power spectrum, the RPE scores determined by RIR may be appropriate. Force dominant power training using relatively heavy intensities (> 80% 1RM) should be performed with maximal intent to accelerate the load while also managing fatigue by performing low repetition sets (one to five) stopping sufficiently short of volitional failure (RIR 2-3) [155, 173]. Like maximal strength training, rest interval between sets should be adequate to allow for complete recovery and should mostly fall in the range of 3-5 minutes [170].

A visual schematic of the relationship between training goal, repetitions and RIR-based RPE is shown in Figure 4.

Figure 4. Relationship of RPE, repetitions and training goals.



Practical applications

The creation of an RIR-based scale is the most recent iteration of RPE that specifically addresses the needs of resistance training. It provides a valid measure of intensity, based on RIR, which retains its reliability when sets are taken near and to volitional failure. While there is a potential advantage in the use of this scale, it should also be pointed out that at this early stage of RIR-based research, a great many questions still remain.

At present, RIR data is available only on novice and experienced male and female lifters performing free weight barbell squats [18] and experienced male lifters performing free weight barbell bench presses and squats [124]. Research that specifically examines potential differences between sexes, examines non-traditional resistance training methods (such as eccentric-only training), compares single-joint to multi-joint exercises, machine-based to free weight exercises and open to closed-chain exercises is lacking at this developmental stage. While it should not be assumed that the RIR-based scale will prove invalid for comparing males to females or assessing other forms of resistance training, rare differences between genders [174] and also resistance training mode [175] have been observed when using traditional RPE that could theoretically extend to an RIR-based scale.

While we encourage the appropriate implementation of this scale, until more research is done, practitioners should be well aware of the limitations of the available research before doing so. For those considering using an RIR-based RPE scale, this article serves to outline its uses, limitations, and how the scale relates to other methods of prescribing intensity such as percentage of 1RM and RM.

It must be stated that this scale is not a standalone method of training, however, by following the strategies outlined in this paper, this scale can be successfully implemented to prescribe and progress training intensity and load within a periodised model to achieve the desired physiological adaptations.

Chapter 4: RPE and Velocity Relationships for the Back Squat, Bench Press, and Deadlift in Powerlifters

This chapter comprises the following paper published in the *Journal of Strength and Conditioning Research.*

Reference:

Helms ER, Storey A, Cross MR, Brown SR, Lenetsky S, Ramsay H, Dillen C, Zourdos MC. RPE and velocity relationships for the back squat, bench press, and deadlift in powerlifters. J Strength Cond Res. 2016:31(2):292-297.

Author contributions:

ERH: 80%, AS: 2.5%, MRC: 2.5%, SRB: 2.5%, SL: 2.5%, HR: 2.5%, CD: 2.5%, MCZ: 5%.

Preface

In Chapter 3, the theoretical framework of how the RIR-based RPE scale could be implemented in practice was established. However, specific investigation of the use of this scale in powerlifting training is required to confirm these theories. In Chapter 4 this process begins by assessing the validity of the RIR-based RPE scale with velocity in powerlifters. By showing that velocity, percentage of 1RM and RPE change in concert when working up to and performing a 1RM on the powerlifts, the construct validity of the RIR-based RPE scale is established, while also highlighting its utility as a 1RM testing aid.

Introduction

During a 1RM test the lifter has the cumbersome goal of reaching a limit lift while avoiding premature fatigue or attempting a load beyond their current capability. Specifically, in powerlifting (i.e. back squat, bench press, and deadlift), athletes are limited to three attempts on each lift and must wisely structure attempt selection to accomplish the described goal. Thus, utilising tools which gauge difficulty and aid in attempt selection are beneficial for the athlete.

Moreover, athletes have utilised RPE to gauge effort for nearly 50 years [138]; thus this self-reported feedback can be used to alter training. Recently Zourdos and colleagues (2016) developed a resistance training-specific RPE scale measuring RIR [18], in which subjects provided an RPE value after a 1RM squat attempt. Additionally, the authors assessed ACV during each 1RM attempt and used this in conjunction with RPE to determine each following attempt. The combination of these variables is thought by the authors to provide more accurate feedback than when used in isolation [18]. Indeed, if lifting is performed at maximal intended velocity, decreasing concentric velocity can objectively determine greater intensity of effort [96, 127]. Importantly, in trained subjects Zourdos et al. (2016) demonstrated a strong inverse relationship between average velocity during the back squat and RPE (r = -0.88, p < 0.001) as a lifter approached 1RM (i.e. slower velocities at higher intensities correlated with higher RPE) [18].

Despite the recent advancement of the RPE/RIR scale and its usage in conjunction with velocity to aid in back squat 1RM attempt selection; questions remain regarding the validity of these methods to determining bench press and deadlift 1RM. Therefore, the purpose of this study was to assess both RIR-based RPE (23) and average velocity in competitive male and female powerlifters, on all three powerlifts, in competition order and determine any relationships between RPE and average velocity. It was hypothesised that resistance training-specific RPE would be an effective gauge of intensity in the bench press and deadlift similar to previous data in the squat (23); and that as RPE increased, average velocity would decrease.

Methods

Experimental approach to the problem

A 1RM testing session consisting of the powerlifting competition lifts (squat, bench press, and then deadlift) was completed. After each graduated increase in load, RPE as reported by the lifter and the corresponding velocities of the attempts were recorded. The resistance training specific RPE scale based on RIR [18] was used. Briefly, this is a 1-10 RPE scale in which 10 is a maximal attempt, 9.5 indicates that a slight increase in load could have been made but no further repetitions could have been performed, a 9 indicates one more repetition could have been performed, 8.5 one to two more repetitions, 8 two more repetitions, and onward in that fashion.

Prior to 1RM testing, all subjects had their height and body mass measured and were interviewed to determine their age, training experience, competitive powerlifting experience, competition results, and what they believed their current 1RMs were on the competition lifts. Following the interview, the subjects completed a standardised dynamic warm-up of body weight movements to prepare for the 1RM testing protocol.

The 1RM testing consisted of successive sets progressing to maximal attempts for the barbell back squat, bench press, and deadlift performed according to the rules of the IPF [1]. Subjects were prescribed a minimum of 3-minutes and a maximum of 5-minutes rest between lift attempts. Both ACV and RPE were recorded on all lifts at ≥ 80% of predicted 1RM.

Subjects

Fifteen subjects (male: n = 12; female: n = 3) were recruited from powerlifting clubs and gyms in the local region (Table 6). To qualify for inclusion in the study, subjects had to have at least one year of resistance training experience and meet the national qualifying requirements for strength either in prior competition or during testing [176]. Additionally, subjects had to abide by the banned substance list of the IPF [177], fall between the age range of 18-49 years old, be apparently healthy and free from injury or illness. All subjects were informed of potential risks and signed an informed consent document prior to participation (University ethics approval number 15/06).

Table 6. Descriptive characteristics of male and female powerlifters.

	Height (m)	Body mass (kg)	BMI (kg/m^2)	Age (yrs)	Training age (years)	Relative squat	Relative bench press	Relative deadlift
Females (n=3)								
Mean ± SD	1.6 ± 0.1	59.0 ± 5.8	22.6 ± 1.4	36.0 ± 6.2	4.6 ± 1.6	1.6 ± 0.3	1.0 ± 0.1	2.1 ± 0.1
Males (n=12)								
Mean ± SD	1.7 ± 0.1	87.9 ± 16.3	28.7 ± 3.1	26.5 ± 8.1	4.5 ± 3.1	2.3 ± 0.3	1.5 ± 0.2	2.7 ± 0.5
Combined (n=15)								
Mean ± SD	1.7 ± 0.1	82.1 ± 18.9	27.5 ± 3.8	28.4 ± 8.5	4.5 ± 2.8	2.1 ± 0.4	1.4 ± 0.3	2.6 ± 0.5

Values are means ± standard deviation (SD).
BMI, body mass index.
Relative strength on the squat, bench press and deadlift presented as 1RM divided by body mass.

Procedures

1RM testing

The 1RM testing protocol was administered following a standardised dynamic warm-up. Powerlifts were performed in competition order (1. squat, 2. bench press, 3. deadlift) and each lift was performed in accordance with IPF regulations using only IPF approved "unequipped" lifting material-aids (knee sleeves and weightlifting belt) [1]. For the squat, participants had to reach a depth where the hip crease passed below the top of the knee when viewed from the lateral aspect. To signal the lifter to initiate the squat, the verbal command "squat" was given and at the completion of the concentric phase the verbal command "rack" was given to signal the lifter to return the barbell to the squat rack. For bench press the necessary contact points must have been maintained (head, upper back, buttocks, and feet flat), once the bar was lowered to the chest a verbal command of "press" was given once the primary investigator (previously a powerlifting referee and an experienced powerlifting coach) visually determined that the bar was motionless. Finally, the deadlift was deemed successful if upon lock out the body was fully erect, the bar did not travel downward in the course of the lift, and if at no time was the bar rested on the legs so that it aided the lifter. To signal the lifter to return the barbell to the floor, the verbal command "down" was given at the completion of the concentric phase.

To begin each lifting discipline subjects first performed 8 repetitions with 50% of their estimated 1RM, followed by 3 repetitions at 60% of estimated 1RM, and 2 repetitions at 70% of estimated 1RM. Next, the subjects performed one repetition at 80% of estimated 1RM, followed by one repetition at 90% of their estimated 1RM. From this point, attempts were performed in order to achieve the highest load possible. The primary investigator used the RPE score, ACV, and participant input to aid in determining subsequent attempts. A final 1RM was recorded if either a 10 RPE was reported by the subject, or if an RPE score of less than 10 was reported, but the lifter then failed to complete the next attempt with an increased load. If the lifter failed an attempt with an increased load, they were given the option to attempt it a second time. However, no decreases in load were allowed and if the lift was missed a second time, the 1RM test for that lift was concluded. Once the final 1RM for a lift was recorded, the actual percentage of 1RM for all previous single repetition sets was determined. For example, if the actual 1RM was 200 kg and the load for the 80% of predicted 1RM was

156 (based off a predicted 195 kg 1RM), the actual percentage of 1RM for this load would be 78%.

RPE

Before 1RM testing began, the RPE scale was shown to the participant and verbally explained in the same manner as done by Zourdos and colleagues [18]. Each value on the 1-10 scale was explained verbally along with a visual presentation of the scale that was visible throughout testing. Immediately following each warm up and 1RM attempt, subjects were shown the RPE scale again and were asked to verbally rate the RPE of the set.

ACV measurement

All subjects had ACV ($m \cdot s^{-1}$) of the barbell measured by the GymAware PowerTool (GymAware, Canberra, Australia) linear position transducer during all single repetition sets, which has been previously validated for test-retest reliability of barbell velocity [178]. The GymAware was synced with a smart phone application that displayed the ACV of each repetition. The device was used according to the instructions of the manufacturers so that when it was attached to the barbell a perpendicular angle was achieved during all lifts.

Height, body mass and body mass index (BMI)

Each participant had height and body mass assessed (Seca, model 876, Germany). Further, BMI as determined via the equation $BMI = \frac{body\ mass\ (kg)}{height\ (m^2)}$ was recorded. The investigator who recorded all anthropometric variables was certified by the International Society for the Advancement of Kinanthropometry.

Statistical analysis

Data were initially screened for outliers through visual assessment of the box plots, in association with the Shapiro-Wilks test for normality, and assessment of skewness and kurtosis values. One outlier case was determined as unreasonable, and excluded from the raw dataset. This decision was based on its magnitude (~4x the SD of the dataset), and the case under which the result was reported (athlete returning to heavy training on the deadlift after minor injury months prior to the study start).

To express the potential range of values that could be reported by powerlifters based on our population sample, means, SD and 90% confidence limits (CL) for RPE were calculated for all intensities. To determine differences in RPE scores at 1RM between the squat, bench press, and deadlift a chi-square test was performed for non-parametric data as an RPE score has a natural limit of 10. The velocity values from the maximal lifts of the squat, bench press and deadlift were compared using a mixed-models approach to repeated measures analysis in a statistical software package (IBM SPSS Statistics 21, SPSS Inc., Chicago, IL). Bonferroni post-hoc adjustments were used for pairwise comparisons, with the alpha level for significance set at 0.05. Further comparisons between lifts were completed using magnitude-based inferences [179], calculated using a modified Excel spreadsheet from sportsci.org (xPostOnlyCrossover.xls) [180]. The ES and 90% confidence intervals (lower limit; upper limit) were calculated to compare the difference between each of the tested condition means. Threshold values of 0.2, 0.6, 1.2 and 2.0 were used to represent small (and the smallest worthwhile difference), moderate, large, and very large effects. Probabilities that differences were higher, lower or similar to the smallest worthwhile difference were evaluated qualitatively as: possibly, 25-74.9%; likely, 75-94.9%, very likely, 95-99.5%; most likely, > 99.5%. The true difference was assessed as unclear if the chance of both higher and lower values was > 5%.

Correlation coefficient r scores and their associated *p* values were calculated to quantify the associations among ACV and RPE at all intensities and also actual percentage of 1RM and RPE. The coefficient of determination r^2 score was also calculated to express the explained variance of the correlation coefficients. The Excel spreadsheet from sportsci.org (xvalid.xls) [181] was used to plot the linear regression of the squat, bench and deadlift data separately where the percentage 1RM (ranging from 80 – 100%) were used as the criterion measure and the ACV of the lifts were used as the practical measure. By plotting the criterion (actual percentage 1RM) and practical measures (mean concentric velocity) in a linear regression model, a calibration equation was derived at which a percentage 1RM (Y) could be predicted based on measured ACV of a submaximal lift (X).

Results

RPE

The mean and SD for RPE on the squat, bench press and deadlift were 9.6 ± 0.5, 9.7 ± 0.4 and 9.6 ± 0.5, respectively. Values reported at 1RM for all three lifts were not significantly different ($p > 0.05$) from one another and their 90% CL's almost completely overlapped (squat; 9.4 to 9.9, bench press; 9.5 to 9.8, deadlift; 9.4 to 9.9).

ACV

Means, SDs and the 90% CL for ACV for the squat, bench press and deadlift are provided in Table 7. As shown, velocities at 1RM were significantly different from one another with the squat occurring at the highest velocity, followed by the deadlift and bench press being the slowest.

Table 7. ACV and differences between lifts.

Lift: comparison:	Mean ± SD ($m \cdot s^{-1}$)	Mean standardised difference ± 90% CL (Cohen's)	*P* value	Qualitative analysis of difference
Squat	0.23 ± 0.05			
vs bench press		2.41 ± 0.54	<0.001	Most likely, very large
vs deadlift		1.51 ± 0.46	<0.001	Most likely, large
Bench press	0.10 ± 0.04			
vs deadlift		0.80 ± 0.46	0.05	Very likely, moderate
Deadlift	0.14 ± 0.05			

$m \cdot s^{-1}$, metres per second.

Values are means ± standard deviation (SD).

Differences shown as standardised Cohen's ES units ± 90% confidence limits (CL)

Qualitative analysis of likelihood: possibly, 25-74%; likely, 75-94%; very likely, 95-99.5%; most likely, >99.5%.

Qualitative analysis of ES threshold: small, 0.2; moderate, 0.6; large, 1.2; very large, 2.0.

Relationship of ACV with RPE

Strong inverse relationships between RPE and velocity were observed on the squat (r = -0.87, $p < 0.001$), bench press (r = -0.79, $p < 0.001$) and deadlift (r = -0.82, $p < 0.001$). In the squat, bench press and deadlift respectively, 76% ($r^2 = 0.76$), 63% ($r^2 = 0.63$) and 67% ($r^2 = 0.67$) of the variance of these correlations were attributable to the relationship between RPE and velocity.

Relationship of actual percentage 1RM with RPE

Very strong relationships between actual percentage 1RM and RPE were observed on the squat (r = 0.91, $p < 0.001$) and deadlift (r = 0.91, $p < 0.001$). A strong relationship was observed between actual percentage 1RM and RPE in the bench press (r = 0.88, $p < 0.001$). In the squat, bench press and deadlift respectively, 83% ($r^2 = 0.83$), 78% ($r^2 = 0.78$) and 83% ($r^2 = 0.83$) of the variance of these correlations were attributable to the relationship between actual percentage 1RM and RPE.

Relationship of ACV with actual percentage 1RM

Very strong relationships between ACV and percentage 1RM were observed on all three competition lifts. Pearson's correlations (r), coefficients of determination (r^2) and regression equations for the relationships between percentage of 1RM (80 to 100% only) and ACV are displayed in Table 8.

Table 8. Relationships between percentage of 1RM and velocity.

	Regression equation	Correlation (*r*)	Coefficient of determination (r^2)
Squat	Y = -0.449X + 1.096	-0.91	0.83
Bench press	Y = -0.600X + 1.051	-0.90	0.81
Deadlift	Y = -0.600X + 1.076	-0.92	0.85

X, measured ACV; Y, predicted percentage of 1RM.

Discussion

The purpose of this investigation was to record the RPE and ACV during all 1RM attempts of the squat, bench press, and deadlift in powerlifters. Our main findings were in support of our hypothesis and indicated: 1) RPE at 1RM reached near maximal scores (RPE 9.6 to 9.7), and 2) each individual discipline revealed a strong inverse correlation between ACV and RPE (r = -0.79 to -0.87, $p < 0.001$). Similar findings exist for the squat [18], however to our knowledge, this is the first investigation to examine both RIR-based RPE and velocity in 1RM bench press and deadlift testing.

Previous research using the Borg RPE scale to gauge intensity during a resistance training set has resulted in individuals recording submaximal RPE despite sets being performed to failure [124, 129, 130]. However, in previous literature using the RIR-based RPE scale (22) and in the present investigation trained lifters were able to accurately gauge intensity as evidenced by the strong and very strong relationships observed in this investigation between RPE and percentage 1RM (r = 0.88-0.91, $p < 0.001$) and velocity (r = -0.79-0.87, $p < 0.001$). Therefore, the present results suggest this RPE scale could be used to prescribe and alter training load [120] in all three powerlifts instead of solely relying on a percentage based model. Prescribing RPE concurrently with percentage 1RM would allow the athlete to alter load dependent upon daily strength levels.

Similarly, the Zourdos et al. (22) RPE scale investigated here may be an attractive method to prescribe load because the validity of percentage 1RM prescription depends upon an athlete’s daily strength levels in comparison to the pre-training 1RM test [107]. An athlete without extensive strength training experience can experience changes in their 1RM after only a few training sessions and the obtained 1RM may not accurately represent the athlete’s true capability due to daily fluctuations in biological readiness and recovery [96, 107]. With that said, the RIR-based RPE scale does have limitations as previous data has shown experienced lifters to more accurately gauge RIR than novice lifters [18]. Thus, previous training experience along with practice recording RPE while following a percentage based program is recommended before solely using RPE to assign and progress training load. However, even though RPE was a reliable gauge of intensity presently, velocity is likely a more objective assessment of intensity [107]. Even though daily strength will fluctuate, the inverse relationship between velocity and RPE will remain the same no matter what the fluctuation in strength might be [107, 182].

Additionally, we explored the relationships between percentage 1RM and velocity for each lift. Due to the strength of the present correlations between ACV and load, we developed regression equations to predict 1RM based upon velocity at intensities ≥ 80% (Table 8). To estimate 1RM using these equations, first ensure the load is expected to be at or above 80% of 1RM as this is what the regression is based on, then after repetition completion enter the ACV recorded, then divide the barbell load used by the percentage provided. For example, if a 200 kg squat was recorded at 0.50 $m{\cdot}s^{-1}$ the equation would be: 200 kg ÷ 0.87 (87 % of 1RM), which would estimate a 1RM of ~230 kg. Despite the strong relationship between ACV and intensity, the practical application of the equations are limited as the 90% CL on all three regression equations amounts to a ± 5% range on predicted percentage 1RM. For example, the 90% CL of the 1RM prediction for a 250 kg deadlift performed at a velocity of 0.25 $m{\cdot}s^{-1}$ provides a wide range of 257 to 284 kg. Thus, it appears an individualised velocity profile, which depends on a myriad of factors (i.e. limb lengths and training age) would need to be determined in order to successfully prescribe training loads purely based on velocity [96]. However, since we did not give specific instructions to lift at maximal intended velocity, it is possible that an equation based on participants who were given these instructions may have greater ability to predict 1RM.

The ACV of the squat at 1RM presently (0.23 ± 0.05 $m{\cdot}s^{-1}$) was similar to the experienced lifters in Zourdos et al. [18] (0.24 ± 0.04 $m{\cdot}s^{-1}$). Previous data from Izquierdo et al. (2006) has reported slightly faster velocity at squat 1RM (0.27 ± 0.02 $m{\cdot}s^{-1}$) [126], however, these authors utilised ‘physically active’ subjects, while our investigation and Zourdos et al. had an average training age of 4.5 and 5.2 years respectively. Indeed, previous research has demonstrated experienced lifters to have slower velocities at 1RM compared to novice lifters (22). Similarly, the present bench press 1RM average velocity (0.10 ± 0.04 $m{\cdot}s^{-1}$) was slower than both Izquierdo et al. (0.15 ± 0.05 $m{\cdot}s^{-1}$) and González-Badillo et al. (0.16 ± 0.04 $m{\cdot}s^{-1}$) [107, 126], which employed less trained individuals. Additionally, in the present study the concentric phase began after a brief pause on the chest and a press command, likely lowering the ACV. Regarding the deadlift, the current study is the first to our knowledge to report ACV at both a 1RM and submaximal intensities; thus further research is needed to examine the relationship between training status and ACV at specific intensities in the deadlift.

Practical applications

Our investigation shows that the resistance training specific RPE scale based on RIR produces nearly identical RPE values for all three lifts when performed up to and including 1RM. Therefore, this novel RPE scale can be used during 1RM testing to help gauge intensity with experienced lifters. To further aid 1RM testing on the squat, bench press and deadlift, the ACV at 1RM that we reported can be used as reference values to aid attempt selection. As velocity approaches the ranges we recorded at 1RM for each lift, smaller increases in load should be implemented so as to get as close as possible to a true 1RM.

While velocity is an intriguing tool for load prescription, it most likely requires the development of individual velocity-load profiles prior to use. RPE shows promise as a tool for trained lifters to gauge intensity on a regular basis without the need for a profile to be developed. It is possible that a combined approach of using percentage 1RM with a reference RPE range could prove a practical and accurate alternative to developing an individual velocity-load profile if the technology to do so is not available. The relationships between velocity, actual percentage of 1RM and RPE all indicate that further study is needed to determine what the most effective way to prescribe and regulate resistance training intensity is.

Chapter 5: RPE as a Method of Volume Autoregulation within a Periodised Program

This chapter comprises the following paper accepted at the *Journal of Strength and Conditioning Research.*

Reference:

Helms ER, Cross MR, Brown SR, Storey A, Cronin J, Zourdos MC. Rating of perceived exertion as a method of volume autoregulation within a periodised program. J Strength Cond Res. 2017: [accepted].

Author contribution:

ERH: 80%, MRC: 5%, SRB: 5%, AS: 2.5%, JC: 2.5%, MCZ: 5%.

Preface

In Chapter 4 the validity of the RIR-based RPE scale in powerlifters was established with velocity. Additionally it was shown that the RIR-based scale has utility in testing 1RM in powerlifters. To continue the investigation of how the scale can aid powerlifting training, Chapter 5 serves as an exploration of how volume can be manipulated through the use of 'RPE stops' (originally called 'fatigue percentages' [24]). Specifically, sets are performed until a certain RPE threshold is reached, which signals the cessation of sets. Much like a recent study of a similar system using a velocity cut-off to signal the cessation of sets, it appears total volume can be effectively autoregulated with this system.

Introduction

The main goal of powerlifting is to increase 1RM in three disciplines; the back squat, bench press and deadlift. It has been well established that higher training volume (i.e. sets x repetitions x load lifted) [183, 184] and increased intensity (i.e. percentage of 1RM) [97] are related to 1RM performance. Furthermore, when intensity progression is autoregulated week-to-week, strength progress has been greater versus a fixed progression [20]. Additionally, volume autoregulation seems necessary as moderate volume was demonstrated to produce superior strength increases compared to both low and high volumes after 10 weeks [185]. Consequently, even though volume is related to strength performance, a point of diminishing returns seems to exist as high volume may hinder session-to-session recovery in the short term. Thus, regulating volume based on readiness and fatigue on a session-to-session basis to ensure the appropriate stimulus seems attractive.

Directly relevant to this topic, autoregulating session volume could be accomplished via measurement of ACV as it has been demonstrated that movement velocity slows in concert with diminished force production [127]. Specifically, with a linear position transducer attached to the barbell [186, 187] a set could be terminated once velocity falls below a pre-determined threshold compared to the first or fastest repetition of the set; referred to as a 'velocity stop' [95, 96, 127, 188]. Indeed, Pareja-Blanco et al. (2016) terminated each set in one group following a 40% velocity reduction and after a 20% velocity reduction in another group [113]. As a result, greater muscular hypertrophy occurred in the 40% reduction group, while greater improvements in vertical jump height occurred in the 20% reduction group. Another usage of a velocity stop is to continue doing sets for a particular number of repetitions during a session until the last repetition of a set falls below a particular velocity threshold (i.e. an absolute number) [96], or percentage of best velocity. Thus, using either form of velocity stop can autoregulate volume to achieve desired adaptations (i.e. more volume for hypertrophy or better maintenance of velocity for power).

Although velocity stops can be used for autoregulating volume, access to linear position transducers for the individual powerlifter is limited due to cost (i.e. > $1,000). Thus, using the recently established resistance training-specific RPE scale [18, 189] may be a practical tool for volume autoregulation as no monetary cost is involved and strong inverse correlations exist between RPE and velocity with this scale in powerlifters for each discipline (squat: r = -0.87, bench press: r = -0.79, deadlift: r = -0.82) [190]. Therefore, it seems that RPE could be used as a method to autoregulate volume in the absence of velocity. Indeed, using 'RPE stops' to dictate the number of sets performed was originally proposed in the powerlifting text "The Reactive Training Manual" [24]. Specifically, it is proposed that an initial set can be performed for a specific number of repetitions with a target RPE for the set (i.e. 5 repetitions at 9 RPE), with subsequent sets performed with a reduced load (i.e. a 0-10% reduction) for the same number of repetitions, until the initial RPE is reached again. It is theorised that a smaller percentage load reduction will result in fewer sets performed (i.e. RPE target is achieved with fewer sets), while a larger load reduction will result in more sets performed. These suggestions are in agreement with volume autoregulation using velocity stops [113].

Therefore, the aim of this study was to observe the impact of implementing RPE stops on training volume in powerlifters performing the back squat, bench press and deadlift in three weekly sessions; one hypertrophy-, one strength-, and one power-type training day for three weeks. Each week was assigned either a 2, 4, or 6% RPE stop for all exercises performed that week. We hypothesised that volume would be greater in the 6% RPE stop week versus the 4% week, and the 4% week would produce more volume than the 2% week. Additionally, it was hypothesised that volume would be greatest during hypertrophy-type sessions compared to power and strength sessions.

Methods

Experimental Approach to the Problem

In this observational study, we set out to compare the volume performed on the three powerlifting competition lifts, during different training session types over three weeks, while using three different levels of volume autoregulation. Competitive powerlifters performed the squat and bench press 3x/wk and the deadlift 2x/wk for three weeks in a daily undulating format. This training structure was outlined by Zourdos and colleagues [17], in which hypertrophy-, power-, and strength-type sessions were performed in that order on non-consecutive days (i.e. Mon., Wed., Fri.). The deadlift was not performed during hypertrophy-type sessions as the muscles trained largely overlap with the squat. An RPE target was provided for each exercise and subjects self-selected the load for the initial set in an attempt to hit the target RPE. For each of the three weeks a different RPE stop (2, 4, or 6%) was employed; thus there were six possible weekly orders the RPE stop percentages could be implemented. To account for the order effect, the order of training weeks was counterbalanced across subjects. Subjects trained at their normal training facility and the investigator went to the facility to observe each subject a total of 10 times (one testing session and nine training sessions). On day 1, 72 hours prior to the first training session, subjects had anthropometrics assessed (i.e. height, and body mass) and were interviewed for further information related to training experience, age, competitive powerlifting experience, competition results, and estimated 1RM for each discipline.

Subjects

Fourteen competitive powerlifters were recruited from powerlifting clubs and gyms in the local region however, two subjects dropped out of the study prior to completion (one due to injury and one due to being unable to complete all training sessions). Thus, twelve subjects completed the protocol in full (male: n = 9; female: n = 3) (Table 9). The subjects had no previous experience utilising a system of RPE-based volume autoregulation however, they were required to have at least one year of resistance training experience and meet the New Zealand national qualifying requirements for strength either in prior competition (within one year) or during testing [176]. Additionally, subjects had to abide by the banned substance list of the IPF [177], fall between the age range of 18-49 years old, and be apparently healthy and free from injury or illness. Subjects were not allowed to compete during the study and were not in the midst of 'peaking' for competition at the time of data collection, which occurred between July and December. All subjects were informed of potential risks and signed an informed consent document prior to participation (University ethics approval number 15/06).

Table 9. Descriptive characteristics of male, female and combined powerlifters.

	Female (*n* = 3)	Male (*n* = 9)	Combined (*n* = 12)
Body-height (m)	1.62 ± 0.08	1.71 ± 0.06	1.69 ± 0.08
Body-mass (kg)	59.0 ± 5.8	81.9 ± 12.5	76.2 ± 15.0
Body-mass index (kg / m^2)	22.6 ± 1.4	27.8 ± 2.3	26.5 ± 3.1
Age (yrs)	36.0 ± 6.2	23.0 ± 2.5	26.3 ± 6.8
Training experience (yrs)	4.6 ± 1.6	5.1 ± 3.4	5.0 ± 2.9
Relative back-squat (1RM [kg] / BM [kg])	1.6 ± 0.3	2.4 ± 0.3	2.2 ± 0.5
Relative bench-press (1RM [kg] / BM [kg])	1.0 ± 0.1	1.6 ± 0.2	1.4 ± 0.3
Relative deadlift (1RM [kg] / BM [kg])	2.1 ± 0.1	2.9 ± 0.4	2.7 ± 0.5

Values are mean ± standard deviation (SD). *n*, sample; m, metre; kg, kilogram; y, year.
Relative back-squat, bench-press and deadlift are presented as one repetition maximum (1RM) in kilograms divided by body-mass (BM) in kilograms.

Procedures

1RM testing

To establish eligibility for the study, to determine loads for warm-up sets during training days (i.e. this was done via % of 1RM), and to familiarize each subject with the RPE scale, a 1RM test was conducted for each lift following a standardised dynamic warm-up. During testing and all training days, competition disciplines were performed in competition order (back squat, bench press, and then, deadlift) and each lift was performed in accordance with IPF regulations for movement standards and in concert with the IPF's definition of "unequipped" powerlifting (i.e. knee sleeves and weightlifting belt only) [1]. To achieve the most accurate 1RM possible on each lift, previously validated procedures [18] were followed to aid in attempt selection. Thus, an RPE score was recorded using the resistance training-specific scale measuring RIR along with ACV (GymAware, Canberra, Australia) following each 1RM attempt. The warm-up sets and other specific procedures of the 1RM test replicated the methods described in a previous investigation [190].

Height, Body Mass and BMI

Each subject's height and body mass was assessed (Seca, model 876, Germany) by an investigator certified by the International Society for the Advancement of Kinanthropometry. Subjects' BMI was determined by the equation $BMI = \frac{body\text{-}mass\ (kg)}{(height\ (m))^2}$.

RPE

As RIR is a more accurate measure of intensity of effort during resistance training near to failure compared to traditional RPE [124], the RIR-based RPE scale (i.e. RPE scores which correspond to RIR) (Figure 1) [18] was used throughout the study. Immediately prior to initial 1RM testing the RPE scale was shown to the participant and described in detail. Each value on the 1-10 scale was explained verbally while showing the scale to the subject. The scale was shown to subjects following every 1RM attempt, along with each warm-up set and working set on training days.

Training Protocol

After pre-testing, each subject was assigned to one of six RPE stop week orders (2%, 4%, 6%, or 4%, 6%, 2% or 4%, 2%, 6% etc.). Similar to a previous undulating powerlifting protocol [17], each day had a specific training goal: Monday: “hypertrophy”, Wednesday: “power” and Friday: “strength”. Exercises performed, repetition targets, rest periods and RPE targets are displayed in Table 10.

Table 10. Training protocol overview.

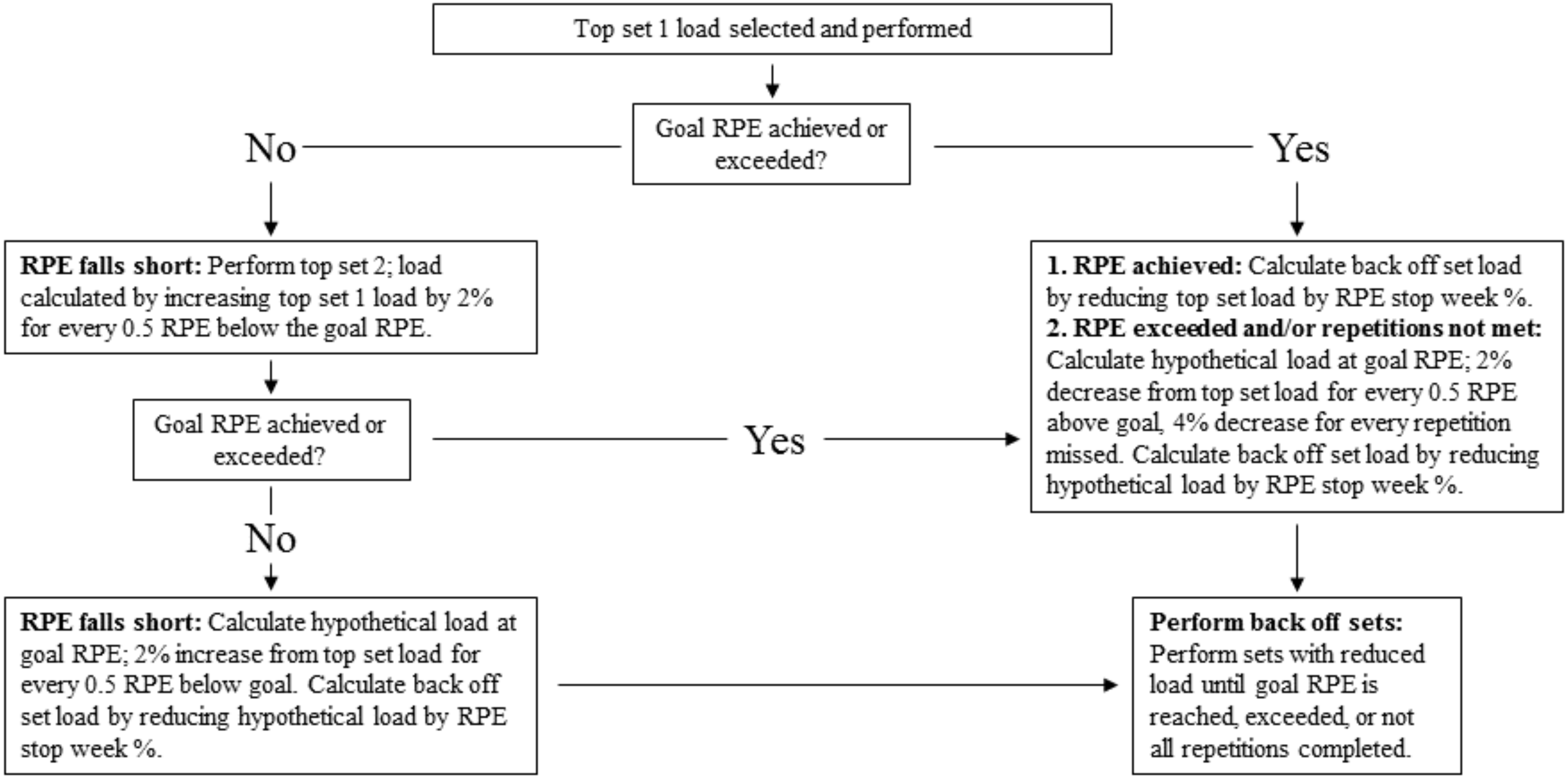
Training Goal	Hypertrophy	Power	Strength
Exercises	Squat Bench Press –	Squat Bench Press Deadlift	Squat Bench Press Deadlift
Repetitions	8	2	3
RPE	8	8	9
Rest Period	3 minutes	3 minutes	3 minutes

Efforts were made to ensure each subject’s training occurred at the same specified time and location when possible. Occasionally rescheduling of training within the same day was necessary, but this occurred once or twice in only three subjects. On all three training days a standardised dynamic warm-up was completed followed by three warm-up sets; 42.5% 1RM for six repetitions, 60% 1RM for three repetitions, and 77.5% 1RM for a single repetition. During hypertrophy sessions, the final warm up weight was often slightly heavier than the working weight selected by the participants. While contrary to typical powerlifting practice, this concession was made to give the subjects standardized practice rating the RPE of the same loads at the start of each session. Subjects were allowed to perform an additional warm-up prior to 42.5% 1RM if desired for a maximum of six repetitions using a lighter weight. After each warm-up set an RPE was obtained, and after all warm-up sets the investigator informed the subject of the repetition and RPE target for the day and asked the subject to select a load they believed would result in the target RPE occurring. Consultation of prior training data was allowed to assist in load selection.

Following a 3-minute rest period, the subject performed the first, or ‘top’ working set (TS1). If the RPE score was lower than the goal RPE on TS1, then a 2nd top set (TS2) was performed with an adjusted load (i.e. +2% load for every 0.5 RPE lower than the goal RPE) after a 3-minute rest period. The 2% load correction value was predetermined in pilot testing. If the RPE score was reached with TS1, TS2 was not performed. Likewise, if the RPE score exceeded the goal for the day, TS2 was not performed. Two top sets was the maximum, after which back off sets commenced, even if the goal RPE was not reached.

Following top set(s), a 3-minute rest period was adhered to, and “back off” sets commenced with a load modified based on the RPE stop percentage for the given week. If the RPE goal was achieved during the top set(s), the back off set load was calculated by reducing the top set load by the RPE stop percentage for the week (98, 96 or 94% of the top set load was used for the 2, 4, and 6% weeks respectively). If the goal RPE was not reached during a top set, the load percentage reduction was applied to a hypothetical load that should have resulted in the goal RPE. The hypothetical load was also calculated by using a 2% increase or decrease for every 0.5 RPE score above or below the goal value. For example, if during the 4% RPE stop week an 8.5 RPE was recorded at 100 kg for TS1 when the goal RPE was 8, top sets would conclude and a hypothetical load of 98 kg would be calculated. At this point, back off sets would begin with 94 kg as the 4% RPE stop percentage would be applied to the hypothetical load of 98 kg (loads for all sets are rounded to the nearest kg). In the case where a repetition was failed on a top set (i.e. seven repetitions successfully completed when the goal was eight), the number of repetitions completed successfully was determined as a 10 RPE, and each missed repetition resulted in a 4% load reduction (as a full repetition is equal to a full RPE score) in calculating the hypothetical load. Thus, if the goal was eight repetitions at an 8 RPE, performing seven repetitions and failing the eighth would result in a hypothetical 8 RPE load calculated at 88% of the load used (a 12% reduction; 4% reduction for the missed repetition and an 8% reduction for the 10 RPE score being four 0.5 increments above the target RPE). Likewise, if RPE fell short of the goal even after TS2, a higher hypothetical load at the goal RPE was determined and back off sets were calculated from this hypothetical value. A flow chart showing how top and back off set loads were determined is shown below in Figure 5.

Figure 5. Load selection flow chart.



After each back off set, an RPE score was obtained and a 3-minute rest period was adhered to. Then, back off sets continued until an RPE equal to or greater than the target RPE was achieved. If an RPE equal to or greater than the target RPE was reported (or if not all repetitions could be completed on a back off set), the specific exercise was ceased for the day; then, a 5-minute rest period occurred prior to the next exercise, or the session concluded if it was following the deadlift. Thus, a minimum of two working sets were always performed (at least TS1 and at least one back off set if the target RPE was reached or exceeded on the first back off set). The number of back off sets was capped at eight to prevent excessive time cost to the investigators, the subjects and to retain ecological validity. The same protocol for load assignment, as outlined above, was used for all three exercises (squat, bench press, and deadlift).

Statistical analysis

To express volume load differences in a group of powerlifters with heterogeneous strength levels, volume load was calculated relative to pre testing 1RM values (sets x reps x % 1RM). Thus, 'relative volume load' was calculated for each subject, for each exercise (back squat, bench press, and deadlift), for the combined lifts (squat, bench press and deadlift volume summed), on each day of training (hypertrophy, power, and strength), and for each RPE stop week (2, 4, and 6%). Means and SD for relative volume load for all conditions were calculated.

We used generalised linear mixed modelling using normal distributions with identity logit links and unstructured covariance to estimate the differences in outcome variables, while adjusting for random effects. Specifically, the model estimated the differences in the following repeated conditions: 1) differences in relative volume load for the back squat, bench press, and deadlift within the same week for different days (hypertrophy, power or strength); and, 2) differences in relative volume load for the back squat, bench press, deadlift and combined lift volume between RPE stop weeks (2, 4 or 6%). This particular type of mixed models analysis allows for the assessment of repeated effects while accounting for individual subject variance and the inclusion of missing values. Bonferroni post-hoc adjustments were used for pairwise comparisons, with the alpha level for significance set at 0.05. Analysis was performed using a statistical software package (IBM SPSS Statistics 21, SPSS Inc., Chicago, IL). To report the magnitude of the differences of the volumes performed, between group ES were calculated for each comparison, such that the difference between means were divided by the pooled SD of each variable [191]. Threshold values of 0.20, 0.60, 1.20 and 2.00 were used to represent small (and the smallest worthwhile, non-trivial difference), moderate, large, and very large effects [179].

Results

The relative volume performed on each lift, for each training goal, for all three RPE stop weeks is displayed in Table 11. Specific differences between, and within each RPE stop week for each lift follow with *p* values and ES listed in text.

Table 11. Comparisons of relative volume load.

RPE stop	Back-Squat			Bench-Press			Deadlift		
	Hypertrophy	Power	Strength	Hypertrophy	Power	Strength	Hypertrophy	Power	Strength
2%	19.8 ± 7.4*	7.0 ± 4.2†	7.4 ± 3.8***, †	20.2 ± 5.1*	8.5 ± 4.2†	9.3 ± 2.1***, †	–	8.0 ± 4.6	7.8 ± 2.5
4%	18.0 ± 3.6*, ††	10.3 ± 3.7	10.5 ± 7.1***	20.6 ± 7.9	14.3 ± 4.7	12.8 ± 5.3***, ††	–	8.8 ± 4.0††	9.2 ± 4.9
6%	23.7 ± 8.4*	13.3 ± 5.3†††	11.7 ± 5.1***, †††	24.6 ± 12.0	17.0 ± 2.3†††	20.3 ± 7.7†††	–	13.7 ± 4.7†††	13.1 ± 6.9†††

Values are presented as mean ± standard deviation. RPE, resistance exercise-specific rating of perceived exertion.
Training goal (column) statistical comparisons where the p value is < 0.05: Hypertrophy *vs*. Power, *; Power *vs*. Strength, **; Strength *vs*. Hypertrophy, ***.
RPE stop (row) statistical comparisons where the p value is < 0.05: 2% *vs*. 4%, †; 4% *vs*. 6%, ††; 6% *vs*. 2%, †††.
Superscript symbols, denoting statistical significance for the comparisons, are associated with the underlined metrics listed within this footnote.

Back squat: RPE stop comparisons

For hypertrophy sessions, the 2% week did not produce significantly greater volume compared to either the 4% (p = 0.28) or 6% weeks (p = 0.17); however, ES revealed a small difference with more volume in 2% vs. 4% (ES = 0.37) and 6% vs. 2% weeks (ES = 0.43). However, the back squat volume produced on the hypertrophy session during the 6% RPE stop week was significantly higher than the volume during the 4% RPE stop week (p = 0.01, ES = 0.88). For power sessions, back squat volume increased linearly as RPE stop percentage increased. These moderate and large differences were significant (p < 0.001 to p = 0.002, ES = 0.81 to 1.28) except between the 6% vs 4% RPE stop week, in which case the difference approached significance (p = 0.06) with 6% producing moderately more volume than 4% (ES = 0.68). For strength sessions, more back squat volume was performed during both the 6% RPE stop week (p = 0.001, ES = 0.87) and the 4% RPE stop week (p = 0.05, ES = 0.56) compared to the 2% RPE stop week. However, the difference between the back squat volume performed on strength sessions during the 4% and 6% RPE stop weeks was not significant (p = 0.42) and while higher during the 6% vs 4% week, the difference was trivial (ES = 0.15). When combining hypertrophy, power and strength sessions, mean back squat volume increased as RPE stop percentage increased. However, only the difference between the 6% vs 2% RPE stop weeks reached significance (p = 0.01, ES = 0.90). The difference between the 6% vs 4% RPE stop weeks approached significance and was moderately higher during 6% (p = 0.09, ES = 0.62). Finally, while the difference between the 4% and 2% RPE stop weeks did not reach significance (p = 0.24), ES analysis revealed a small difference with more volume performed during 4% vs 2% week (ES = 0.35).

Bench press: RPE stop comparisons

For hypertrophy sessions, there was statistically similar volume when comparing 2% and 4% RPE stop weeks (p = 0.80), with the 4% week's volume being only trivially greater (ES = 0.08). Differences in volume performed for hypertrophy sessions between the 2% and 6% RPE stop weeks (p = 0.49) and the 4% and 6% RPE stop weeks (p = 0.53) did not reach significance. However, ES revealed a small difference with more volume in 6% vs. 2% (ES = 0.54) and 6% vs. 4% weeks (ES = 0.41). During power sessions, more volume was performed with the bench press during the 4% and 6% RPE stop weeks compared to the 2% RPE stop week (p < 0.001) and the magnitude of these differences were large and very large, respectively (ES = 1.30 to 2.42). The greater amount of volume performed with bench press on power sessions during the 6% vs. 4% RPE stop week approached significance ($p = 0.07$) and was moderately higher (ES = 0.70). For strength sessions, volume increased linearly with the bench press when comparing 4% vs. 2% RPE stop weeks ($p = 0.02$, ES = 0.96), 6% vs. 4% ($p = 0.01$, ES = 1.15) and 6% vs. 2% ($p < 0.001$, ES = 2.21). When combining hypertrophy, power and strength sessions, the relationship of increasing bench press volume as RPE stop percentage increased, was statistically significant and moderate to large among weeks ($p < 0.001$ to $p = 0.01$, ES = 0.98 to 1.96).

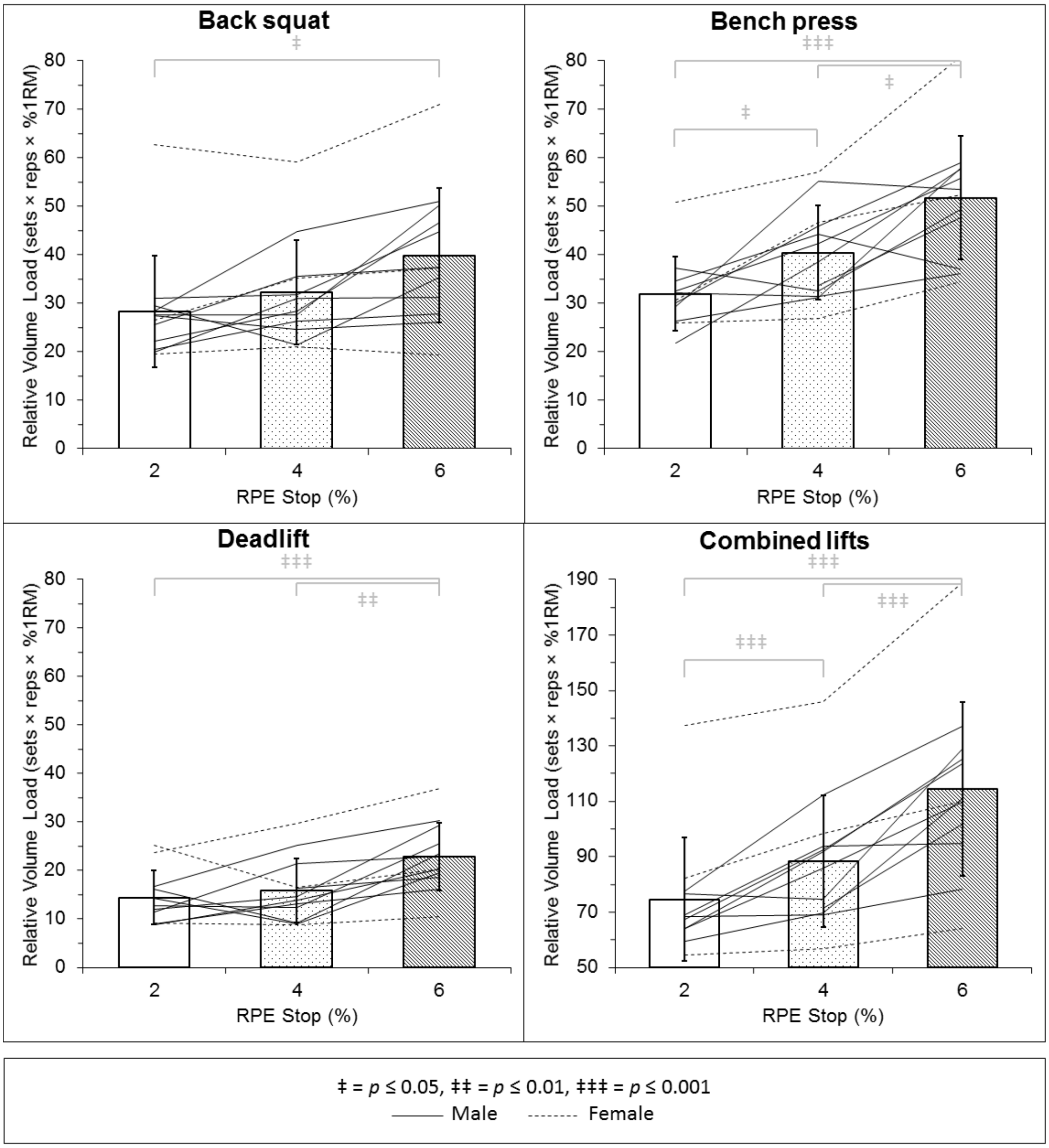
Deadlift: RPE stop comparisons

For power sessions, participants performed significantly more volume during the 6% RPE stop week vs. 2% ($p = 0.01$, ES = 1.05) and 4% RPE stop weeks ($p = 0.002$, ES = 1.09). However, there were not significant differences between the volume performed with the deadlift on power sessions during the 2% and 4% RPE stop weeks ($p = 0.81$). While mean volume was greater during the 4% vs 2% week, the difference was trivial (ES = 0.08). During strength sessions, participants performed significantly more volume during the 6% RPE stop week compared to the 2% RPE stop week ($p = 0.02$, ES = 1.05). The differences between the 2% and 4% RPE stop weeks ($p = 0.274$) and the 4% and 6% RPE stop weeks ($p = 0.13$) did not reach significance. However ES analysis revealed a small and moderate difference respectively, with more volume in 4% vs. 2% (ES = 0.34) and 6% vs. 4% weeks (ES = 0.63). When combining power and strength sessions, more volume was performed with the deadlift during the 6% RPE stop week compared to both the 4% ($p = 0.002$, ES = 1.03) and the 2% RPE stop weeks ($p < 0.001$, ES = 1.32). However, the aggregate deadlift volume difference between the 2% and 4% RPE stop weeks was not statistically significant ($p = 0.45$); yet, ES analysis revealed a small difference with more volume performed in the 4% vs 2% week (ES = 0.22).

Combined lift volume: RPE stop comparisons

When combining all volume performed with the back squat, bench press and deadlift from hypertrophy, power and strength sessions, within the same RPE stop week, volume increased linearly with RPE stop percentage. Thus, there was a significant difference in volume among all three weeks ($p < 0.001$). The magnitude of the difference in total combined volume during the 4% vs 2% RPE stop week was moderate (ES = 0.60), as was the difference between the 6% vs 4% RPE stop week (ES = 0.94). Finally, there was a large difference in total combined volume comparing the 6% vs 2% RPE stop week (ES = 1.48). Comparisons for the back squat, bench press, and combined lift volume for each RPE stop week are displayed, along with individual data delineated by sex (each line represents an individual participant), in Figure 6.

Figure 6. Relative volume load totals.



Back squat: training session differences within week

When comparing sessions (hypertrophy, power and strength) within each RPE stop week, back squat volume was greater on hypertrophy sessions than on power or strength sessions during the 2% ($p < 0.001$, ES=1.93 to 1.95), 4% ($p < 0.001$ to $p = 0.001$, ES =

1.00 to 1.58) and 6% RPE stop weeks (*p* < 0.001, ES = 1.11 to 1.44). The differences in back squat volume performed on power sessions relative to strength sessions within each week did not approach or reach significance during the 2% (*p* = 0.59), 4% (*p* = 0.81) or 6% RPE stop weeks (*p* = 0.21). However, ES revealed a small difference, with more volume performed during power vs strength during the 6% week (ES = 0.35).

Bench press: training session differences within week

When comparing training sessions within each RPE stop week, bench press volume was greater during the hypertrophy session than both the strength and power session during the 2% RPE stop week (*p* < 0.001, ES = 2.20 to 2.70). Bench press volume was not significantly higher (*p* = 0.42) for the strength compared to the power session during the 2% RPE stop week. However, ES analysis revealed a small difference, with more volume performed during strength vs power during the 2% week (ES = 0.30). During the 4% RPE stop week bench press volume was greater for the hypertrophy session than the strength session (*p* = 0.04, ES = 0.93). However, the hypertrophy session was not significantly different from the power session during the 4% week (*p* = 0.11); yet ES analysis revealed a moderate difference with more volume performed during hypertrophy (ES = 0.72). While not significant (*p* = 0.43), there was small difference in volume performed favouring the power session when compared to the strength session during the 4% RPE stop week (ES = 0.29). During the 6% RPE stop week bench press volume differences between hypertrophy, power and strength sessions did not approach or reach significance (*p* = 0.22 to 0.66). However, ES analysis revealed a moderate difference in volume favouring hypertrophy (ES = 0.80), as well as strength (ES = 0.69) compared to the power session. The volume performed on hypertrophy was trivially higher compared to the strength session (ES = 0.17) during the 6% week.

Deadlift: training session differences within week

Comparing power and strength sessions, deadlift volume was similar among the 2% (*p* = 0.65), 4% (*p* = 0.77) and the 6% RPE stop weeks (*p* = 0.79). The magnitude of these differences in volume for power sessions relative to strength sessions was trivial (ES = -0.09 to 0.15) in all RPE stop weeks.

Discussion

The purpose of this study was to examine the magnitude of volume performed with various RPE stop percentages. Our hypothesis was supported in that combined lift volume (sum of squat, bench press and deadlift volume) was greater during higher RPE stop percentages (Figure 6, panel D). However, regarding session-type our hypothesis was only partially supported. Specifically, volume during squat hypertrophy sessions was highest compared to power and strength sessions during all weeks; however, hypertrophy session bench press volume was only significantly greater than both power and strength volume ($p < 0.001$, ES = 0.93) in the 2% RPE stop week. During the 4% stop week hypertrophy session bench volume was significantly greater than strength ($p = 0.04$), but not power session volume ($p = 0.11$, ES = 0.72); while no significant differences between session volume for bench press existed in the 6% week. Furthermore, no significant differences existed in any week for session-type deadlift volume. Overall, it appears that the RPE stop system results in increased volume with higher percentages stops (i.e. 6 vs. 4 vs. 2%), however volume distribution between session-type is variable.

To illustrate the unexpected variability of volume distribution, back squat volume in strength sessions during 4% and 6% weeks was similar (9.3 ± 6.1 vs 10.1 ± 4.5; $p = 0.42$), as was deadlift volume in power sessions during 2% and 4% weeks (7.5 ± 4.1 vs 7.8 ± 3.3; $p = 0.81$) and bench press volume in hypertrophy sessions during 2% and 4% weeks (15.8 ± 3.5 vs 16.2 ± 5.6; $p = 0.80$). Combined weekly volume followed a linear trend corresponding to the RPE stop percentage (i.e. higher volume on greater % stops), however the distribution of this volume was more varied within each week. Specifically, only the combined bench press volume (sum of hypertrophy, power, and strength bench press volume) was significantly different between all three RPE stop percentage weeks (i.e. 6% > 4%, 6% > 2% and 4% > 2%), while neither the combined volume of the back squat or deadlift was significantly different between all weeks. One explanation, is that the biomechanical similarities of the back squat and deadlift caused overlapping fatigue, which impacted volume performance on each lift for the remainder of a specific week. In contrast, the bench press, as the only upper body movement utilised presently, was not affected by other lifts.

It is also plausible that the mixed-sex population contributed to a varied volume distribution since strength performance changes during different phases of the menstrual cycle [30, 192] and because there are sex-related differences in fatigability [193-196].

However, many sex related differences dissipate with increased training experience [197]; thus, given only three participants were females and their experience level, it is likely that any sex-influenced difference was minor. Individual levels of relative volume load are presented in Figure 6, delineated by sex to display potential differences between males and females.

In the most similar study to the present, Pareja-Blanco et al. autoregulated volume with velocity stops [113]. Specifically, Pareja-Blanco terminated each set once a repetition was completed at a velocity that had decreased by either 20% or 40% compared to the set's initial repetition; which resulted in almost 60% more total repetitions over 8 weeks in the 40% vs. 20% velocity reduction group despite training at a similar percentage 1RM [113]. In the present study, total relative volume of all lifts combined, was 18.6% greater with 4% vs. 2%, 29.3% greater with 6% vs. 4%, and 53.4% greater with 6% vs. 2% RPE stop percentages. Despite the RPE stop percentage increasing the same amount from 2% to 4%, and 4% to 6%, volume increased ~10% more from 4% to 6% compared to the difference from 2% to 4%. Thus, while volume is greater with higher RPE stop percentages, it does not necessarily follow a predictable pattern of increase.

One potential concern when programming resistance training is managing fatigue within the weekly design. As established by Zourdos and colleagues [17], the modified DUP model we used places a power session between the hypertrophy and strength sessions. This order has been demonstrated to yield improved recovery and performance during a training week compared to a traditional configuration (i.e. hypertrophy, strength, and then power); [17] thus it was implemented within this study. The power session had the lowest number of repetitions paired with the lowest RPE of all days (i.e. 2 repetitions at 8 RPE); thus most times that the maximum back off set limit was reached (i.e. 8 sets) was during the power session. This could prove problematic if too much volume is performed during power sessions so that it subverts the purpose of recovery; therefore it is possible a lower back off set limit could be implemented during power sessions to avoid this issue.

To conclude, while this system does result in an overall predictable change in training volume, it may pose problems if a coach desires to emphasize a specific lift in training. Additionally, a limitation is that this system has only been studied in competitive powerlifters. Previously researchers have established that the RIR-based RPE scale that this system is based on is less accurate when used by novice lifters [18]. Consequently, caution should be exercised before applying these results to different populations, and particularly with less experienced lifters. Finally, future research should compare this system to a traditional system of predetermined daily volume over time for muscle performance.

Practical applications

Given that the overall goal of modulating training volume was achieved using RPE stop percentages, this system of volume autoregulation could be utilised to allow training volume and stress to coincide with the desired focus of a specific training block within a periodised macrocycle. For example, when an athlete is training within a high volume mesocycle an RPE stop percentage of 6-8% could be utilised to ensure enough volume is completed. Likewise, RPE goals can be applied uniformly throughout an entire phase of training versus using differing RPE goals for different days as was done in the present investigation. For example, in place of or in addition to a higher RPE stop percentage, a lower RPE goal could be used throughout a higher volume mesocycle to slow the rate of fatigue, allowing more sets to be performed. Conversely, during an intensity focused training block closer to competition, a lower RPE stop percentage of 2-4% could be used alongside the option of a higher RPE goal throughout the block to ensure heavier loads are lifted in an effort to peak. Even during a taper, a period of time where intensity is maintained and volume reduced, a 0-2% RPE stop could be programmed to ensure diminished volume.

Importantly, individual fatigability should be taken into account. Some subjects in this study indicated that the 3-minute rest period was too short during hypertrophy sessions, and that they could have completed more sets with a longer rest period. Additionally, since some individuals performed the maximum 8 back off sets during power sessions, we recommend a lower maximum allowed volume during power sessions. This prevents total volume during power sessions from becoming similar to hypertrophy or strength sessions, in order to maintain the session goal of recovery. Another potential solution would be to apply different RPE stop percentages to different days within the week instead of applying the percentage to the entire week. For example, if varying RPE stop percentages were applied within the week to the training model in this study, a 4-6% percentage could have been used for hypertrophy sessions, a 0-2% percentage for power sessions and a 2-4% percentage for strength sessions.

While this system is important because it has potential utility in autoregulating volume within a resistance training plan, it is currently unknown how this system would compare to a traditional model using a predetermined volume prescription. However, as it stands this system provides a practical approach to volume regulation. Thus, practitioners are encouraged to use this method (or iterations of it; for example, different RPE stop percentages) as a way of autoregulating volume within periodised training protocols.

Chapter 6: Self-rated Accuracy of RPE-based Load Prescription in Powerlifters

This chapter comprises the following paper which is currently in review, as a short research report in *The Journal of Strength and Conditioning Research.*

Reference:

Helms ER, Brown SR, Cross MR, Storey A, Cronin J, Zourdos MC. Self-rated accuracy of RPE-based load prescription in powerlifters. J Strength Cond Res. 2017: [in review].

Author contributions:

ERH: 80%, SRB: 5%, MRC: 5%, AS: 2.5%, JC: 2.5%, MCZ: 5%.

Preface

This short research report is an examination of the RPE scores from the initial set performed from Chapter 5. The load for this initial set was selected by the participants, based on an RPE target. After the set was completed with that load, the participants rated their RPE, which allowed the analysis of how accurately they could select loads based on an RPE prescription. This is an important step in this thesis, as the overall validity of the RPE scale was established in Chapter 4, and the utility of the scale for autoregulating volume was established in Chapter 5. Thus, in this chapter the goal was to determine if powerlifters could accurately self-select loads with a target RPE. Therefore, if individuals can accurately use the RPE scale to determine load for multiple repetition sets, then it is possible that assigning load via RPE during a training program may lead to greater adaptations than load assignment via percentage of 1RM due to individual differences in repetitions allowed at specific intensities. Ultimately, the concept just proposed will conclude the thesis in the following chapter

Introduction

It has been reported that there is a wide disparity of repetitions allowed at various percentages of 1RM among individuals [152] and large fluctuations of resistance training performance based upon daily readiness [22, 125]. Thus, the RIR–based RPE scale [18] was designed to autoregulate training load based upon daily readiness [189], and equate effort per set across individuals. Therefore, instead of prescribing a number of repetitions at a particular percentage of 1RM, a number of repetitions can be prescribed with a target RPE i.e. 8 repetitions at an 8 RPE (2 RIR).

Importantly, it was demonstrated that trained males and females estimated RIR accurately (an RIR error of < 1 repetition) when performing sets 0-3 repetitions from failure with a predetermined load [133] however, RIR was less accurate when performing sets further from failure [124, 133]. Additionally, RPE/RIR accuracy has been shown to improve with training experience [189]. However, researchers have not examined the accuracy of self-selected loads (i.e. no predetermined load) to comply with the desired RPE.

Given these limitations, the aim of this study was to assess nationally qualified male and female powerlifters' ability to accurately select loads resulting in a target RPE for a single set in the squat, bench press and deadlift during hypertrophy-, power- and strength-type sessions over three weeks. We hypothesised accuracy would be the same between lifts, as similar RPE has been previously reported among the powerlifts at 1RM in powerlifters [190]. Additionally, we hypothesised accuracy during lower RPE hypertrophy and power sessions (target RPE = 8) would be less than the higher RPE strength sessions (target RPE = 9). Finally, we postulated accuracy would improve over three weeks as subjects gained familiarity with this training approach.

Methods

Experimental approach to the problem

Competitive powerlifters performed the squat and bench press 3x/wk and the deadlift 2x/wk (only strength and power sessions) for three weeks in a daily undulating format. Weekly session order was hypertrophy-, power-, and then strength-type on non-consecutive days (i.e. Mon, Wed, Fri) [17]. Immediately before an initial 1RM testing session, which occurred 72 hours prior to the first training session, the RIR-based RPE scale was shown to each participant and described in detail [18]. The scale was shown to subjects following all warm-up and working sets during testing.

During training, an RPE target was provided for a specific number of repetitions on the initial working set for each lift; thus, subjects self-selected the load they believed would result in the target RPE. Only the load for the initial set was selected by the participants (subsequent sets were adjusted based on post-set RPE score). Therefore, to determine RPE accuracy, differences between the target RPE and actual RPE after the initial set for each exercise were analysed.

Subjects

Fourteen powerlifters were recruited and twelve completed the protocol; nine males and three females (Table 9). Two (male: n = 2) dropped out due to minor injury from training that prevented uninterrupted participation or inability to complete all sessions. Inclusion criteria were as follows: 1) a minimum resistance training experience of 1 yr; 2) meeting the New Zealand powerlifting national qualifying strength requirements in prior competition (within one year) or during testing [176]; 3) compliance with the banned substance list of the IPF [177]; 4) be between 18-49 years of age; and, 5) be free from injury/illness. All subjects were informed of potential risks and signed an informed consent document prior to participation (University ethics approval number 15/06).

Procedures

RPE

The RIR-based RPE scale (i.e. RPE scores which correspond to RIR) (Figure 1) [18] was used throughout the study. The scale was shown and explained to each subject in the same exact manner prior to pre-testing and was shown again following all warm-up and working sets.

Training protocol

Three weeks of training were completed with a program similar to a previous undulating powerlifting protocol [17] in that each session had a specific goal: Monday: “hypertrophy” (8-repetitions at an 8 RPE), Wednesday: “power” (2-repetitions at an 8 RPE) and Friday: “strength” (3-repetitions at a 9 RPE). The squat and bench press were performed in all sessions, while deadlift was performed only on power and strength sessions to minimize injury risk and to comply with common powerlifting methods. In each session, lifts were performed in competition order: squat, bench press and then deadlift (if performed), following a dynamic warm-up and warm-up sets. There was a 5-minute rest period after the completion of a lift before the next was initiated. After each warm-up set RPE was obtained, and after all warm-up sets the subject was informed of the repetition and RPE target for the day. Following warm-up sets, a 3-minute rest was administered, then subjects performed the working set with a self-selected load with the goal of meeting the target repetitions and RPE. Consultation of prior session data was allowed to assist load selection.

Statistical analysis

To quantify the directionality of error, 'RPE difference' (RPEDIFF) of target versus reported RPE was recorded (reported RPE score - RPE target). Thus, negative numbers represent 'undershooting' target RPE, while positive represent an 'overshoot'. Since RPE corresponds to RIR, missed repetitions counted as a full RPE score overshoot. This data is displayed in Figure 7.

To display 'absolute accuracy', the mean absolute RPEDIFF (negative sign excluded for RPE undershoot) for each lift for each session was calculated. Thus, absolute RPEDIFF values were averaged for squat hypertrophy week 1, 2 and 3, bench press power week 1, 2 and 3, deadlift strength week 1, 2, and 3 etc., for each subject. This data is displayed in Table 12.

Non-parametric statistical comparisons were made using RPEDIFF values (sign included). Both RPEDIFF over and undershoot values were averaged to generate means so that differences in directionality (under and overshooting) of accuracy could be assessed. Comparisons were made from each week, for each lift, for the same training session compared to the other lifts (i.e. squat hypertrophy vs. bench press hypertrophy). Additionally, comparisons were made within the same lift, between training sessions (i.e. bench press hypertrophy vs. bench press power vs. bench press strength). Finally, comparisons were made between weeks for the same lift, during the same session to assess the effect of time (i.e. deadlift power week 1 vs deadlift power week 2 vs deadlift power week 3).

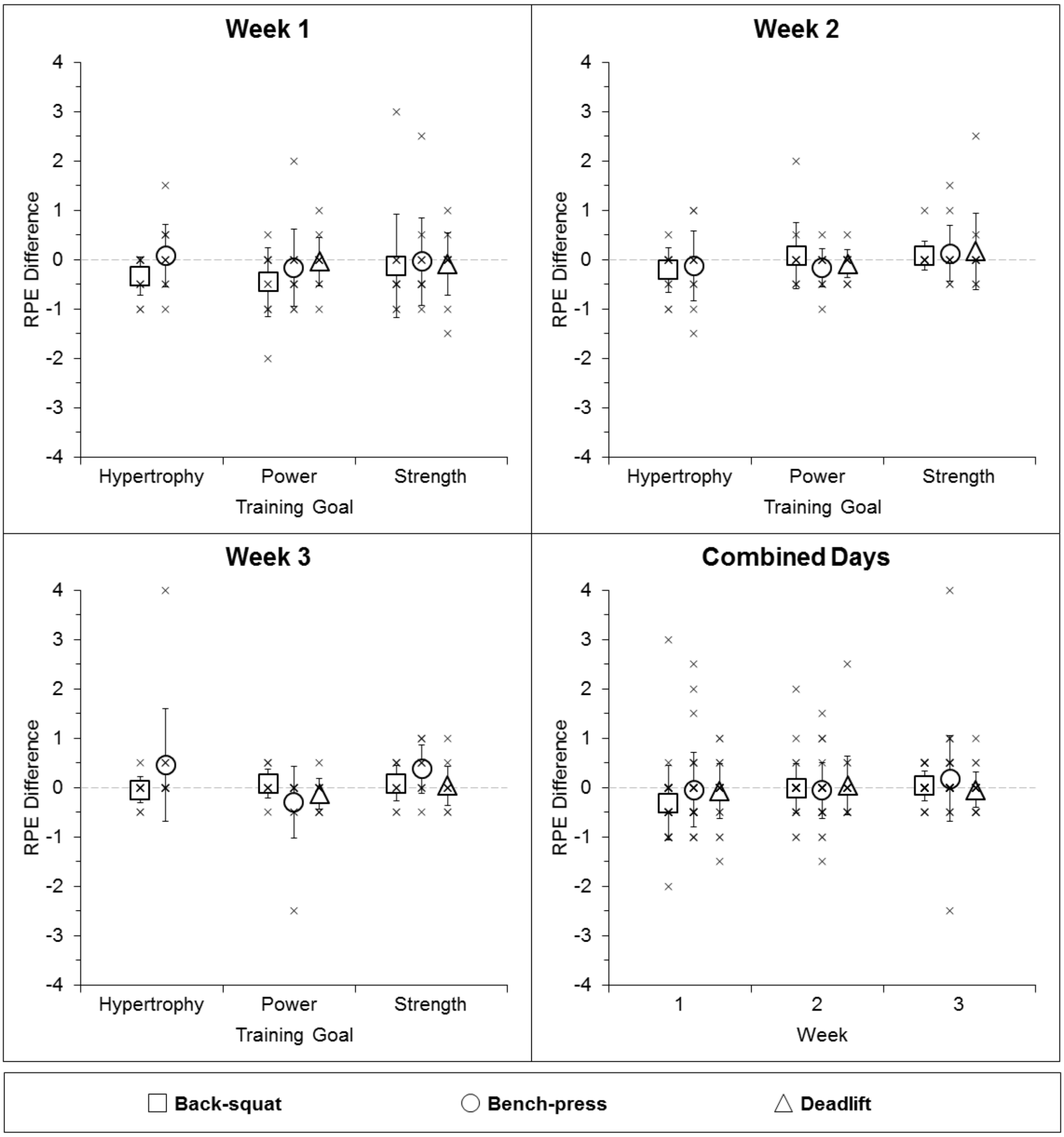
A Friedman test with an alpha set at 0.05 was used for comparisons between two variables (i.e. squat and bench press comparisons on hypertrophy sessions). When three variables were compared (i.e. hypertrophy vs. power vs. strength for the bench press), a Friedman test followed by a post hoc Wilcoxon signed rank test was used. A Bonferonni correction was used for three variable comparisons. Analysis was performed using a statistical software package (IBM SPSS Statistics 21, SPSS Inc., Chicago, IL).

Results

RPE 'under' and 'overshoot'

Figure 7 displays RPEDIFF without the sign dropped to demonstrate RPE 'over' and 'undershoot' throughout the study with 'X' values displaying RPEDIFF among individual subjects (darker x's signify a greater number of subjects with the same RPEDIFF). Mean RPEDIFF values for all lifts and training session-types were never greater than 0.5 RPE from the daily target. When all session-types were combined for each lift, mean RPEDIFF values were < 0.5 RPE from the target with SD values of ~0.5 at the highest.

Figure 7. RPEDIFF values of powerlifters over 3 weeks.



Absolute RPEDIFF scores

RPEDIFF values, with the sign dropped, for the group and individuals to show 'absolute accuracy' can be observed in Table 12. The mean of the combined average absolute RPEDIFF was 0.33 ± 0.28 RPE with a range from 0.25-0.44 RPE.

Table 12. 3-week average absolute RPEDIFF values.

Subject Number	Squat hypertrophy	Squat power	Squat strength	Bench press hypertrophy	Bench press power	Bench press strength	Deadlift power	Deadlift strength	Combined averages
1	0.33	0.00	0.17	0.50	0.33	0.50	0.33	0.00	0.27
2	0.00	0.50	0.17	0.00	0.17	0.50	0.17	0.50	0.25
3	0.33	0.00	0.33	0.00	0.00	0.33	0.33	0.00	0.17
4	0.17	0.50	0.33	1.17	1.00	0.83	0.00	0.50	0.56
5	0.33	0.33	0.17	0.17	0.50	0.33	0.50	0.83	0.40
6	0.17	0.17	0.17	0.50	0.17	0.00	0.17	0.17	0.19
7	0.17	0.17	0.00	0.50	0.00	0.00	0.17	0.17	0.15
8	0.50	0.17	0.33	1.33	0.50	1.00	0.33	0.33	0.56
9	0.17	0.17	0.17	0.33	0.17	0.33	0.17	0.00	0.19
10	0.33	0.50	0.33	0.33	0.17	0.33	0.17	0.83	0.38
11	0.00	0.83	0.67	0.17	0.17	0.33	0.17	0.00	0.29
12	0.50	0.83	1.00	0.33	1.00	0.67	0.17	0.17	0.58
Mean	0.25	0.35	0.32	0.44	0.35	0.43	0.22	0.29	0.33
SD	0.17	0.29	0.27	0.42	0.34	0.30	0.13	0.31	0.28

Absolute RPEDIFF = reported RPE - target RPE with sign dropped.

Values are the 3-week average of each subject's absolute RPEDIFF score for the listed lift and session.

Within-lift RPEDIFF comparisons between sessions

Squat RPEDIFF comparisons between hypertrophy (-0.19 ± 0.21 RPE), power (-0.10 ± 0.45 RPE) and strength (0.01 ± 0.37 RPE) sessions were not significantly different (raw p = 0.07 to 0.76; Bonferroni corrected p = 0.22 to 0.99). Bench press RPEDIFF for hypertrophy (0.14 ± 0.44 RPE) was closer to the RPE target compared to power (-0.21 ± 0.35 RPE), but this difference only approached significance after ad hoc testing (raw p = 0.03; Bonferroni corrected p = 0.10). Bench press RPEDIFF for strength (0.15 ± 0.42 RPE) was significantly closer than power to the target RPE (raw p = 0.02; Bonferroni corrected p = 0.05). Bench press RPEDIFF for strength vs. hypertrophy were not significantly different (raw p = 0.94; Bonferroni corrected p = 0.99). Finally, deadlift RPEDIFF for strength (0.04 ± 0.41 RPE) was not significantly different than power (-0.08 ± 0.23 RPE, p = 0.16).

Within-session RPEDIFF comparisons between lifts

Bench press RPEDIFF was closer to the RPE target compared to squat on hypertrophy sessions (p = 0.02). All comparisons of RPEDIFF during power sessions among the lifts were non-significant (raw p = 0.17 to 0.72; Bonferroni corrected p = 0.50 to 0.99). Likewise, all comparisons of RPEDIFF during strength sessions among the lifts were non-significant (raw p = 0.58 to 0.81; Bonferroni corrected p = 0.99).

RPEDIFF over time

To assess whether the accuracy of load selection to reach RPE targets changed over time, RPEDIFF was assessed across weeks. There was a difference approaching statistical significance indicating that week-3 (-0.04 ± 0.26 RPE) vs. week-1 (-0.33 ± 0.39 RPE) accuracy may have improved during squat hypertrophy sessions (raw p = 0.04; Bonferroni corrected p = 0.11). Likewise, a difference approaching significance indicated that week-2 (0.08 ± 0.67 RPE) vs. week-1 (-0.46 ± 0.69 RPE) accuracy may have improved for squat in power sessions (raw p = 0.03; Bonferroni corrected p = 0.09). Week-3 RPEDIFF for squat in power sessions (0.08 ± 0.29 RPE) was significantly more accurate vs. week-1 (raw p = 0.01; Bonferroni corrected p = 0.03). All other comparisons across weeks did not approach nor reach significance after Bonferroni correction.

Discussion

The purpose of this investigation was to assess if powerlifters could accurately self-select loads corresponding to a target RPE and number of repetitions. Our first hypothesis, that RPEDIFF would be similar between lifts, was mostly supported in that the comparisons were non-significant during strength and power sessions. However, RPE scores for bench press were closer to the target RPE than squat during hypertrophy sessions (p = 0.02). Our second hypothesis, that RPE scores during strength sessions would be closer to the target (RPE 9) than hypertrophy and power sessions (RPE 8), was mostly unsupported as the accuracy of strength session RPE was only statistically superior to power for the bench press (Bonferroni corrected p = 0.05). Finally, our premise that reported RPE would be closer to the target over time as accuracy improved, was only true for squat hypertrophy sessions in week three vs. week one (Bonferroni corrected p = 0.03).

A potential explanation for why RPE was closer to the target for bench press compared to squat during hypertrophy sessions, is that squats arguably require more technical skill and generate more systemic fatigue due to the amount of musculature involved. Thus, there is a greater chance of a technique error, causing greater RPE variability, with high repetition squats compared to the bench press. To reconcile our second hypothesis being unsupported, Hackett and colleagues recently reported RIR to be accurately estimated when repetitions were within 0-3 of failure [124, 133], which would encompass all present target RPEs (8-9 RPE = 1-2 RIR). Regarding our final hypothesis of improvement over time with RPE, statistically there was only an improvement in the squat during power sessions (week 2 vs. 1, Bonferroni corrected p = 0.09; week 3 vs. 1, Bonferroni corrected p = 0.03). Although, there was also a trend for improvement during squat hypertrophy sessions (week 3 vs. 1, Bonferroni corrected p = 0.11). As previously stated, the squat arguably requires the most technical proficiency to perform. This, combined with lower target RPE on power and hypertrophy sessions relative to strength sessions, may be why a learning effect was observed only when a lower RPE was combined with the most complex lift. However, it can be observed from the data in Figure 7 (panels A, B and C) that the spread of RPE scores tightened around the target as the lifters progressed from weeks 1 to 3, with the exception of two outlier performances in week 3. Additionally, it is possible that 3 weeks is not a long enough time frame to demonstrate improvements in RPE accuracy.

Overall, accurate loads were selected to reach the target RPE. Even when extending absolute RPEDIFF two SDs from the mean, values were ~1 RPE from the target on average (Table 12). However, limitations do exist: sets were not performed to failure (except in error when exceeding the target RPE) thus, whether RPE scores represented 'true' RIR is unknown; however, it has previously been reported that intra-set RIR ratings were accurate when sets were close to failure [124, 133]. Finally, accuracy was only examined in one set, thus future research should examine the ability to meet an RPE target with a self-selected load on subsequent sets once fatigue (neuromuscular and metabolic) is present.

Practical applications

Powerlifters can select loads to reach a self-rated target RPE with precision after a familiarisation session explaining and using the RPE scale. However, in powerlifters at the experience level that we observed, achieving peak accuracy levels for the squat at RPE targets below 9 may require at least three weeks of training with this exercise. Additionally, it seems that RPE ratings for the bench press are more accurate when performing low repetition sets closer to failure, and powerlifters are slightly better at selecting a load for an RPE target with high repetitions (8-repetitions at RPE 8) in the bench press vs. squat. However, the between lift difference magnitude is low in that on average, powerlifters had an absolute error of 0.33 RPE, with a mean range of 0.22-0.44 RPE (Table 12). Thus, practical differences in accuracy between lifts and sessions may be inconsequential. Practically, we recommend that RPE targets can be used for load prescription in powerlifters however, it is unknown if untrained lifters can effectively self-select a target RPE load.

Chapter 7: RPE and Percentage 1RM Loading in Periodised Programs Matched for Sets and Repetitions

This chapter comprises the following paper prepared for *Medicine and Science in Sports and Exercise.*

Reference:

Helms ER, Byrnes RK, Cooke DM, Cross MR, Cronin J, Storey A, Zourdos MC. RPE and percentage 1RM loading in periodised programs matched for sets and repetitions. Med Sci Sports Exerc. 2017:[in preparation].

Author contributions:

ERH: 80%, RKB: 5%, DMC: 2.5%, MRC: 2.5%, JC: 2.5%, AS: 2.5%, MCZ: 5%.

Preface

In Chapters 4, 5, and 6, the utility and validity of the RIR-based RPE scale was established for various aspects of powerlifting training to include 1RM testing, volume manipulation and load prescription, respectively. With the utility of this scale established, the next logical step was to implement the scale in a controlled trial. Chapter 7 is the principal study of this PhD, which was designed to accomplish this final step. In this chapter, the hypothesis that autoregulating intensity with RPE-based load prescription may improve muscular adaptations to resistance training, is directly tested.

Introduction

Inclusion of the principle of individualisation is paramount in the design of resistance training protocols to optimize resistance training adaptations [19, 25]. Indeed, evidence exists demonstrating that training adaptation is improved when program-design is tailored to the athlete [33-35]. One method of individualising resistance training is ‘autoregulating’ load prescription through the use of a rating of RPE [189].

Recently, an iteration of the traditional RPE scale based on RIR prior to muscular failure at the end of a set, was introduced to the literature [18]. The RIR-based RPE scale may have more utility compared to traditional Borg RPE, which has yielded submaximal scores (6.8-9.0) even when an individual performs a set to volitional failure [124, 129, 130]. Therefore, it has been recently suggested RIR-based RPE is superior to traditional RPE for assessing intensity during resistance training [189]. Additionally, researchers have reported males and females to determine RIR accurately (within ~1 repetition) during the leg and chest press exercises when sets are performed within 0-3 repetitions from failure [133]. In further support of the RIR-based RPE approach, scores have been strongly and inversely correlated with velocity for both the squat (r = -0.87, $p < 0.001$) and bench press (r = -0.79, $p < 0.001$) [190], the implications being that as movement velocity decreases with higher intensities, reported RPE increases (RIR decreases).

Despite recent research regarding RIR-based RPE and the importance of individualisation in resistance training prescription, training load is commonly prescribed as a percentage of pre-test 1RM [198]. However, if an atypical performance occurred during testing or if there were testing administration errors, loading based on percentage 1RM could then lead to an inappropriate stimulus during training [18]. Furthermore, the number of repetitions which can be performed at the same percentage of 1RM can differ substantially between athletes based on genetic differences and training background [152]. Thus, various issues exist when prescribing load solely with percentage of 1RM, whereas RPE can account for individual differences in repetitions allowed and rate of adaptation. However, to our knowledge there is no study which has compared changes in strength and hypertrophy over time between percentage based and RPE based training programs.

Given these limitations, the purpose of this study was to compare two resistance training protocols with matched repetitions, sets, exercises, and rest periods, but with differing methods of load prescription; one group using percentage of pre-test 1RM and the other using the RIR-based RPE scale. We hypothesized the method of load prescription would create minimal differences in total volume (sets x repetitions x load) between groups and likewise, minimal differences in hypertrophy [157]. However, we hypothesized that intensity (both RPE and percentage of pre-test 1RM) would differ between groups, and that the RPE group would increase strength to a greater extent than the percentage-based group due to load progression aligning more closely to individual participant's capabilities [20].

Methods

Participants

A total of 24 males began this study. Three participants dropped out, two due to minor injury (joint pain or muscular discomfort) and one due to a family emergency; therefore, 21 participants completed the protocol (Table 13). Inclusion criteria was as follows: 1) minimum resistance training experience of 2 years while also performing the back squat and bench press a minimum of once per week for the last 6 months; 2) a minimum 1RM back squat and bench press of 1.5x and 1.25x body mass, respectively; and 3) be free from injury/illness that would contraindicate participation. Resistance training history was determined by completing a questionnaire previously used with similar populations [17, 116]. All participants were informed of potential risks and signed an informed consent document prior to participation. Ethics approval was granted by the Florida Atlantic University Institutional Review Board.

Table 13. Descriptive characteristics of participants.

Variable	1RMG (n = 11 males)	RPEG (n = 10 males)	Combined (n = 21 males)
Height (m)	1.75 ± 0.08	1.72 ± 0.06	1.74 ± 0.07
Weight (kg)	80.2 ± 12.2	78.8 ± 9.72	79.5 ± 10.8
Body fat (%)	10.8 ± 6.1	11.4 ± 5.1	11.1 ± 5.5
Age (yrs)	23.8 ± 4.2	20.9 ± 1.4	22.4 ± 3.4
PMT (mm)	28.5 ± 6.4	30.6 ± 6.5	29.5 ± 6.4
VLMT50 (mm)	27.9 ± 3.6	27.3 ± 4.5	27.6 ± 4.0
VLMT70 (mm)	24.2 ± 3.1	23.8 ± 3.4	24.0 ± 3.2
Squat 1RM (kg)	139.2 ± 18.2	143.7 ± 24.9	141.3 ± 21.2
Bench press 1RM (kg)	113.9 ± 18.7	120.9 ± 19.3	117.2 ± 18.8
Squat Wilks	96.6 ± 15.0	99.4 ± 11.9	98.0 ± 13.3
Bench press Wilks	78.0 ± 7.9	83.8 ± 9.5	80.8 ± 8.9

1RMG = percentage 1RM load group; RPEG = RPE load group. Values are mean ± standard deviation.

1RM = one repetition maximum; PMT = pectoralis major muscle thickness; VLMT50 = vastus lateralis muscle thickness at 50% femur length; VLMT70 = vastus lateralis muscle thickness at 50% femur length.

Wilks points [199] are the scoring system used in powerlifting to determine strength relative to body weight.

Experimental design

The aim of this study was to compare strength and hypertrophy adaptations in trained individuals following a DUP model, differentiated only by load prescription (RPE or percentage 1RM). Groups were counterbalanced to ensure minimal differences (mean 1RMs as similar as possible with as high a p value as possible when comparing means) in absolute and relative 1RM strength as measured by the Wilks coefficient (a validated method of measuring relative strength in competitive powerlifting) [199]. Participants were assigned to either a percentage 1RM group (1RMG, n=11) with load assigned as percentages of pre-test 1RMs, or to an RPE group (RPEG, n=10) with load selected by participants to reach target RPE ranges.

A training duration of 8 weeks was selected as significant 1RM and muscle thickness increases were recently reported in two studies of this length on a similarly sized and trained population of males [17, 116]. Exercise selection, rest periods, and set and repetition targets were identical among groups. Both groups trained 3 times/week on non-consecutive days (i.e., Mon., Wed., Fri.) and performed the specified repetitions in a fixed, descending order each week. In a linear format, every two weeks (after the introductory week) the repetition targets decreased as load (either RPE or percentage 1RM) increased throughout. The final week consisted of a lowered volume taper leading into post-testing on the final day. The specific details of the programs' structure are outlined in Table 14.

Table 14. Summary of training plans.

	Percentage 1RM group (1RMG)			RPE group (RPEG)		
Week	Mon	Wed	Fri	Mon	Wed	Fri
0	x	x	1RM Testing	x	x	1RM Testing
1	2 x 8 x 65%	2 x 6 x 70%	2 x 4 x 75%	2 x 8 x 5-7 RPE	2 x 6 x 5-7 RPE	2 x 4 x 5-7 RPE
2	3 x 8 x 70%	3 x 6 x 75%	3 x 4 x 80%	3 x 8 x 6-8 RPE	3 x 6 x 6-8 RPE	3 x 4 x 6-8 RPE
3	3 x 8 x 72.5%*	3 x 6 x 77.5%*	3 x 4 x 82.5%*	3 x 8 x 6-8 RPE	3 x 6 x 6-8 RPE	3 x 4 x 6-8 RPE
4	3 x 7 x 75%	3 x 5 x 80%	3 x 3 x 85%	3 x 7 x 7-9 RPE	3 x 5 x 7-9 RPE	3 x 3 x 7-9 RPE
5	3 x 7 x 77.5%*	3 x 5 x 82.5%*	3 x 3 x 87.5%*	3 x 7 x 7-9 RPE	3 x 5 x 7-9 RPE	3 x 3 x 7-9 RPE
6	3 x 6 x 80%	3 x 4 x 85%	3 x 2 x 90%	3 x 6 x 8-10 RPE	3 x 4 x 8-10 RPE	3 x 2 x 8-10 RPE
7	3 x 6 x 82.5%*	3 x 4 x 87.5%*	3 x 2 x 92.5%*	3 x 6 x 8-10 RPE	3 x 4 x 8-10 RPE	3 x 2 x 8-10 RPE
8	2 x 4 x 80%	2 x 3 x 85%	1RM Testing	2 x 4 x 6-8 RPE	2 x 3 x 6-8 RPE	1RM Testing

1RMG uses percentages of pre-test 1RM to assign loads while RPEG uses RPE based on repetitions in reserve. Values are displayed as sets x repetitions x load.

* If all repetitions were completed with previous week's assigned loads, load is increased as listed. If any repetitions are missed, load remains the same as prior week. 1RM = one repetition maximum; RPE = rating of perceived exertion.

1RM testing

Participants were shown the resistance-training specific RPE scale based on RIR while receiving verbal instruction on how scores are determined (Figure 1). Following this explanation, participants performed a standardized, bodyweight, dynamic warm up and then according to previously validated procedures [18], the investigators proceeded to test the 1RM of their back squat, followed by their bench press. To aid the researchers in attempt selection, ACV using a Tendo Weightlifting Analyzer (TENDO Sports Machines, Trencin, Slovak Republic), and RPE scores were collected after the final warm up and each 1RM attempt [18]. Previously researchers have identified that trained lifters approached ~0.20 $m \cdot s^{-1}$ and ~0.15 $m \cdot s^{-1}$ on average for the squat and bench press, respectively, at 1RM [125, 128, 137, 190]. Thus, the investigators made smaller increases in load for 1RM attempts as velocity neared these thresholds. Additionally, during post-testing the velocity at which pre-test 1RMs were recorded was used to gauge when a participant was approaching 1RM. Likewise, the proximity to this velocity was used to aid 1RM post-test attempt selection. Both exercises were performed in accordance with the standards of the IPF [1] and a National Strength and Conditioning Association certified strength and conditioning specialist with experience coaching powerlifters monitored all testing and training sessions. Barbells and weight plates were calibrated (Eleiko Sport, Korsvägen, Halmstad, Sweden), and fractional plates (to the nearest 0.25 kg) were used to ensure loading precision in all testing sessions.

Training protocol

While the RPEG self-selected their loads to reach the target RPE range, both groups provided RPE scores after their final warm up set and all working sets to allow RPE comparisons between groups throughout the study. Percentage 1RM assignments in 1RMG were based upon recently published loading relationships [189], so as to ensure that on average, the assigned percentages in 1RMG would fall within the corresponding RPE ranges assigned to RPEG. Participants reported to the laboratory to perform monitored resistance training for a total of 25 days over 8 consecutive weeks. Each training session took place at the same time each day to account for any diurnal changes in strength. Pre- and post-testing for anthropometric measurements, muscle thickness, and 1RM strength took place 48–72 h before week 1 and at the end of week 8, respectively. After pre-testing, participants returned to the lab 48–72 h later to begin a lower volume and load introductory microcycle during week 1 (Table 14). The ‘main training program’ consisted of weeks 2–7 and during week 8, participants completed taper sessions on the first two days of training, and post-testing occurred on the final day of the training week.

In the 1RMG load was assigned as a percentage of pre-test 1RM and progressed in a linear fashion throughout the study. However, on weeks 3, 5 and 7, load was only increased by 2.5% of 1RM if all sets and repetitions were completed on the same day from the prior week. If any repetitions were not able to be completed from the prior week, load remained the same (Table 14). Within-week, if a participant was unable to complete repetitions, load was reduced 4% for every repetition missed on the subsequent set for the same exercise. During week 1 for the RPEG, the researchers selected loads for the participants to ensure the goal of the introductory week was accomplished (acclimating the participants to the frequency and total volume of training) and to aid in familiarising the participants with RPE-based load selection. The researchers explained their rationale for load selection to the participants during week 1 to better familiarize the participants for weeks 2-8 where they self-selected load. Investigators selected load based on the combined factors of the percentage of 1RM they expected to fall within the RPE range, the RPE of the last warm up set and visual assessment of bar speed. Additionally, researchers conservatively estimated loads to land at the lower end of the target RPE range to prevent cumulative fatigue from pushing the subsequent set above the RPE range.

In weeks 2-8, RPEG participants were given access to the records of their previous training days and were specifically shown the record of their performance on the same day of the prior week to assist them in daily load selection. In all weeks, when the reported RPE score for a completed set fell outside of the target RPE range, an automatic adjustment to the load was made for the subsequent set. Based on previous research (Chapter 5), for every 0.5 RPE above or below the upper or lower RPE threshold, respectively, load was decreased or increased by 2% in an attempt to bring the subsequent set’s RPE closer to the assigned range. An example of how this load adjustment protocol was implemented for an RPE range of 6-8 is displayed in Table 15. When the load fell within the assigned RPE range, the participant (or the researchers in the case of week 1) had the choice to modify load as desired so long as they believed it would still fall within the target RPE range. If a participant missed assigned repetitions, for example completing 7 repetitions when 8 were assigned, the set was considered a 10

RPE and each missed repetition was considered a full RPE point for load-adjustment purposes (i.e. if 5 repetitions at a 7-9 RPE was assigned, and 4 repetitions were completed, load on the subsequent set would be reduced by 8%; 4% for being a full RPE point above the upper threshold of the range and an additional 4% for being 1 repetition short of the target). In both groups, 5-7 minute rest periods were administered between working sets and after the final warm up set before the first working set. Additionally, the squat was performed prior to the bench press and a 10 minute rest period occurred after concluding the squat prior to initiating the bench press.

Table 15. Example RPE load adjustments.

	Assigned RPE range
Actual RPE	6-8
1	Increase load by 20%
2	Increase load by 16%
3	Increase load by 12%
4	Increase load by 8%
5	Increase load by 4%
6	Participant choice
7	Participant choice
7.5	Participant choice
8	Participant choice
8.5	Decrease load by 2%
9	Decrease load by 4%
9.5	Decrease load by 6%
10	Decrease load by 8%

RPE = rating of perceived exertion

Dietary logs, protein and amino acid provision

To encourage consistent energy and food intake throughout training and testing, a 3 consecutive-day food log was completed during the first week of training and then again during the final week. In the interim period and prior to the final week food log, participants were instructed to continue their normal dietary habits. To control for the potential impact of nutrient timing between groups, participants ingested branched chain amino acids (Xtend, Scivation, Burlington, N.C., USA) containing 3.5 g of leucine approximately 20 min prior to each training and testing session (upon arriving at the lab, then they began their dynamic warm up 10 minutes after) and 30 g of whey protein (Scivation Whey, Scivation, Burlington, N.C., USA) immediately after each session. Both whey protein and branched-chain amino acids were provided because of their ability to enhance muscle protein synthesis [200, 201].

Muscle thickness testing

Pectoralis major muscle thickness (PMT) and 50% (VLMT50) and 70% vastus lateralis muscle thickness (VLMT70) were assessed via ultrasonography (Bodymetrix Pro System, Intelemetrix Inc., Livermore, Calif., USA) prior to 1RM pre and post-testing. This method of testing was previously used to assess the growth response to resistance training [157, 202] and was validated with magnetic resonance imaging [203]. Scans were performed prior to 1RM assessment on the right side of the body during pre- and post-testing. Sites were scanned lateral to medial with the transducer perpendicular to the skin. Sites were scanned twice and an average of the two scans was recorded. However, if the difference between the two scans was greater than 2 mm, a third was performed and the two values within 2 mm were averaged. The site for the chest was designated as half the distance between the nipple and the anterior axillary line. Vastus lateralis scans were performed in the supine position. Sites were marked and measured at 50% and 70%, respectively, of the distance from the greater trochanter to the lateral epicondyle of the femur [204, 205]. All scans were performed by the same investigator.

Readiness questionnaires

Prior to beginning warm up sets, participants completed part A and B of the daily analysis of life demands for athletes (DALDA) and recorded a 1-10 perceived recovery status (PRS) score by hand. The DALDA is a two part questionnaire consisting of an a, b or c Likert scale in which users record whether they a, feel worse than normal, b, feel normal or c, feel better than normal. Part A consists of 9 broad categories in which stress can be assessed and part B consists of a list of 25 questions pertaining to specific sources of stress [206]. The PRS scale is a simple 1-10 scoring system where the higher the score, the more ready the athlete feels and the more likely they would expect improved performance [207].

Statistical analysis

To assess within group pre to post changes in muscle thickness and strength, we performed independent paired T-tests set at an alpha of 0.05. Despite relative homogeneity due to counterbalancing, there was still some variation between groups in 1RM strength and muscle thickness. Thus, to analyse differences between groups we utilized analyses of covariance with pre-test scores as covariates. This is the preferred method of analysis to account for the fact that participants with low pre-test scores generally improve more than those with high pre-test scores [208].

To supplement null hypothesis testing, we calculated between group ES values such that each groups' change score (post-test – pre-test) was divided by the pooled SD of both groups' change scores [191, 209, 210]. Thresholds for ES were based on Hopkins' scale such that an ES of < 0.20 was considered trivial, and threshold values of 0.20, 0.60, 1.20 and 2.00 were used to represent small (and the smallest worthwhile effect), moderate, large, and very large effects [179, 211]. Additionally, we calculated the 90% CLs of each ES, using the small sample size bias adjustment of the SD outlined by Becker [212, 213], to determine the probability that there was a positive (≥ 0.20 ES), trivial (0.19 to -0.19 ES), or negative (≤ -0.20 ES) effect of the 'intervention' (RPEG). Based on the same rationale for utilising an analysis of covariance, we used the Hopkins spreadsheet "analysis of a pre-post parallel-groups controlled trial with adjustment for a predictor" [180] with the pre-test values as the covariate for the above calculations. For clarity of interpretation, rather than presenting the likelihood of a negative effect of the 'intervention' (RPEG) relative to the 'control' (1RMG) with negative ES values, we removed the sign and presented this as the probability of an advantage of the 1RMG. Thus, data is presented as the probability of an advantage of RPEG, 1RMG or a trivial difference between groups.

Finally, differences between groups for the mean total across the 8-week study and at each time point (weeks 1-8) for the average weekly RPE, relative volume load (sets x repetitions x percentage 1RM), relative intensity per repetition (average percentage 1RM per repetition for the week), change in PRS and change in DALDA scores were determined by 2 tailed independent T-tests with an alpha of 0.05. Analyses were performed using a statistical software package (IBM SPSS Statistics 21, SPSS Inc., Chicago, IL).

Results

Participant adherence

Participants were required to complete at least 90% of all sessions to be included (no more than 2 missed sessions and no missed sessions during the taper). The 1RMG as a whole completed 98% of all sessions. The RPEG as a whole completed 97% of the squat portion and 96.5% of the bench portion of the sessions (in one instance a participant decided not to perform the bench press portion of the session due to shoulder discomfort that subsided by the next training session).

1RM strength and muscle thickness

Both 1RMG and RPEG significantly increased back squat, bench press and combined 1RM strength relative to baseline (p < 0.001). Specifically, squat 1RM increased in 1RMG by 13.9 ± 5.9 kg and in RPEG by 17.1 ± 5.4 kg while bench press 1RM increased by 9.6 ± 5.4 kg and 10.7 ± 3.3 kg in 1RMG and RPEG, respectively. Combined squat and bench press 1RM increased by 23.6 ± 10.4 kg in 1RMG and by 27.8 ± 7.9 kg in RPEG.

Additionally, muscle thickness significantly increased at all measurement sites in both groups relative to baseline. Specifically, PMT increased in 1RMG by 1.6 ± 1.3 mm (p < 0.001) and in RPEG by 1.9 ± 1.9 mm (p < 0.001). Likewise, VLMT50 increased by 2.1 ± 2.0 mm (p = 0.004) and 1.9 ± 2.0 mm (p = 0.01) in 1RMG and RPEG, respectively. Finally, VLMT70 increased in 1RMG by 2.4 ± 2.2 mm (p = 0.004) and in RPEG by 2.3 ± 2.3 mm (p = 0.02).

Overall, there were no significant differences observed between groups for 1RM or muscle thickness. However, small between group ES values in 1RM which favoured RPEG were observed. Exact p values and the ES 90% CL, along with probabilities of advantage or trivial difference are displayed in Table 16.

Table 16. Strength and muscle thickness changes.

Variable	*P*-value	Size of effect (mean ± 90% CL)	Chance of RPE-loading advantage (≥ 0.20 ES)	Chance of trivial difference (-0.19 to 0.19 ES)	Chance of %1RM-loading advantage (≥ 0.20 ES)
Squat 1RM	0.32	0.50 ± 0.63	79%	18%	4%
Bench 1RM	0.52	0.28 ± 0.73	57%	29%	14%
Combined 1RM	0.38	0.48 ± 0.68	72%	22%	6%
PMT	0.66	0.15 ± 0.79	46%	32%	22%
VLMT50	0.76	-0.13 ± 0.76	23%	33%	44%
VLMT70	0.79	-0.06 ± 0.68	25%	38%	37%

Between group differences in strength and muscle thickness.

CL = confidence limit; RPE = rating of perceived exertion; ES = effect size; 1RM = one repetition maximum; PMT = pectoralis major muscle thickness; VLMT50 = vastus lateralis muscle thickness at 50% femur length; VLMT70 = vastus lateralis muscle thickness at 50% femur length.

Training RPE, volume and intensity

For the squat, RPE was significantly higher in RPEG vs. 1RMG in weeks 4, 6, 7 and 8, and the difference approached significance ($p = 0.09$) in week 5. Likewise, RPE was higher for the bench press in RPEG during weeks 2-8 compared to 1RMG. Figure 8 displays the weekly average RPE scores for both groups, for both lifts, throughout the study. Average squat RPE for the entire 8-week period also significantly differed ($p = 0.04$) with higher values in RPEG (7.2 ± 0.3) compared to 1RMG (6.5 ± 1.0). Likewise, average bench press RPE for the 8-week period was significantly ($p < 0.001$) higher in RPEG (7.3 ± 0.3) compared to 1RMG (5.8 ± 1.0).

Figure 8. Weekly average RPE values.

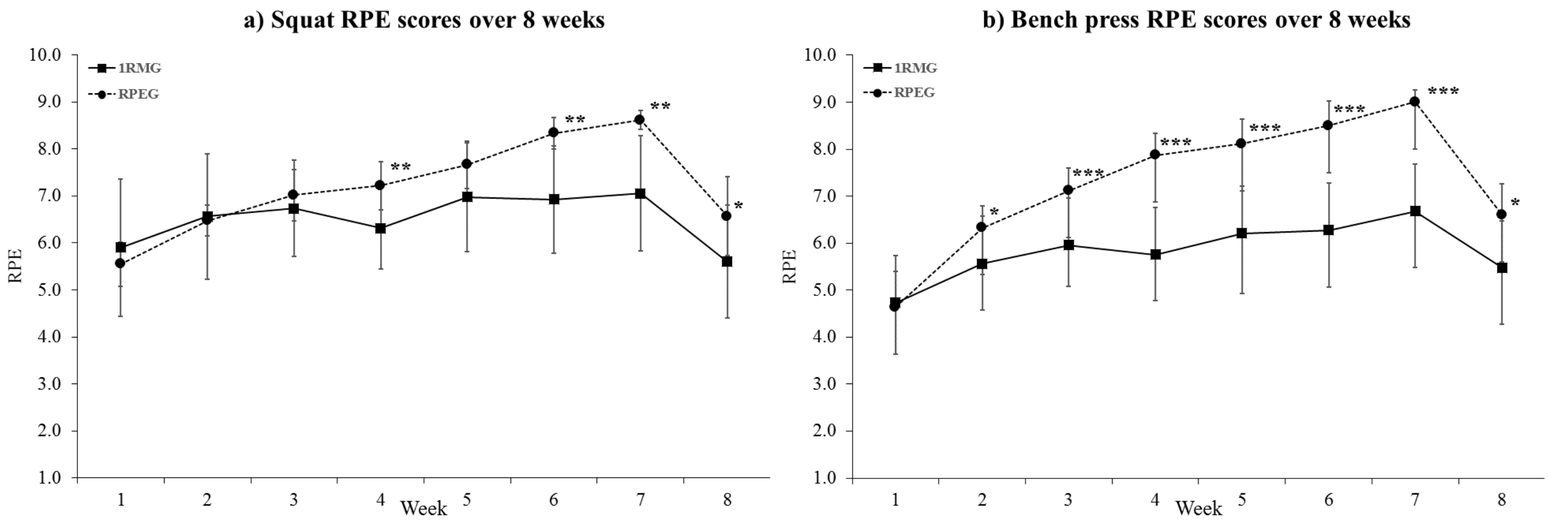


Figure 8 – Weekly average RPE values for a) for squat and b) bench press.
* = p < 0.05; ** = p < 0.01; *** = p < 0.001
RPE= rating of perceived exertion

Similarly, weekly average relative intensity per repetition diverged with significantly higher values in RPEG at weeks 6-8 and 2-8 in the squat and bench press respectively, compared to 1RMG. Lastly, relative volume load differed significantly between groups with RPEG performing more volume than 1RMG at weeks 7 and 8 and weeks 3 and 8 for the squat and bench press, respectively. The relative intensity per repetition and relative volume load values for both groups, for both lifts, throughout the study are displayed in Figure 9.

Figure 9. Weekly average intensity per repetition and relative volume load.

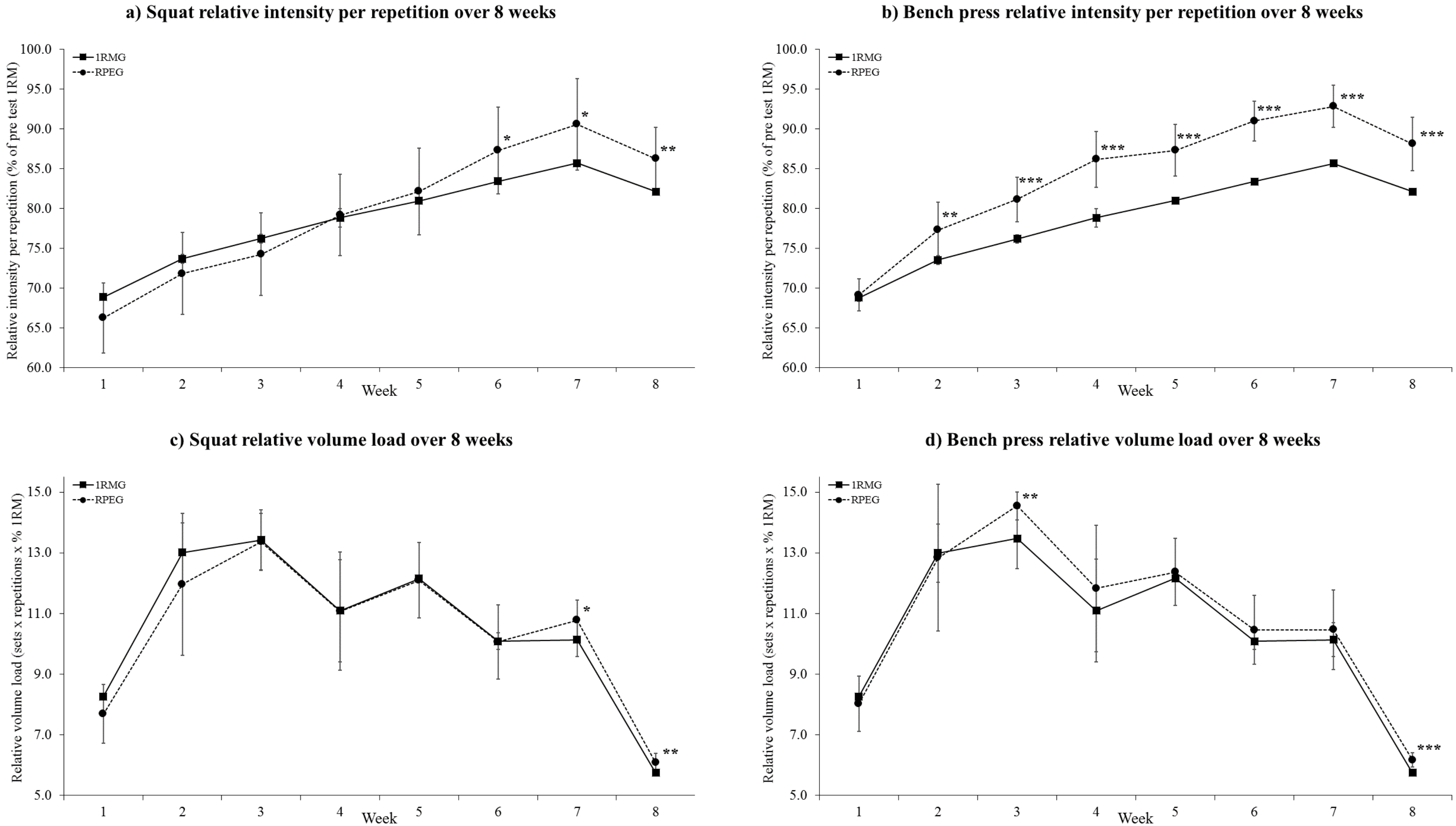


Figure 9 – Weekly average values for a) intensity relative to pre test 1RM per repetition for squat, b) bench press and c) volume load relative to pre test 1RM for squat and d) bench press.
* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$
1RM = one repetition maximum

Average relative intensity for the entire 8-week period was non-significantly different between 1RMG (78.73 ± 0.20%) and RPEG (79.73 ± 4.44%) for squat (p = 0.49). Likewise, average relative volume load for the entire 8-week period was not significantly different between 1RMG (10.49 ± 0.21) and RPEG (10.39 ± 0.67) for squat (p = 0.66). However, average relative intensity for the entire 8-week period was significantly greater in RPEG (84.14 ± 2.02%) compared to 1RMG (78.70 ± 0.18%) for bench press (p < 0.001). Additionally, average relative volume load for the entire 8-week period was also significantly greater in RPEG (10.84 ± 0.41) compared to 1RMG (10.49 ± 0.21) for bench press (p = 0.03).

Perceived readiness

Week to week changes in DALDA part A, part B and PRS scores were not significantly different between groups at any time point (data not shown). However, the change in average PRS score from week 6 to 7 in RPEG (-0.6 ± 0.5) vs 1RMG (-0.1 ± 0.8) approached significance (p = 0.08). Likewise, the change from week 7 to 8 in RPEG (1.1 ± 1.1) vs 1RMG (0.3 ± 1.0) also approached significance (p = 0.09).

Discussion

The goal of this study was to compare two resistance training protocols differentiated only by loading strategy to determine if they would produce different effects. Our first hypothesis that greater strength gains would be achieved by individualising load assignment via RPE was partially supported. Null hypothesis testing did not reveal a significant difference between groups. However, small (0.28-0.50) between group ES differences were found with probabilities favouring RPEG. Our second hypothesis, that muscle thickness changes would be similar between groups was supported as there were no significant differences between 1RMG and RPEG for any muscle thickness measurement. Furthermore, between group ESs were trivial and probabilities were unclear.

Since the recent introduction of the RIR-based RPE scale to the literature [18], researchers have postulated that greater performance could be achieved by using the scale to ‘autoregulate’ load [18, 128, 189, 190]. To our knowledge, this is the first study that has addressed and provided initial support for this claim. With that said, strength differences between groups were small and variable enough to fall short of statistical significance. This may indicate that while some individuals could benefit from using RPE as a loading strategy, for others, the choice between using percentage 1RM- or RPE-based loading is inconsequential (at least in the short term). However, on a group level the RPEG trained at a higher average RPE than 1RMG. Specifically, RPE diverged at week 4 for squat and week 2 for bench press with RPE then remaining higher in RPEG throughout the rest of the study. Interestingly, significant increases in strength and hypertrophy occurred in both groups, despite the majority of training occurring ~3-4 repetitions from failure (RPE ~6-7). This provides further evidence that training to failure at all times is not necessary to make significant gains in hypertrophy [214] or strength [101, 102], at least when training with moderate to heavy loads [215].

Mirroring this divergence in RPE, relative intensity per repetition was also higher beginning at week 6 for squats and week 2 for bench press in RPEG compared to 1RMG. Thus, it appears that for a large part of the study RPEG trained at a higher RPE and percentage of pre-test 1RM, which may explain the higher probability of enhanced strength gain observed in this group. Differences in relative volume load were not expected due to the fact that we matched sets and repetitions. Nonetheless, likely due to the higher relative intensity (as relative volume is sets x repetitions x percentage 1RM), RPEG performed more bench press volume overall and more volume at two time points for the squat (weeks 7 and 8) and bench press (weeks 3 and 8). Related to the volume performed, our second hypothesis that muscle thickness changes would be similar between groups, was supported. As stated, while there were some differences in volume performed between groups, it was not substantial enough to generate greater hypertrophy in the short-term.

Interestingly, the PRS changes between groups approached significance (p = 0.08-0.09) at weeks 7 and 8. The RPEG had a larger decrease in PRS from week 6 to 7 and then a larger increase in PRS from week 7 to 8, compared to 1RMG. This might indicate that at the final week prior to the taper where load was the highest (week 7), RPEG overreached to a greater extent than 1RMG and that the taper was more effective for RPEG, as their PRS score rebounded to a greater degree during week 8. This PRS score pattern provides some insight into how RPE-based loading may help to ensure the temporal goals of a mesocycle are adhered to. On the other hand, changes in DALDA scores between groups were non-significant at all time points. However, based on our anecdotal observation of the participants, as time went on the DALDA forms were completed more quickly, with less effort and with less attention to detail. This might highlight a potential advantage of the PRS compared to the DALDA, in that it takes less effort and time to evaluate readiness using a singular 1-10 scale compared to a 34 item, 3 point Likert-scale questionnaire.

A limitation of this study is that strength improvement may have been greater in RPEG because the prescribed percentages of 1RM were too low or the progression rate was too slow in 1RMG, whereas participants in RPEG were able to progress at an individualised rate. While we made an effort to assign percentages of 1RM which should yield similar RPE to the range prescribed in RPEG [189], greater total volume ($p = 0.03$) at a higher average intensity ($p < 0.001$) was performed by RPEG for the bench press. However, the relevance of this difference is questionable, as there were not significant differences between groups for the squat in total volume ($p = 0.49$) or average intensity per repetition ($p = 0.66$), yet the squat had the highest probability of greater strength gain due to RPE-based loading. Alternatively, if this is a limitation of the study, it might also be a limitation of percentage 1RM-based loading in general, as the number of 'repetitions allowed' at a given percentage of 1RM and rates of adaptation differ substantially between individuals [152].

In summary, both 1RMG and RPEG increased 1RM squat and bench press ($p < 0.001$) along with both upper and lower body muscle thickness ($p < 0.05$) over the course of 8 weeks. Although no statistically significant differences between groups existed, there were small between-group ESs in favour of RPEG for 1RM squat (0.50) and bench press (0.28), which when analysed probabilistically, translated to 79 and 57% greater odds for strength gain in favour of RPEG, respectively. Moreover, there were various points throughout the study where average RPE per set, relative volume and relative intensity per repetition were higher in RPEG vs. 1RMG, possibly explaining the likelihood of a small advantage in favour of RPEG for strength improvement.

Practically speaking, although RPEG may have provided a slight benefit in the present study for strength, this does not mean that RPE and percentage of 1RM should be seen as mutually exclusive for load prescription. For example, RPE accuracy may vary by individual; thus, a lifter who is inaccurate with RPE may not be advised to use solely RPE for load prescription. In this situation, a conservative percentage of 1RM can be assigned for a set number of repetitions for the initial set. However, a 'goal' RPE range could also be established (i.e. 4 sets of 8 at 70% of 1RM with goal RPE of 6-8), and the individual could adjust the subsequent sets if the first set RPE is out of the goal range. The proposed strategy could also be used in a sports team setting where athletes with different training backgrounds and muscle characteristics may perform substantially different repetitions at the same percentage of 1RM [152]; thus athletes could use the goal RPE range to adjust load accordingly. Furthermore, the strategy of using percentage 1RM and RPE in conjunction also accounts for daily readiness with a baseline structure, in that the individual has a pre-determined load, yet can adjust in accordance with the goal RPE if recovery between sessions was inadequate.

For future research, we recommend that inter-individual differences be explored. It has already been established that training age may impact the ability to accurately rate RPE [18]. However, other characteristics such as temperament or social attitudes towards resistance training may influence RPE ratings and therefore could be used to predict which individuals might respond better to an RPE-based loading strategy.

Chapter 8: Summary, Future Research Directions and Practical Applications

Summary

The purpose of this PhD was to answer the question, "Can autoregulation through the use of the RIR-based RPE scale improve the efficacy of powerlifting training?" In order to answer this question, it was first necessary to describe the sport of powerlifting, the training strategies used by powerlifters, the concept of autoregulation and the history of the RIR-based RPE scale in powerlifting (Chapter 1). Following this introduction, a broad review of the literature (Chapter 2) highlighted a number of regulatory tools available to the practitioner, along with specifically identifying the need for future research to investigate the proposed claim that the RIR-based scale could be used to autoregulate load prescription. To fully assess this claim, a targeted review of the available research on RIR and RIR-based RPE was conducted (Chapter 3). Specifically, it covered how the scale could be used in resistance training prescription and identified what future research was necessary to fully elucidate this topic.

With the theory and practice of RPE-based autoregulation strategies established (Chapters 1-3), the next step was to move from review and speculation, to experimentation. To better understand the potential utility of the RIR-based scale in powerlifting training, its use in 1RM testing for the powerlifts (Chapter 4), autoregulating volume (Chapter 5) and self-selecting loads based on an RPE prescription (Chapter 6) was explored. Interestingly, RPE was found to have strong correlations with ACV on all three competition lifts when performing single repetition sets ≥ 80% 1RM. Additionally, RPE was nearly identical for all lifts at 1RM, while ACV at 1RM differed between the three lifts (Chapter 4). Prescribing load via ACV zones is a promising area of research, however, doing so requires that individual velocity load profiles for each lift and lifter are completed. Thus, RPE provides a cost-free alternative to quantifying ACV that can be used across lifts and individuals, assuming the individual has adequate resistance training experience (≥ 1yr).

It was also found that volume could be effectively manipulated through the RPE stop method (Chapter 5), whereby a lifter continues to perform sets until an RPE threshold is met. Greater or fewer number of sets can be prescribed by using smaller or larger percentage reductions from the initial set's load prior to implementing the RPE stop threshold. While this method was effective in manipulating total 3-lift volume across an entire week of training, only the bench press was predictably manipulated in isolation through this method, indicating that the squat and deadlift cause overlapping fatigue, which affects the volume performed on these lifts when using this method.

In the final chapter of Section 2, the self-rated accuracy of powerlifters when using RPE targets to select loads was assessed (Chapter 6). Encouragingly, the powerlifters studied in this thesis showed a high degree of accuracy on average, across all lifts and training goals (0.22-0.44 RPE), when comparing their reported RPE, versus the target RPE they were attempting to reach. However, minor differences did arise between lifts, indicating it may be more difficult to accurately select loads for RPE 8 sets when performing the squat (arguably the most technical lift), compared to the other lifts. Indeed, it may take at least three weeks for powerlifters to reach peak accuracy for RPE 8 sets when selecting load using RPE for the squat.

With the theory, limitations and methods of RPE-based autoregulation explored, the final hurdle was to directly answer the question of whether powerlifting training could be improved through the use of the RIR-based RPE scale. In Chapter 8, two groups of college-aged resistance trained males with at least 2 years of experience performing the back squat and bench press followed identical 8-week training protocols, differentiated only by the method of load prescription. Overall, both groups increased upper and lower body 1RM strength and muscle size without significant differences between groups. However, the RPE group trained at a higher RPE, performed more volume at a higher percentage of 1RM overall for the bench press, and at specific time points for the back squat, performed more volume (weeks 7-8) and performed a higher percentage of 1RM (weeks 6-8), compared to the 1RM group. Thus, it appears that the RPE group was able to train closer to the intended focus of the assigned weeks, i.e. their RPEs increased in a more linear fashion throughout training, coinciding with the intent of the protocol. These differences in training load, volume and effort may be why probabilities (57-79%) favoured the RPE group compared to the 1RM group with greater ES (0.28-0.50) changes for 1RM strength.

So, can autoregulation through the use of the RIR-based RPE scale improve the efficacy of powerlifting training? It appears that indeed, when all else is equal, load prescription through the use of RPE is at least as effective, and probably more effective to a small degree compared to percentage 1RM loading in resistance trained males performing the back squat and bench press.

Future research directions

While it may be that the RIR-based RPE scale can be effectively used to increase strength, many questions are left unanswered due to the limitations of the research contained in this thesis. Chapter 7 served to address the concept of RPE-based loading, however, it lacked perfect ecological validity for the sport of powerlifting. While the participants were moderately strong and experienced, they were not competitive powerlifters and they did not perform the deadlift. While the use of this population was a practical necessity to achieve an appropriate sample size, future researchers should seek to evaluate RPE-based loading in competitive powerlifters and other strength athletes performing more complete resistance training programs. Likewise, this study included only male participants, requiring future research to determine if a cohort of trained females would respond similarly. Additionally, given the probabilities of an advantage due to RPE based loading, yet the lack of statistically significant differences between groups found in Chapter 7, future research should determine what factors (such as motivation, training history or temperament) might predict who is more likely to gain an advantage using RPE load prescription on an individual basis.

Additionally, it was established that RPE stops could be used to manipulate training volume in Chapter 5. However, future research is necessary to determine whether this autoregulated approach to volume manipulation would prove superior in comparison to a traditional pre-set manipulation of volume over multiple mesocycles of training. Furthermore, only 2, 4, and 6% RPE stops were explored in Chapter 5. These RPE stops were selected based on pilot testing and current powerlifting practice, but many other RPE stop percentages are yet unexplored.

Chapters 4 through 6 had a mixed group of male and female participants, however, only three participants in each chapter were female. With such a small sample, it is unknown how this influenced the outcomes in terms of velocity and RPE at 1RM, relative volume performed, or ability to self-select load based on RPE. Future research with a larger cohort of female powerlifters is needed to full elucidate any potential sex differences.

Finally, while the theoretical framework of constructing an RPE scale based on RIR is based on research in which participants could accurately gauge RIR, a comparison of accuracy between the RIR-based RPE scale and a pure RIR score has not been conducted. It is possible that basing an RPE rating on RIR, “adds a step” to the process of gauging distance from failure, and it would be more efficient (or potentially accurate) for individuals to simply report a pure RIR number. However, as discussed in Chapter

3, RIR loses its accuracy further from failure, thus the lower RPE targets (4 RPE or less) could be used as a cap when training for power. Additionally, half-point RPE scores (i.e. 7.5, 8.5 and 9.5) may allow skilled users to be more specific in their ratings compared to pure RIR. Thus, to explore the differences and pros and cons between pure RIR and an RIR-based RPE scale, comparative research is needed.

Practical applications

Given the totality of findings in this body of work, the practical applications are as follows:

1. The RIR-based RPE scale strongly correlates with velocity, which has an almost perfect inverse relationship with percentage 1RM.
2. Lifters not yet familiarised with the RPE scale should spend 2-3 weeks rating RPE after sets before using it as an intensity prescription tool to develop their rating ability.
3. The RIR-based RPE scale can be used to assist attempt selection (ideally alongside ACV) when doing laboratory-based or field 1RM testing in powerlifters to increase accuracy of testing.
4. Experienced lifters can effectively gauge how far from failure they are at the completion of a set using the RIR-based RPE scale.
5. Given the above points, experienced lifters can use RPE to autoregulate load prescription, either in isolation, or in conjunction with percentage 1RM to avoid over or undershooting the target RPE on a lift's initial set.
6. The RPE stop method can be used to manipulate total volume load across the three powerlifts in a predictable manner. Appropriate percentages for RPE stop back-off percentages should likely be between 2-8% depending on goal and phase of training.
7. When using the RPE stop method, lifts with overlapping muscle groups or that generate more total body fatigue may not follow predictable patterns. However, movements such as the bench press, which target a smaller group of muscles, may.
8. It seems that lifters may benefit to a small degree when using RPE-based load prescriptions to enhance 1RM strength. However, this is likely not universal. Individual differences related to motivation, ability to accurately gauge RPE and temperament may influence outcomes on an athlete-to-athlete basis.

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Appendix I. Additional Research Outputs Since Starting the PhD.

Publications:

1. **Helms ER**, Aragon AA, and Fitschen PJ. Evidence-based recommendations for natural bodybuilding contest preparation: nutrition and supplementation. Journal of the International Society of Sports Nutrition 11: 20, 2014.
2. **Helms ER**, Fitschen PJ, Aragon AA, Cronin J, and Schoenfeld BJ. Recommendations for natural bodybuilding contest preparation: resistance and cardiovascular training. The Journal of Sports Medicine and Physical Fitness 55: 164-178, 2015.
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4. **Helms ER**, Zinn C, Rowlands DS, Naidoo R, and Cronin J. High-protein, low-fat, short-term diet results in less stress and fatigue than moderate-protein moderate-fat diet during weight loss in male weightlifters: a pilot study. International Journal of Sport Nutrition and Exercise Metabolism 25: 163-170, 2015.
5. Zourdos MC, Klemp A, Dolan C, Quiles JM, Schau KA, Jo E, **Helms E**, Esgro B, Duncan S, Garcia Merino S, and Blanco R. Novel Resistance Training-Specific Rating of Perceived Exertion Scale Measuring Repetitions in Reserve. Journal of Strength and Conditioning Research 30: 267-275, 2016.
6. Glassbrook DJ, Brown SR, **Helms ER**, Duncan SJ, Storey AG. The high-bar and low-bar back-squats: A biomechanical analysis. Journal of Strength and Conditioning Research. Published ahead of print, 2017.
7. Fairman CM, Zourdos MC, **Helms ER**, Focht BC. A Scientific Rationale to Improve Resistance Exercise Recommendations in Exercise Oncology. Sports Medicine. Published ahead of print, 2017.
8. Phillips SM, Aragon AA, Arciero PJ, Arent SM, Close GL, Hamilton DL, **Helms ER**, Henselmans M, Loenneke JP, Norton LE, Ormsbee MJ, Sale C, Schoenfeld BJ, SmithRyan AE, Tipton KD, Vukovich MD, Wilborn C, Willoughby DS. Changes in body composition and performance with supplemental HMB-FA+ATP. Journal of Strength and Conditioning Research. Published ahead of print, 2017.

9. Brown SR, Feldman ER, Cross MR, **Helms ER**, Marrier B, Samozino P, Morin JB. The Potential for a Targeted Strength Training Programme to Decrease Asymmetry and Increase Performance: A Proof-of-Concept in Sprinting. International Journal of Sports Physiology and Performance. Published ahead of print, 2017.
10. Chatterton S, Zinn C, Storey AG, **Helms ER**. The effect of an 8-week LCHF diet in sub-elite Olympic weightlifters and powerlifters on strength and power performance: A pilot case-study. Journal of Australian Strength and Conditioning [accepted].
11. Glassbrook DJ, **Helms ER**, Brown SR, Storey AG. A review of biomechanical and muscle activity differences between the high-bar and low-bar back-squat. Journal of Strength and Conditioning Research [in review].
12. Morton RW, Murphy KT, McKellar SR, Schoenfeld BJ, Henselmans M, **Helms E**, Aragon AA, Devries MC, Banfield L, Krieger JW, Phllips SM. A systematic review, meta-analysis and meta-regression of the effect of protein supplementation on resistance training-induced gains in muscle mass and strength. British Journal of Sports Medicine [in review].

Invited Conference Presentations:

1. NSCA National Conference 2016, New Orleans USA, Invited Presenter – Gauging Resistance Training Intensity for Max Strength and Power.

Conference Poster Presentations:

1. Fairman CM, **Helms ER**, and Focht BC. Resistance Exercise Prescription Using Rate Of Perceived Exertion In Exercise Oncology-a Novel Concept: 1287 Board #8 June 2, 8:00 AM - 10:00 AM. Medicine and science in sports and exercise 48: 334-335, 2016.
2. Cooke DM, Goldsmith JA, Byrnes RK, Perlmutter JH, Haischer MH, Velazquez JC, Sayih A, **Helms ER**, Dolan C, and Zourdos MC. Total repetitions per set effects RIR-based RPE accuracy. Southeast American College of Sports Medicine 2017 Annual Meeting.
3. Haischer MH, Goldsmith JA, Cooke DM, Byrnes RK, Perlmutter JH, Velazquez JC, Sayih A, **Helms ER**, Dolan C, and Zourdos MC. Training and chronological age effect RIR-based RPE accuracy. Southeast American College of Sports Medicine 2017 Annual Meeting

4. Halle JL, Goldsmith JA, Cooke DM, Byrnes RK, Perlmutter JH, Haischer MH, Velazquez JC, Sayih A, **Helms ER**, Dolan C, and Zourdos MC. Assessment of repetitions allowed at 70% of one-repetition maximum in the back squat in trained males. Southeast American College of Sports Medicine 2017 Annual Meeting.

Appendix II. Ethics Approval for Chapters 4 – 6.

A U T E C

S E C R E T A R I A T

19 February 2015

John Cronin

Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **15/06 Practical auto-regulation in resistance training.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 18 February 2018.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 18 February 2018;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 18 February 2018 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor

Executive Secretary

Auckland University of Technology Ethics Committee

Cc:Eric Helms

Appendix III. Ethics Approval for Chapter 7

FLORIDA ATLANTIC UNIVERSITY

Institutional Review Board
Division of Research
777 Glades Rd.
Boca Raton, FL 33431
Tel: 561.297.0777
fau.edu/research/researchint

Christine Williams, R.N., D.N.Sc., Chair

DATE:	July 15, 2016
TO:	Michael Zourdos, PhD
FROM:	Florida Atlantic University Health Sciences IRB
IRBNET ID #:	918291-2
PROTOCOL TITLE:	[918291-2] Percentage Based Versus Autoregulated Resistance Training for Muscle Strength and Hypertrophy in Trained Males
PROJECT TYPE:	*New Project*
ACTION:	APPROVED
APPROVAL DATE:	July 15, 2016
EXPIRATION DATE:	July 15, 2017
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *B4*

Thank you for your submission of Response/Follow-Up materials for this research study. The Florida Atlantic University Health Sciences IRB has APPROVED your *New Project*. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

- This study is approved for a maximum of **30** participants.
- It is important that you use the approved, stamped consent documents or procedures included with this letter.
    - Adult Consent Form - 7 14 2016 (stamped) - Zourdos H16-97 AutoregulationConsentRevisions 7 14 2016.docx
    - Daily Analysis of Life Demands of Athletes Survey (stamped) - DALDA.docx
    - Medical History Form.doc (stamped)
    - Perceived Recovery Status Survey (stamped) - PRSscale.docx
    - Physical Activity Questionnaire Resistance.doc (stamped)
    - Protocol Dated: July 14, 2016 (stamped) - AutoregulationIRBprotocolRevisedR2.docx
- ****Please note that any revision to previously approved materials or procedures, including modifications to numbers of subjects, must be approved by the IRB before it is initiated.** Please use the amendment form to request IRB approval of a proposed revision.
- All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All regulatory and sponsor reporting requirements should also be followed, if applicable.

- Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.
- Please note that all research records must be retained for a minimum of three years.
- **This approval is valid for one year.** A Continuing Review form will be required prior to the expiration date if this project will continue beyond one year.

If you have any questions or comments about this correspondence, please contact Donna Simonovitch at:

Institutional Review Board
Research Integrity/Division of Research
Florida Atlantic University
Boca Raton, FL 33431
Phone: 561-297-1383
researchintegrity@fau.edu

* Please include your protocol number and title in all correspondence with this office.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within our records.

The End