Implementation of a Low-Volume Power-Type Day to Improve Resistance Training Performance and Recovery

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Abstract

Training recovery is multifaceted. Within this thesis, it describes inter-session resistance training (RT) performance restoration. To enhance performance, sufficient stress often resulting in fatigue occurs. To maximise performance, stress, fatigue, and recovery must be balanced. Despite abundant literature on this topic, findings are equivocal. Therefore, this thesis explored how microcycle (one RT week) configuration affects physiological, perceptual, and performance recovery.

First, a literature review examined the influence of RT microcyle configuration on inter-session recovery. Overall, training to failure lengthens recovery and high-volumes may require longer recovery suggesting its cautious use. Training frequency can serve to distribute volume, facilitating fatigue management by providing time for inter-session recovery. Exercises involving lower body, multi-joint, larger muscle groups, longer muscle lengths or eccentric phases may require longer recovery. Daily undulating programming (DUP) structures incorporating low-volume power-type or aerobic sessions between hypertrophy or strength sessions may provide active recovery (AR) and/or prime performance. Finally, tapering/training cessation may be combined with priming to peak performance in training or testing. Many variables influence inter-session recovery, warranting consideration.

To examine practices of coaches' who program RT, a survey was conducted focusing on microcycle construction. Ninety-two coaches reported opinions on RT programming and non-programming factors influencing recovery and recovery monitoring methods. Coaches believed key variables influencing recovery were sleep, program design, and nutrition, and monitored self-reported sleep, muscle soreness, perceived exertion, and proximity to failure. Coaches placed high-priority sessions early in microcycles after easier lower volume, load, and proximity to failure sessions to improve recovery and performance. Coaches implemented pre-planned progression schemes while also making real-time decisions per individual recovery. These insights on practitioners' recovery beliefs and practices highlight its importance and influence on microcycle construction, while providing application examples.

With the literature and practitioners consulted, an intervention was conducted investigating the effects of four AR methods: i. four sets of one repetition (4x1) with 80% one repetition maximum (1RM) ii. 4x2x40%, iii. 20 minutes of light rowing, and iv. passive recovery (PR) control, on RT- recovery and performance measured subjectively and objectively following a muscle-damaging RT bout. Findings were reported in two publications/chapters, the first on relationships between recovery and performance, the second comparing the protocols' effect on performance. The following recovery and performance metrics were significantly associated: (i) perceived recovery status (PRS) – squat and bench press repetitions, (ii) movement velocity at 75% 1RM (v75) – squat and bench press repetitions, and plyometric push-up (PPU), (iii) squat movement velocity against a load that elicited 1 m/s (v1) – countermovement jump (CMJ), (iv) soreness – bench press repetitions (v) heart rate variability (HRV) – PPU, and (vi) PPU – bench press repetitions. Therefore, practitioners may utilise PRS, low and high-load velocity, muscle soreness, and HRV to assess recovery and predict repetition and power performance.

Comparing protocols, low-volume power-type training significantly affected subsequent low and high-load velocity. Specifically, 4x2x40% in the squat and 4x1x80% in the bench press significantly improved squat v1 and bench v75 recovery, respectively, without other significant differences between conditions. Thus, low-volume power-type AR may be programmed to enhance recovery and subsequent high-velocity, power-based performance.

Future research should investigate recovery over longer periods, with different exercises, populations, and ecologically valid protocols. Mechanistic research distinguishing the impact of recovery from priming is needed. When programming RT, one should consider which variables affect recovery and use metrics that accurately assess performance. However, recovery is multifaceted, variable, and context dependent, requiring individualised approaches.

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List of commonly used abbreviations

1RM: One repetition maximum

AR: Active Recovery

CMJ: Countermovement jump

CK: Creatine kinase

CWI: Cold water immersion

DOMS: Delayed onset muscle soreness

DUP: Daily undulating programming

HRV: Heart rate variability

PAP: Post activation potentiation

PPU: Plyometric push up

PR: Passive recovery

PRS: Perceived recovery status

RIR-based RPE: Repetitions in reserve-based rate of perceived exertion

RT: Resistance training

V1: Movement velocity against the load that elicits 1 m/s

V75: Movement velocity against 75% of 1RM

VAS: Visual analogue scale

VBT: Velocity based training

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.”

Colby Sousa

Co-authored works

Sousa, CA, Storey, A, Zourdos, MC, and Helms, ER
The importance of recovery in resistance training micro-cycle construction. Journal of Human Kinetics *(In review)*

(Contribution of co-authors: Sousa 87%, Storey 3%, Zourdos 3%, Helms 7%)

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(Contribution of co-authors: Sousa 90%, Storey 3%, Helms 7%)

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(Contribution of co-authors: Sousa 81%, Cross 6%, Storey 3%, Zourdos 3%, Helms 7%)

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

Colby Sousa

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"Tough, the path ahead

But today you are stronger

Believe in yourself"

Ethics approval

The Auckland University of Technology Ethics Committee (AUTEC) granted ethical approval for the thesis research on:

- 30 March 2023 AUTEC reference number 23/82 (Chapter 3) (Appendix A)
- 23 September 2020 AUTEC reference number 20/54 (Chapters 4 and 5) (Appendix B)

Chapter 1 Introduction

Section 1: Background and rationale

Recovery in the context of exercise is the process of restoring what was lost, involving the compensation for deficit states like fatigue and decreased performance, and aligning with the principle of homeostasis for a return to the initial state (Kellmann, 2010; Sands et al., 2007). It is a two-stage process encompassing fatigue reduction and adaptation to training demands, with inadequate recovery risking temporary force reduction, decreased performance, and increased injury risk (Brown et al., 1997; Burt & Twist, 2011; Cheung et al., 2003). Achieving a balance between training stress and recovery is crucial (Bird, 2013), requiring a greater level of fitness, indicative of stress adaptation (Sands et al., 2007). Different exercise modes elicit distinct physiological responses impacting recovery time and capacity, influenced by training program variables such as volume, intensity, and frequency (Nosaka & Newton, 2002; Paschalis et al., 2005). Systematic program design, referred to as either periodisation or programming (depending on time course), can be used to balance stress, fatigue, and recovery (Fleck, 1999). Beyond training configuration, factors such as adequate sleep (Bird, 2013), nutrition (Beck et al., 2015), and stress management (Bartholomew et al., 2008) contribute significantly to recovery. Once these factors are accounted for, additional strategies to potentially enhance recovery and/or prime performance may be considered.

Numerous methods in exercise science exist to assess recovery and predict performance, encompassing both objective and subjective approaches. Biomarkers such as enzymes and cytokines in the blood, along with hormonal markers such as testosterone-cortisol ratio, offer physiological insight to muscle damage, inflammation, and stress levels (Lee et al., 2017). However, these methods may be impractical due to their invasive, expensive, and time-consuming nature. Alternative quantitative measures include HRV (Flatt et al., 2019), performance metrics (Jukic et al., 2023; Watkins et al., 2017), and psychological questionnaires (Lee et al., 1991; McLean et al., 2010; Sikorski et al., 2013) offering practical and non-invasive

alternatives. Combining these diverse monitoring methods allows for a comprehensive assessment, facilitating informed decisions for enhancing recovery and performance.

If an appropriate training setup, adequate sleep, proper nutrition, and thorough recovery assessments are present, incorporating methods to expedite the recovery process, both from physiological and perceptual perspectives, may be advantageous. Numerous recovery interventions, including stretching (Herbert & Gabriel, 2002), electrostimulation (Bieuzen et al., 2014), compression (Marqués-Jiménez et al., 2016), massage (Kargarfard et al., 2016), cold temperature applications like cryotherapy (Costello et al., 2015) or cold-water immersion (CWI) (Leeder et al., 2012), foam rolling (D'Amico & Gillis, 2019), and AR (Zainuddin et al., 2006), have been proposed. However, context is crucial in selecting the appropriate technique, as different situations may warrant specific applications. Furthermore, practicality considerations, such as time commitment, difficulty, and accessibility, should be taken into consideration when deciding on the use of these methods.

AR involves engaging in any form of exercise as a method to enhance recovery, typically featuring lower volume, intensity, and/or duration. AR can occur between bouts of exercise or during the recovery phase following a training session, aiming to reduce muscle edema (Clarkson et al., 1992), promote enhanced muscle fibre regeneration (Clarkson & Sayers, 1999), and decrease inflammatory responses (Peake, Neubauer, et al., 2017) from strenuous exercise sessions. Some studies have explored the effects of AR after RT, revealing similar impacts on the inflammatory process in response to AR consisting of low-intensity cycling as compared to CWI following a high-volume lower-body session (Peake, Roberts, et al., 2017). With comparable recovery outcomes, opting for AR via low intensity cardiovascular training may be favoured to avoid the documented negative effects to the anabolic response to RT that may be experienced with chronic use of CWI (Fyfe et al., 2019; Roberts et al., 2015).

Other forms of AR for RT have been studied, including performing upper body exercises after a damaging lower body session (Abaidia et al., 2017), training the same muscle group with lighter loads after a damaging session (Bartolomei et al., 2019), and placing a low-volume power-type session between a hypertrophy and strength session (Zourdos et al., 2016). The theoretical benefits of these AR modalities include facilitating recovery and potentially

"priming" subsequent performance; however, only limited research on the potential priming effects of low-volume power-type training for improving RT performance in the following 24-48 hours exists (Tsoukos et al., 2018).

Section 2: Purpose of the research

The overarching aim of this thesis was to expand the knowledge base on AR, specifically, with regards to improving RT recovery and performance and to answer the questions:

1. What current evidence exists regarding the influence of microcycle configuration on recovery between RT sessions?
    a. How does the manipulation of RT variables (i.e., volume, intensity, exercise characteristics, etc.) affect subsequent recovery demands?
    b. What role do programming strategies have on enhancing recovery and ultimately, RT adaptation?
2. What are the current recovery-related practices of coaches who create RT programs, with a focus on short-term training plan construction?
    a. What level of importance are given to factors related to recovery such as program design, sleep, and nutrition?
    b. Do coaches actively think about recovery when designing RT programs and how does this affect subsequent decision making?
    c. How do coaches measure recovery and does this influence program design?
3. How accurate are different monitoring metrics at assessing recovery and predicting RT-relevant performance?
    a. What information about recovery can objective metrics such as movement velocity, movement specific barbell and plyometric performance, and HRV provide, and do these translate to performance outcomes of interest?
    b. What information about recovery can subjective metrics such as perceived recovery, muscle soreness, sleep quality, stress, and mood provide, and do these translate to performance outcomes of interest?

4. Are there differences between different AR methods on RT-relevant performance following a damaging bout of RT?
    a. Is there a difference between AR and PR?
    b. Do different prescriptions of AR in the form of low-volume, power-type training lead to enhancement of different outcomes (i.e., heavier loads for repetition performance and low loads for velocity performance)?

Section 3: Significance of the thesis

RT is widely employed to boost athletic performance (Kraemer & Ratamess, 2004) in a wide variety of sports, particularly in strength-focused sports like powerlifting and strongman competitions (Pritchard, 2015), those emphasising power production such as weightlifting, sprinting, jumping, and throwing (Suchomel et al., 2016), and in physique sports like bodybuilding, where athletes aim to achieve a specific level of muscularity and leanness, emphasising muscular hypertrophy (Alves et al., 2020). The significant role that adequate recovery plays in performance is well established (Brown et al., 1997; Burt & Twist, 2011; Cheung et al., 2003) suggesting that it be considered and that a balance between stress, fatigue, and recovery is achieved (Bird, 2013). When designing a microcycle of training, focus is often given to how the manipulation of training variables affects performance; however, limited research exists examining the importance of recovery in this process. Therefore, shifting the narrative to be more recovery centric may aid in making the configuration of training more straightforward while also maximising desired training outcomes.

Of the research that exists, the use of AR in the form of a low-volume power-type RT session shows promise (Bartolomei et al., 2019; Zourdos et al., 2016) and provides a practical option to consider during microcycle construction. However, an unanswered question pertains to whether performance potentiation, or "priming," can coincide with recovery, potentially leading to enhanced performance after power-type days. This thesis aims to address these gaps in the literature by examining the acute effects of various AR methods, including the implementation of different low-volume power-type sessions, light aerobic exercise, and PR.

Further, additional insight will be gained on which recovery monitoring metrics are useful and worth considering based on desired outcomes. If proven effective, this strategy can be readily adopted by coaches, athletes, or individuals seeking to optimize their training outcomes.

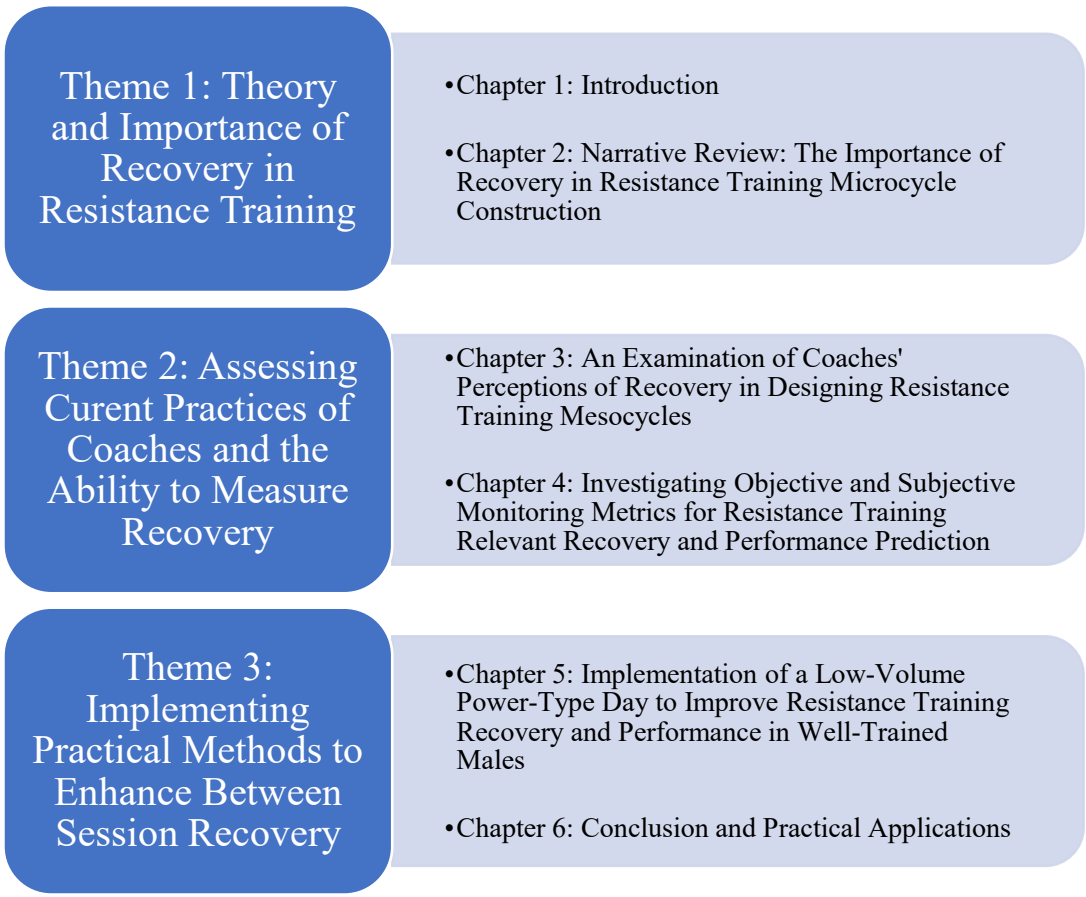
Section 4: Structure of the thesis

This thesis is presented as a "thesis by publication"; inclusive of journal-style articles (referred to by AUT as 'Format 2') excepting the introduction and discussion chapters. It is organised into three sections (Figure 1-1). The first section introduces the thesis (Chapter 1) and reviews the current literature regarding the influence of microcycle configuration on recovery between RT sessions (Chapter 2). The second section presents data from a survey which examined current recovery-related practices of coaches who create RT programs with an emphasis on short-term training plan construction (Chapter 3). This section also presents data collected from a randomised-control trial with the dual purpose of assessing the relationship between selected objective and subjective RT recovery and performance metrics (Chapter 4) as well as comparing the effects of various AR strategies and PR on subsequent RT recovery and performance (presented in the subsequent section). The third and final section of this thesis investigates the effects of AR in the form of two low-volume power-type sessions, light aerobic exercise, and PR on RT recovery and performance in well-trained males (Chapter 5) and concludes with discussion of the thesis with an aim to inform practice and recommendations for related future research (Chapter 6).

Chapters 2, 3, 4, and 5 are in various stages of publication in peer-reviewed journals. Chapter 2 is currently under review with the Journal of Human Kinetics, Chapter 3 has been submitted to the European Journal of Sports Science, and Chapters 4 and 5 are submitted to the Journal of Strength and Conditioning Research. Consequently, the chapters are presented in the format of the respective journal, thus, some inherent repetition between chapters representing journal articles and the final discussion is present. The COVID-19 pandemic and subsequent lockdowns in New Zealand resulted in significant interference with data collection as going in and out of lockdown periods, a high prevalence of COVID-19 in the community, and frequent illness made participants reluctant or unable to participate. However, with timeline extensions

and modifications to the original plan of collecting data in the United States, a sufficient amount of data was eventually collected.

Figure 1-1 Thesis structure



Chapter 2 Literature review

Submitted to the Journal of Human Kinetics (In review)

Prelude

While RT researchers often discuss the importance of recovery, there are not definitive reviews which explore, contrast and compare practical strategies for recovery. Importantly, many recovery modalities require a laboratory, or are prohibitively expensive, or invasive, limiting their practical use. Practical methods are also unexplored, with RT programming for the purpose of enhancing recovery especially under-explored. Specifically, the impact of manipulating microcycle-timescale RT variables to modify recovery and improve performance has not been reviewed and synthesised to provide real-world recommendations to coaches and to identify gaps in the literature ripe for future research. Thus, the following review was the first step in this thesis to address the research questions.

Section 1: Introduction

The goal of systemic RT is to improve performance; however, to accomplish this goal a training program must obtain the appropriate balance of stress, fatigue, and recovery (Bird, 2013), which are all interrelated. Fatigue, referred to as physical and/or mental exhaustion causing a deterioration in performance (Plisk & Stone, 2003) is expected from training; however, inadequate recovery may lead to a temporary reduction in force (Brown et al., 1997), decreased performance (Burt & Twist, 2011), and an increased risk of injury (Cheung et al., 2003). Recovery is as a two-stage process involving the reduction of fatigue and adapting to imposed training demands. Specifically, an individual should at least be able to return to baseline performance or potentially, beyond that (Sands et al., 2007).

Trainers and practitioners have the potential to help even highly experienced athletes improve their RT performance if they carefully balance their training stress and stimulus (Helms et al., 2020). This starts with having a systematic approach to training through specific and

purposeful manipulation of training variables such as volume, load, and proximity to failure commonly referred to as periodisation (Fleck, 1999); however, there has been discussion about proper use of terminology. Specifically, a clear distinction between programming and periodisation is needed as they represent different aspects of program design and may cause confusion if used incorrectly (Hammert et al., 2021; Hornsby et al., 2020; Steele et al., 2023). Distinct from periodisation, which refers to longer term changes, programming refers primarily to session-to-session or within microcycle changes to training variables, which have a more acute impact on training stress and stimulus. When focusing on recovery, attention is mainly given between sessions within a week of training (i.e., a microcycle) to enhance acute performance with the hope of eliciting further adaptation accumulated from multiple weeks of training (i.e., a mesocycle). These daily changes within a training program are often referred to as daily or weekly undulating programming (D/WUP). DUP approaches are often favoured as they have exhibited a greater degree of muscular strength development compared with linear periodisation (Rhea et al., 2002) in trained individuals. When looking at the effects of periodisation for enhancing muscle hypertrophy, undulating and linear models appear to be equally effective (Evans, 2019); however, studies have not been conducted in trained individuals.

Practically, when constructing a microcycle, considering the amount of recovery required between sessions may influence the placement of certain sessions throughout the week. For example, if there is a session that is of high priority (i.e., heavy single repetitions, technical lifts requiring high focus, high volume sessions, or a combination of these), allowing for enough time to recover prior to this session might enhance performance of this high priority session. For example, this could mean altering the traditional order of DUP training from hypertrophy, strength, then power (HSP) to hypertrophy, power, then strength (HPS), to allow for recovery during a power session following a hypertrophy session, therefore leading to greater training volume and total repetitions in the high priority strength session (Zourdos et al., 2016). This is only one such example where adjusting microcycle construction led to enhanced recovery, yet no reviews have discussed this topic in depth to facilitate better programming decisions by coaches and trainers.

Therefore, the primary aim of this review is to examine current evidence regarding the influence of microcycle construction factors (e.g., proximity to failure, allocation of training volume, single session difficulty) on recovery between RT sessions. Primarily, research examining the manipulation of RT variables and the subsequent effects on recovery will be addressed with additional insight on the role of programming to allow for appropriate recovery and long-term adaptation.

Section 2: Methods

To inform this narrative review, PubMed, Medline, SPORTDiscus, Scopus and CINAHL electronic databases were searched online in addition to further hand searching of the reference lists of articles found in the search. In the Scopus database, subject area was limited to "medicine" and "health professions" with only "articles", "reviews", and "articles in press" included for search parameters. The search string: (resistance OR strength OR weight) AND training AND recover* AND athlet* was used for initial selection of manuscripts, limiting database results to peer reviewed studies of human subjects in English.

After obtaining all manuscript records, initial screening included: (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 investigated recovery between RT sessions within a microcycle.

Due to the variation in methods across studies, this review is presented in a narrative format with the intention of providing an overview of the current literature, new perspectives on training program construction, and direction for future research.

Section 3: Results

The search and study selection process are presented in figure 2-1. After examining the included articles, specific themes emerged which led to the layout of the discussion. The major

sections are separated into 1) “the influence of RT variables on recovery” and 2) “the influence of programming” (i.e., how the discussed variables are structured and manipulated) on recovery, with sub sections in the former on proximity to failure, volume, and exercise selection, and AR, and priming/training cessation also discussed in the latter. Finally, the discussion concludes with a limitations and considerations for future research section and practical applications.

As shown in figure 1, a total of 24 articles were reviewed. These articles included a variety of participants, measurements, and outcomes which were extracted from all studies for analysis. A comprehensive description of the extracted results from each reviewed study can be found in Table 2-1.

Figure 2-1 Search and selection process

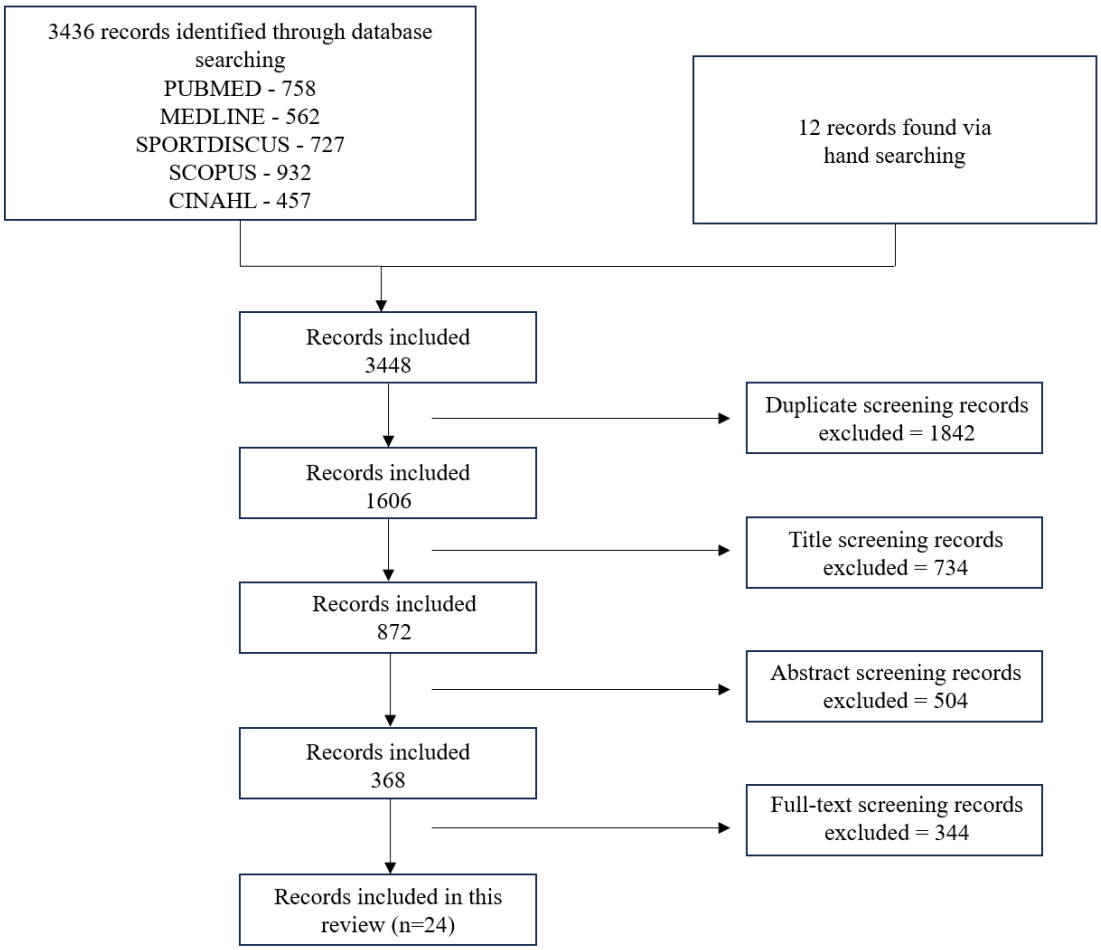


Table 2-1 Summaries of studies included in the review

Study	Participants	Intervention	Outcomes Measured	Summary of findings
((Abaidia et al., 2017)	20 active M	5 x 15, ECC knee flexion. AR (upper STR Tr-3x70%1RM to failure) vs. PR	CK, hamstring STR, DOMS. Pre, 0, 20,24,48 hr post	AR ↑ slow concentric force. No negative effects other metrics
(Bartolomei et al., 2017)	12 RT M	High VOL: 8x10x70%1RM & high intensity: 8x3x90%1RM in BS	CMJ, iso-kinetic & -metric KE, IMTP, ISO BS, CSA, T:C, IL-6, C-reactive protein, CK, LDH, pre, 30 min, 24, 48, & 72hr post	High-VOL = > performance deficits & MD vs. high intensity
(Bartolomei et al., 2019)	25 RT M	High VOL BP (8x10x70%1RM), PR or AR (BP, 5x10x10%1RM) 6- & 30-hrs post	BP throw, ISO BP & MT pec & triceps, & DOMS 15 min, 24, & 48hr post	BP throw, max ISO force, & pec MT restored 24hr in AR. No diff. DOMS
(Bartolomei et al., 2023)	22 RT M	Mixed or block periodisation. Mixed = HYP, POW, STR each session. Block = one per mesocycle. 10 wks	BF%, MT, 1RM BS + bench, CMJ + BPT, IBP, ILE, load & VOL	Mixed = > FFM, MT &1RM BP. Block = > CMJ
(Belcher et al., 2019)	12 well Tr. M	BS, BP, & DL 4x80%1RM to failure	Swell, ROM, DOMS, ACV 70% 1RM, CK, LDH, & cfDNA pre, 0, 24, 48, 72, & 96hr post	ACV < in BS 72hrs & BP at 0hr. cfDNA related to ACV all conditions at 0hr

(Dourado et al., 2023)	14 un-Tr. young M	Unilateral KE & LP, 8x10x70-90%10RM	Peak torque, CMJ, & MT pre, 0, 24, 48, 72, & 96 hrs post	LP = < performance & REC rectus femoris muscle edema. VLa REC delayed post KEs
(González-Badillo et al., 2016)	9 experienced RT M	3x4 vs. 8x80% 1RM in BS & BP	CMJ, V1-Load, T:C, GH, prolactin, IGF-1, CK, HRV & HRC pre, 0, 6, 24, & 48hr post	3 x 4 = < ↓velocity, CMJ, hormonal, MD, HRV & HRC & faster REC
(Held et al., 2021)	4 F & 17 M Tr. rowers	Same intensity VBT, 10% VL vs. traditional 1RM Tr., 5 exercises, 4x80%1RMx fail, 8 wks	BS, DL, bench row, & BP 1RM, VO2 max rowing, & REC/stress	VL10 = > BS, row, & BP 1RM & REC & stress 24 + 48hr post
(Helland et al., 2020)	8 M & 8 F STR Tr.	1 STR (5RM) & 1 POW (50%5RM) session	BS jump, CMJ, 20m sprint, BS & BP peak POW, e1RM, RPE & PRS pre, 0, 24, & 48hr post	Large NM impairment & > REC times post STR vs. POW session
(Howatson et al., 2016)	10 elite track & field athletes	STR (4x5xRPE 17/20) or POW (4x5x30% load) in BS/speed BS, split BS/split-BS jump, push/POW press	MVC, jump height, central activation ratio, & lactate pre, 0, & 24hr post	> NM & metabolic demand post STR impaired max force up to 24hr

(Kotikangas et al., 2022)	8 POW + 8 STR athletes & 7 non-athletes	POW (7x6x50%1RM), STR (7x3x3RM), or HYP (5x10x10RM), smith BS	CMJ, T:C, GH, & lactate pre, middle testing, 0, 24 & 48 hr post	POW condition = > ↓in POW vs. STR athletes in CMJ. Higher GH in STR athletes vs. non-athletes
(Lewis et al., 2022)	16 M & 12 F RT	Pre, REC (4,24, or 48 hrs), & post REC 4x10RM bicep curls & KE to failure	REC = reps in post REC. Fatigue = reps set to set	REC = no sex diff. Fatigue = < reps in later sets & F > reps bicep curls
(Mika et al., 2007)	10 healthy M	3x50%MVC dynamic KE & flexion. PR, stretch, or AR. Post test = ISO KE at 50%MVC	ISO KE, 50%MVC to failure & VLa EMG	Significant ↑ in motor unit activation post AR
(Morán-Navarro et al., 2017)	10 RT M	3 protocols (sets x reps x [max reps]): 3x5(10), 6x5(10), & 3x10(10), BS & BP	CMJ, MPV V1 & 75% 1RM loads, T:C, GH, & CK at AM + PM, 0, 6, 24, 48, & 72 hr post	Failure = > REC of NM function & hormonal homeostasis
(Pareja-Blanco et al., 2019)	10 RT active M	Reps (R) per set, max predicted (P): R(P) - 6(12), 12(12), 5(10), 10(10), 4(8), 8(8), 3(6), 6(6), 2(4), & 4(4). 3 sets, BS & BP	CMJ, V1, T:C, GH, prolactin, IGF-1, & CK, -24hr, pre, 0, 6, 24, & 48hr post	Failure = > fatigue, hormonal response, MD, & slower NM REC, especially in high rep sets
(Peake, Roberts, et al., 2017)	9 active M	Single LP & squat, KEs, & walking lunges, 8-12 reps. CWI (10°C, 10 min) or AR (cycling, low intensity, 10 min)	Biopsies pre, 2, 24, & 48hr post - inflammation, cytokines, neurotrophins, & HSP	CWI & AR = similar to minimise inflammatory response

(Pritchard et al., 2018)	8 RT M	4-wk STR Tr, then 3.5- or 5.5-days Tr. cessation	T:C, CK, psychological tests, CMJ, IMTP, IBP pre-Tr., final day, & post Tr. cessation	CMJ & IBP ↑ over time. CMJ & IBP ↑ pre & final day Tr.
(Raastad & Hallen, 2000)	10 M STR athletes	100%3RM back & front squat & 6RM KEs or load 70% of that	Isokinetic KEs, ES, & squat jumps pre, 3, 7, 11, 22, 26, 30, & 33hr	All variables REC 3hr post in moderate, 33hr in 100% intensity
(Raeder et al., 2016)	14 M & 9 F STR Tr.	6-days STR Tr.: 2x/day, high resistance + max ECC STR, full but mainly lower body	e1RM, MVIC, CMJ, MRJ, RSI, CK, DOMS, PRS, & stress pre & post & 3 days REC	↓ in all variables. 3 days, return to baseline in e1RM, CMJ, & MRJ
(Thomas et al., 2018)	10 young M	3 x max effort in RT (10x5x80%1RM), jump (10x5 jump squat), & sprinting (15x30m)	ES KE & fatigue via VAS pre, 0, 24,48, & 72hr post	REC 48hr jump & 72hr STR & sprint
(Travis et al., 2021)	14 M & 2 F PL	6-wk program, 1-wk overreach, either 1-wk step or 3-wk exponential taper	Pre & post ultrasound, biopsies, CMJ, ISO & 1RM BS	Step taper = ↑ HYP. Exponential taper = ↑ NM performance
(Travis et al., 2022)	16 M & 3 F STR Tr. athletes	4-wk PL block. 3 or 5 days of Tr. cessation	Body comp, psychometrics, & BS, BP & DL 1RM pre & post the block & at 3- or 5-days post	No ↓ in ISO BS, psychometrics, & body comp. Small ↓ in ISO BP post 5, not 3 days cessation

(Tsoukos et al., 2018)	17 Tr. M POW + team sport athletes	Low-VOL, POW-type Tr. = 5x4x40%1RM jump squats	CMJ, RSI in drop jump, LP max ISO force, & RFD pre, 24, & 48hrs post	Low-VOL, POW-type Tr. = > CMJ, RSI, & RFD 24-48hrs post
(Zourdos et al., 2016)	18 M college PL	HYP (3-5x8x75%+1RM), POW (3-5x1x80-90%1RM), STR (3x max reps x85%1RM) vs. HYP, STR, POW. BS, BP, & DL	1RM, total Tr. VOL, & T:C pre & post	HYP, POW, STR = > total VOL in BS & BP, > ↑ in 1RM BP

Training interventions are expresses as sets x repetitions x load/intensity. ↓decrease, ↑increase, ACV average concentric velocity, AR active recovery, BF % body fat percentage, BP bench press, BPT bench press throw, BS back squat, cfDNA cell free DNA, CK creatine kinase, CMJ counter movement jump, CSA cross sectional area, CWI cold water immersion, DL deadlift, DOMS delayed onset muscle soreness, E1RM estimated 1 repetition maximum, ECC eccentric, EMG electromyography, ES electrical stimulation, F female, GH growth hormone, HRC heart rate complexity, HRV heart rate variability, HSP heat shock proteins, HYP hypertrophy, IBP isometric bench press, ILE isometric leg extension, IGF-1 insulin like growth factor 1, IL-6 interleukin 6, IMTP isometric midthigh pull, ISO isometric, KE knee extension, LDH lactate dehydrogenase, LP leg press, M male, MD muscle damage, MPV mean propulsive velocity, MRJ multiple rebound jump, MT muscle thickness, MVC maximal voluntary contraction, NM neuromuscular, PL powerlift-er/ing, POW power, PR passive recovery, PRS perceived recovery status, Reps repetitions, REC recovery, RFD rate of force development, RM repetition maximum, ROM range of motion, RPE rating of perceived exertion, RSI reactive strength index, RT resistance trained, STR strength, T:C testosterone cortisol ratio, Tr. Train-ed/ing), V1 movement velocity against the load that elicits 1 m/s, VAS visual analogue scale, VBT velocity-based training, VL velocity loss, VLa vastus lateralis, VOL volume

Section 4: Discussion

The present narrative review is the first to examine the current evidence regarding the impact of microcycle construction on RT recovery. Synthesising and creating practical recommendations from this body of research may help athletes and coaches understand what variables to focus on and how to manipulate them to enhance adaptation. The main findings of our review are that training to failure, greater training volumes, and exercises with higher eccentric torques, especially when they occur at longer muscle lengths, and when more musculature is trained (i.e., lower body exercises) often increases recovery demands. Further, programming strategies can effectively manage fatigue by strategically planning sessions within the microcycle, prioritising easier or less demanding sessions (or even training cessation) to serve as AR before more intense sessions. This approach may reduce fatigue and improve recovery, leading to acute performance enhancements and potentially fostering long-term adaptations.

In the following sections and sub-sections, studies which inform specific approaches to microcycle construction for recovery enhancement are reviewed to inform future coaching practice.

Influence of Resistance Training Variables on Recovery

There are many factors to consider when designing a RT program. When emphasising recovery within a microcycle, proximity to failure, training volume, and exercise selection all can determine the amount of recovery needed after a training session.

Proximity to failure

Traditionally, it has been recommended that RT sets be performed to muscular failure to maximize strength gains and hypertrophy; however, recent meta-analyses have reported no significant differences for muscular strength or hypertrophy (Grgic et al., 2022; Refalo et al., 2023). Importantly, training to failure has also been found to elongate recovery time courses and elicit greater perception of fatigue compared to not training to failure; leading to performance

impairments (Vieira et al., 2021). In comparing three sets of eight repetition to failure with three sets of four repetitions at 80% of 1RM in the squat and bench press, less fatigue, faster recovery and mean velocities were observed with the latter approach, leading to reduced hormonal response, muscle damage, and less impact on HRV and complexity (González-Badillo et al., 2016). Similar results were observed but with three sets of six vs. twelve repetitions at 70% of 1RM (Pareja-Blanco et al., 2016) and across a variety of set configurations (Pareja-Blanco et al., 2020) in the squat and bench press. Certain variables such as the CMJ returned to baseline as soon as six hours post training in the non-failure groups whereas CMJ performance remained reduced up to 48 hours in the failure group.

Notably, in each example, proximity to failure was manipulated with a static number of sets and load, leading to lower volume in the non-failure comparisons, warranting further volume-equated investigation. However, in such subsequent comparisons when volume was equated, training to failure still increased recovery demands. For example, metabolic markers of fatigue and low, medium, and high load strength performance required 24-48 hours longer to return to baseline in a group completing three sets of 10 repetitions to failure compared to six sets of five repetitions with the same load (Morán-Navarro et al., 2017). Therefore, even when volume is equated, a closer proximity to failure has an independent impact, elongating the time course of recovery.

Another common way to prescribe RT load and volume is via velocity-based training (VBT). Load can be prescribed by targeting a specific mean concentric velocity on initial repetitions in a set, and the subsequent set-volume can then be regulated based on neuromuscular fatigue by stopping a set after a repetition produces a certain amount of velocity loss as the set approaches failure (expressed as a percentage). The approach of VBT may be favoured as it offers a more individualised approach which can help account for the variability seen when using a traditional percentage-based approach (Cooke et al., 2019). Confirming the prior research comparing failure to non-failure training in a VBT model, a 10% velocity loss led to greater back squat, prone row, and bench press 1RM improvements in addition to greater recovery and improved stress levels compared to traditional sets to failure with 80% 1RM in one study (Held

et al., 2021). When examining 15 vs 30% velocity loss in the leg press and leg extensions, no statistically significant differences between increases in strength or muscle thickness were observed (Andersen et al., 2021). However, a recent review with meta-analysis reported when sets and relative intensity were equated, velocity loss thresholds ≤25% were superior for promoting strength potentially due to minimising acute neuromuscular fatigue while maximising chronic neuromuscular adaptation. Conversely, velocity loss thresholds > 20-25% were superior for promoting hypertrophy by accumulating greater relative volume (Hickmott et al., 2022). Importantly, upon further analysis, it seems that if velocity losses >20% are compared when set volume and relative load are equated, differences in volume load have little to no additional impact on muscle hypertrophy. Rather, other factors such as neuromuscular fatigue may preside over the influence of proximity to failure on muscle hypertrophy for different velocity loss thresholds (Refalo et al., 2023). Therefore, given the totality of data on VBT, while higher thresholds may produce slightly more hypertrophy on average (Jukic et al., 2023), it is important to consider the individual response to different velocity loss thresholds as proximity to failure can vary substantially (Jukic et al., 2023). Further, when considering their implementation within a microcycle, a session using higher velocity loss thresholds may potentially result in greater fatigue and recovery times, especially when those thresholds result in training closer to failure.

While performance, hormonal response, and more objective measures give important insight into recovery, perceptual responses must be considered as they also influence how an individual approaches a training session. Specifically, when comparing sets to failure vs not to failure across four sets in the back squat, training to failure resulted in more repetitions during the first set and non-failure training resulted in more repetitions on the last set with total repetitions across all sets being similar (Santos et al., 2018). Despite total repetitions being similar between groups, velocity across all repetitions in the non-failure condition group were faster and self-reported exertion and discomfort were greater in the failure condition. Therefore, with similar performance outcomes and higher RPE and discomfort reported, it is apparent that training to failure imposes an extra perceptual recovery demand which should be considered when designing training micro- and mesocycles.

Overall, training to failure can increase recovery times, potentially negatively impacting subsequent performance on high priority sessions. Such an impact warrants careful consideration of training stress allocation when programming. However, training to failure may have a time and place if implemented with caution. Specifically, if enough time is given between sessions involving the same muscle groups, adequate recovery may be achieved, minimising any potential negative consequences. Application of failure training may be more feasible in isolation movements involving less musculature (i.e., leg extension vs leg press) (Dourado et al., 2023), machine-based exercises as opposed to high-skill, demanding barbell movements (Haff, 2000; Saeterbakken & Fimland, 2013), or that emphasise shorter muscle lengths (Nosaka & Newton, 2002), as each may have lower recovery demands. Additionally, one could perform only the last set of an exercise for a given muscle group at the end of the session to failure so as to not have fatigue bleed into subsequent exercises of that session. If applied appropriately, training to failure in such a manner could not only yield an increased stimulus, but may help individuals accurately gauge their RPE in subsequent training by better anchoring the point of muscular failure. However, further research is required to determine exactly how far from failure one can be to balance stimulus and stress, for which movements, and in what time course relative to high priority sessions to maximise such outcomes.

Volume

Training volume also plays a significant role in training outcomes, particularly for hypertrophy (Currier et al., 2023); however, more may not always be better and may come at a cost. When comparing 12-20 sets per muscle group per week to 20+, there were no significant differences in muscle hypertrophy for most muscle groups (Baz-Valle et al., 2022). Practically, if similar results can be obtained with roughly half of the work, one must consider the potentially greater fatigue accumulation from higher volume sessions and whether the – at best – marginal improvements in adaptation are worth the cost of an increased recovery time course between sessions and any negative impact on subsequent performance.

Notably, high volume training is not performed in a vacuum. Its effects interact with proximity to failure. For example, when volume is equal between conditions, similar outcomes in hypertrophy are typically seen with strength largely moderated by load (i.e., higher loads leading to better strength improvements) (Andersen et al., 2021; Carvalho et al., 2022). Indeed, while a reasonably strong (albeit non-linear) dose response between higher set volumes and hypertrophy exists (Schoenfeld & Grgic, 2018), the relationship between higher set volumes and maximal strength is trivial to small (Ralston et al., 2017).

When the goal is increasing maximal strength, given the relatively minor impact of volume on adaptation, the impact of higher volumes on recovery should be considered. For example, when comparing an acute bout of high volume, moderate load with short rest training to moderate volume, high load with longer rest training, various measures of muscular strength and power decreased significantly more and for a longer period of time after such high-volume training (Bartolomei et al., 2017). Similarly, as discussed, high volume, high velocity loss training results in greater neuromuscular fatigue and recovery times compared to high load, high RPE training with various set configurations (Pareja-Blanco et al., 2020; Pareja-Blanco et al., 2019).

Overall, within a microcycle, specific consideration should be given to proper volume allocation as greater volumes within a session may impose greater recovery demands. Specifically, if higher volume sessions are to be introduced, proper placement of these sessions must be considered as inadequate recovery times may impair performance in subsequent sessions. A wide range of 10-20 sets per muscle group per week is associated with superior hypertrophy (Baz-Valle et al., 2022; Schoenfeld & Grgic, 2018) and a wide – albeit lower – range of 5+ sets per movement per week is associated with superior strength gains (Ralston et al., 2017), demonstrating that higher volumes may have utility, on average. However, the individual response to higher or more moderate volume is notable (Damas et al., 2019). Thus, like training to failure, high volume training should be implemented with caution and purpose. Specifically, higher volumes could be implemented for a certain muscle group or movement in a “specialisation phase” while volume is brought to lower or “maintenance” levels for other muscle groups or movements of interest. Such a strategy may prevent the accrual of excess fatigue while increasing

the stimulus on the target muscle group/movement. Further, to avoid exceeding individual volume tolerances, it may be wise to err on the lower end of volume prescriptions initially, assess recovery, then if needed gradually increase volume on specific days of the microcycle while accounting for the likely increased recovery time course impacting subsequent days. Finally, the additive effects of higher volume and closer proximity to failure should be considered, as this relationship requires further empirical exploration, as their combination may compound fatigue and recovery demands if implemented inappropriately.

Exercise Selection

While the relationship between volume, fatigue, and adaptation has been examined as total working sets performed per week in recent meta-analyses (Baz-Valle et al., 2022; Ralston et al., 2017; Schoenfeld et al., 2019), *how* that volume is performed (i.e., how frequently it is distributed within the week and with what exercises) may moderate this relationship. Indeed, in four recent meta-analyses, three assessing the impact of how frequently exercises are performed in a week on maximal strength gains (Cuthbert et al., 2021; Grgic et al., 2018; Ralston et al., 2018) and one examining the impact of how frequently muscle groups are trained in a week on hypertrophy (Grgic et al., 2019), there was a positive relationship between higher frequency training and adaptation. However, this was only when higher frequency training led to higher volumes, with the effect diminishing or disappearing in volume-equated sub analyses. Indeed, the authors of these analyses suggest that training frequency can be looked at as a tool to allocate weekly training volume in an appropriate manner, facilitating more efficient, high-volume training by allowing inter-session recovery (Grgic et al., 2019; Ralston et al., 2018; Schoenfeld et al., 2019). Thus, frequency manipulation may be used decrease fatigue accumulation and allow for adequate recovery throughout the microcycle. However, it is important to consider the type of exercise used to accumulate volume as this may influence the time required to recover.

Specifically, when comparing lower versus upper body exercises, greater recovery times are needed for the lower body (48-72 hours) compared to 24 hours or less for the upper body (Bartolomei et al., 2017; Belcher et al., 2019; Lewis et al., 2022; Raeder et al., 2016). However,

even within the lower body, differences between exercises can be observed as greater impairment of functional performance and delayed recovery of muscle edema was reported in the leg press compared to knee extensions (Dourado et al., 2023). This suggests that multi-joint movements may require additional recovery times perhaps due to the greater amount of musculature involved, the subsequently higher absolute loads used, and greater coordination demands (Haff, 2000; Saeterbakken & Fimland, 2013). The degree to which exercise selection impacts recovery may vary depending on how the microcycle is organised (i.e., upper/lower split vs. full body, etc.), how other training variables are manipulated, and the goals of the individual as these aspects operate interdependently, but nonetheless, exercise selection warrants specific consideration.

Another way to categorise movements is by the type of contraction and the portion of the length-tension relationship in which they primarily operate. Notably, when comparing full to partial range of motion (ROM) training, while full ROM training produces greater strength and hypertrophy than partial ROM training at shorter muscle lengths, partial ROM training at longer muscle lengths may produce similar if not slightly superior muscular adaptations to full ROM training (Wolf et al., 2023). With that said, higher volumes with exercises that produce high versus low eccentric torques at long versus short muscle lengths resulted in more severe exercise induced muscle damage (Nosaka & Newton, 2002). Thus, while such exercises, contraction modes (i.e., eccentric training) or performance techniques (i.e., purposeful long-muscle length partial ROM training) may enhance the stimulus of training, they also may increase fatigue, requiring coaches and athletes to consider their placement in a microcycle and monitor and assess recovery.

To conclude, exercise characteristics such as where the highest torque occurs on the length-tension relationship of the trained musculature, contraction mode, total musculature trained, and ROM influence recovery, and thus, should be considered when constructing a microcycle. Specifically, exercises that are lower body focused, multi-joint, more complex, recruit greater musculature, emphasise the lengthened position, and/or emphasise the eccentric portion of the movement should be strategically placed in a microcycle as greater recovery times may be needed following their performance. When implemented, the volume allocated to such

exercises and their frequency can be manipulated to alter the time course of recovery; however, the specific application of such programming decisions will heavily depend on the goals of the individual and the logistical demands of their current training, but nonetheless, warrants consideration.

Influence of Programming on Recovery

After considering how these variables may influence recovery individually, it is important to examine how they interact and subsequently, how this may influence program design. However, such a discussion requires the proper use of terminology: programming versus periodisation (Hammert et al., 2021; Hornsby et al., 2020; Steele et al., 2023). Periodisation can be viewed as having a particular focus (i.e., strength or hypertrophy) for a phase of training (>6 weeks) that fits within the larger overall design (macrocycle), whereas programming involves manipulation of training variables within these phases that in turn, emphasise maximising the desired outcomes (Steele et al., 2023).

When comparing the magnitude of strength gains and hypertrophy between volume-equated periodised and non-periodised strength programs, periodised training led to significantly greater strength gains than non-periodised with no significant differences in hypertrophy, while undulating models produced greater strength gains than linear models in trained individuals (Moesgaard et al., 2022). However, undulating models are arguably programming not periodisation strategies and thus, it is important to examine what specific programming changes may lead to such results to further understand program design. Consequently, one proposed method of undulating programming is to designate a specific focus of training on each day such as strength, hypertrophy, and power (i.e., DUP). When comparing two DUP models with a weekly order of either HSP or HPS across six weeks of training, there were greater training volumes produced in squat and bench press and greater increases in 1RM bench press in favour of HPS (Zourdos et al., 2016). Likewise, a similar DUP approach produced greater improvements in bench press 1RM and pectoral muscle thickness compared to block periodisation (Bartolomei et al., 2023). Therefore, the structure and order of each training session within a microcycle may

have an influence on recovery, and performance in subsequent training sessions, which summate to produce better outcomes over the course of a full mesocycle. These acute programming benefits may be due to greater neuromuscular impairments and recovery times seen after a strength compared to a power session (Helland et al., 2020) and thus, it is speculated that by placing an "easier" day in between two "harder" days as opposed to having two "hard" days in a row, individuals may be able to perform better throughout the week. However, outcomes may vary for individuals based on their training background which can also influence acute responses, thus, warranting sport specific and individual-specific consideration (Kotikangas et al., 2022).

When comparing the effects on strength versus power style back squats on neuromuscular fatigue, heavy loads led to significant reductions in power, maximal voluntary isometric contraction, rate of force development, and evoked peak twitch force while light sessions resulted in no change in power production during, and the least number of decreases in performance post-training (Howatson et al., 2016). Essentially, due to the low fatigue nature of power-type training, individuals may experience better recovery between sessions in a modified DUP model. With that said, these mechanisms were not the specific aim of the aforementioned study, so the underlying mechanistic rationale is yet unclear. Ultimately, regardless of mechanism, it seems the placement and difficulty level of specific exercises or sessions can influence recovery and performance which should be considered when constructing a microcycle.

DUP can be modified to elicit better performance in harder/priority days, while still making easy days purposeful, and productive. However, knowing exactly what easy days should consist of, and how many easy days relative to hard days should be performed, is yet unexplored. Another option besides implementing power days for this purpose is light cardio aerobic sessions, possibly prompting AR better than actual training. However, it is also possible that a priming effect that enhances subsequent day power or strength performance could occur with an appropriately structured light RT power day, or, finally, full training cessation could possibly be the best option in some instances to fully maximise recovery prior to a very challenging session.

Active Recovery

Low fatiguing power sessions may act as a form of AR defined as any form of exercise as a method to improve recovery (Barnett, 2006). Typically, this exercise is of lower volume, intensity, and duration and is performed during the recovery bouts of exercise (Spierer et al., 2004) or during the recovery phase after a training session (Mika et al., 2007). The proposed mechanisms to enhance recovery are reductions in muscle edema, enhanced muscle fibre generation, and a decrease in the inflammatory response from high-demand exercise sessions (Clarkson et al., 1992; Clarkson & Sayers, 1999; Peake, Neubauer, et al., 2017). AR is an effective technique for improving recovery after physical exercise (Dupuy et al., 2018); however, few studies have examined the effects of AR after RT. Compared to CWI, AR consisting of low intensity cycling had similar effects on the inflammatory response following high-volume lower body RT (Peake, Roberts, et al., 2017). Consequently, if recovery was similar, then opting for AR may be preferred due to ease of implementation, accessibility, and to avoid the potential negative effects that repeated CWI may have on muscle hypertrophy (Fyfe et al., 2019; Roberts et al., 2015).

Low-volume power-type sessions are a common way to prescribe AR in RT. Specifically, when an upper body exercise session was performed the day after a lower-body workout, recovery rates of strength performance were improved compared with PR, with positive outcomes attributed to changes in microvascular blood flow and increased concentrations of anabolic hormones after exercise (Abaidia et al., 2017). Importantly, there were also no observed negative effects due to the inclusion of an upper body session after a damaging lower body session, indicating the potential utility of placing sessions which train different muscle groups in close proximity to one another as means of AR. However, it is important to monitor individual responses as total body and/or mental fatigue may linger, potentially impairing subsequent performance (Kotikangas et al., 2022). Another method of implementing AR, rather than training a different exercise or muscle group, is training the same exercise, but far lighter. For example, light bench press AR sessions performed 6 and 30 hours after a high-volume exercise protocol accelerated reductions in pectoralis major muscle swelling compared to a PR group whose pectoralis major muscle thickness was still significantly increased from baseline 48 hours post-

training (Bartolomei et al., 2019). While these results show promise, and could plausibly enhance adaptation longitudinally, practically, the study protocol of 5 sets of 10 repetitions with 10% of 1RM may not be feasible for certain exercises and other ecologically valid options should be explored.

Overall, AR could take the form of training opposing muscle groups on back-to-back days, or could consist of light aerobic cardio sessions or low-volume power-type RT, all of which may enhance recovery compared to PR. When choosing a modality that involves similar muscle groups or exercise patterns, the proposed mechanism of recovery enhancement is enhanced blood flow to the designated area. However, appropriate volumes and intensity of AR are crucial, as improper manipulation of training variables may lead to exercise being too taxing, and counterproductive (Zarrouk et al., 2011). As the exact volume, intensity, and frequency of AR is not yet well understood, further research is needed to develop specific guidelines for application.

Is it priming, recovery, or simply training cessation?

When exploring the effects of AR, the question to whether results are due to dissipation of fatigue or a potential "priming" effect, or both, warrant consideration. While, the idea of RT performed 24-48 hours before a competition "priming" performance is proposed in textbooks, research on the efficacy of this concept is limited (Mujika, 2009; Raastad & Hallen, 2000). Such proposed benefits have been attributed to post activation potentiation (PAP), the increase in muscular contractile capacity following a high intensity voluntary contraction (Wyland et al., 2015). Thus, the rationale of what causes the outcome of "priming" (i.e., an acute performance enhancement) is that a low volume RT session may result in not only improved recovery, but also a short-term supercompensation of explosive strength performance (Bishop et al., 2008). However, such speculation is relatively unexplored, and further investigation is needed. With that said some evidence does support this theory, as Tsoukos and colleagues (Tsoukos et al., 2018) examined the delayed effects of a low-volume, power-type training priming session on explosive performance 24 and 48 hours after priming. This priming session, consisting of jump squats of 5 sets of 4 repetitions with 40% of 1RM, led to the greatest increase in explosive muscle

performance 24 hours post-session. While these results are intriguing, jump squats are not typically programmed for those with the goal of increasing hypertrophy and strength. Thus, future work should see if priming with greater specificity confers similar or improved benefits, with increased ecological validity and coach/athlete buy-in.

To determine if AR has utility primarily via recovery and not priming, however, it is important to examine whether similar outcomes can be observed by strategically decreasing training demands via tapering or training cessation. When comparing a step vs exponential taper, enhanced skeletal muscle adaptations and neuromuscular performance have been observed (Travis et al., 2021). Additionally, Pritchard and colleagues (Pritchard et al., 2018) demonstrated that taking either 3.5 or 5.5 days off resulted in significant improvements in CMJ height and isometric bench press relative peak force with no significant differences between the two periods. However, maximal lower-body strength was preserved, but not enhanced, during 3 and 5 days of training cessation while upper body strength slightly decreased after 5 days of training cessation in another study (Travis et al., 2022). Therefore, it is possible that the positive effects of training cessation on max strength expression only last so long, are likely due to short term decreases in neuromuscular fatigue and improved recovery, and suggest that a gradual decrease in volume or a short-term cessation of training may be a strategy to consider when constructing micro- and meso cycles. However, it's possible such strategies might be further improved if combined with priming.

Consequently, implementing AR within microcycles in a purposeful manner may allow for improved recovery and subsequent performance increases as a result of a potential PAP priming effect. However, the specific window of time, exercises, and prescription guidelines for combining priming AR sessions and training cessation or tapers requires further investigation. However, theoretical approaches based on existing data can be proposed. For example, at the end of a 4-week meso cycle, a taper could commence in the fourth week, with a priming session on the second to last day of the week, followed by 1RM testing the following day. Similarly, instead of a taper, in the fourth week training could be reduced from five days per week to two, with the first three days being skipped, and the last two consisting of a priming day and a 1RM testing

session the following day. However, these suggestions are speculative, as it is unclear, based on the current research, how to manage such programming strategies in a systematic manner.

Limitations and Considerations for Future Research

There are several limitations that should be considered when interpreting or applying the herein discussed concepts. While a systematic approach was adopted to select the current studies, this review is in a narrative format. The narrative style was chosen to provide a more descriptive approach of the literature and propose more practical applications, but the current literature is not yet at a confidently prescriptive stage. Ultimately, this review focuses on the ecological validity of the proposed topic and how individuals may utilise this information in their own training practices. The studies included vary in terms of population, training protocols, and measurement techniques which may influence the generalisability of the findings. Due to studies being conducted in controlled laboratory settings, extrapolating these findings to real world training settings requires careful consideration as numerous variables may influence outcomes. Individual responses to training outcomes are also widely documented (Bamman et al., 2007; Hubal et al., 2005); therefore, any application from this discussion should be considered within the context of an individualised approach. Practitioners are advised to monitor objective and subjective individual athlete data to determine the success or lack thereof of any novel recovery strategy, and such monitoring should dictate subsequent changes to training as appropriate.

Due to the multifaceted nature of recovery, it is often difficult to determine if a specific variable was indeed what caused a result. For example, if studies did not control or monitor sleep, nutrition, or stress, these variables may have influenced outcomes (Bartholomew et al., 2008; Beck et al., 2015; Bird, 2013). Future research should attempt to account for these variables in order to provide additional context and understanding when interpreting results. Limited research exists examining the long-term effects of emphasising recovery when constructing a microcycle. Of the research that exists, recovery is typically not directly assessed but inferred by performance (i.e., repetitions completed, muscle thickness, 1RM, etc.), making the determination of a mechanism or mechanisms impossible. In the future, research specifically examining recovery

and performance over a longer duration, while assessing potential mechanistic causes to delineate the effect of recovery versus priming, is suggested to further enhance our understanding of how these variables influence microcycle construction.

Section 5: Conclusions

While training to failure may lengthen recovery periods, if done so cautiously, training to failure can provide utility. For example, with sufficient time between training sessions which engage the same muscle groups, adequate recovery may occur. Failure training may also be more practical when applied to machine-based exercises rather than high-skill barbell movements, isolation exercises involving less musculature, or exercises that emphasise shorter muscle lengths to reduce recovery demands. Additional consideration should also be given to volume allocation as greater training volumes within a session also increase recovery time. Volume may be most easily quantified as the number of sets per muscle group and/or movement pattern per week, and on average results are optimized in the range of 10-20 sets per muscle group for hypertrophy and a smaller but wide range of 5+ sets per movement for strength. However, individual responsiveness to higher or more moderate volume is noteworthy. Therefore, like training to failure, high volume training should be undertaken with care and purposefully planned. For example, higher volumes could be utilised for a certain muscle group or movement in a "specialisation phase" while volume could be reduced to lower or "maintenance" levels for other muscle groups or movements. This approach could increase the stimulus to the targeted muscle group/movement while preventing the accumulation of undue fatigue. Practically, these concepts can be applied with a DUP format as well, as it may be wise to start on the lower end of volume prescriptions, evaluate recovery, and then, if necessary, gradually increase volume on particular days of the microcycle where the increased recovery time won't unduly impact subsequent days. Importantly, the additive effect of higher volume and closer proximity to failure should be accounted for as this combination may compound fatigue and recovery demands if implemented inappropriately. However, further research is required to enhance the understanding of their interaction.

Frequency may be viewed as a tool for disseminating weekly training volume to manage fatigue and allow for adequate recovery during the microcycle. For example, instead of designating a large amount of volume in one session for a specific muscle group or movement, it can be spread across two or three. Additional consideration should be given to exercise characteristics as those that target the lower body, involve multiple joints, recruit greater musculature, emphasise the lengthened position, and/or eccentric portion of the movement may require greater recovery times. Thus, greater volumes and/or exercises with such characteristics placed further away from sessions of priority may lead to less fatigue accumulation allowing for maximal performance on that day. A DUP format whereby low-volume power-type or aerobic sessions placed between more demanding sessions may improve performance in such priority days. This may be viewed as a form of AR and/or synergistically invoke a possible priming effect that improves subsequent day power or strength performance. Practically, training opposing muscle groups or selecting low-fatiguing modalities that involve similar muscle groups or exercise patterns on consecutive days may improve recovery via enhanced blood flow. For example, a light cycling or upper body session prior to a lower body session would likely not result in high enough fatigue levels to impair performance on the subsequent day. Furthermore, tapering and cessation of training may be used in conjunction with priming sessions to allow for maximal performance on testing sessions. For instance, a taper or reduction of training may begin on the last week of a mesocycle with a priming session placed one or two days prior to the day of testing. However, the exact volume, intensity, frequency, and specific window of time of AR and implementation of such programming strategies are not well understood, therefore, further research is necessary to provide specific guidelines for application.

Chapter 3 An Examination of Coaches' Perceptions of Recovery in Designing Resistance Training Mesocycles

Submitted to the European Journal of Sport Science (In review)

Prelude

The review of the literature (Chapter 2) unveiled that manipulating RT-variables impacts the time course of recovery and performance within a microcycle of training. Specifically, training to failure and high-volume sessions may lengthen recovery periods, especially for exercises targeting the lower body and engaging multiple joints. Additionally, training frequency manipulation may serve to manage fatigue and ensure adequate recovery. Finally, the related concept of altering session configuration, such as adopting a DUP approach by allocating lower-volume/intensity sessions between more difficult sessions, may have merit. However, it was unknown as to what degree these research-based strategies are used by coaches in the field, and how they are implemented. Therefore, priority for this thesis was given to investigating the beliefs of coaches who design RT programs regarding the importance of recovery and how these beliefs influence RT program design. To capture these data, the following anonymous survey was conducted.

Section 1: Introduction

RT is commonly performed to enhance athletic performance (Kraemer & Ratamess, 2004). In strength focused sports such as powerlifting and strongman, the primary goal is to improve the ability to produce maximal force (Pritchard, 2015). Increases in maximal force may also improve power, thus, RT is often also used by athletes participating in other sports such as weightlifting, throwing, jumping, and sprinting (Suchomel et al., 2016). For physique sports such as bodybuilding, the goal of the athlete is to attain a level of muscularity and leanness which determines the overall outcome of their competition as opposed to specific athletic performance (Mitchell et al., 2018), but which requires RT that places an emphasis on muscular hypertrophy (Alves et al., 2020).

Strategic and purposeful blocks of training built around the competition schedule which are systematically programmed (i.e., periodisation) (Fleck, 1999) may be important for improving performance. Sustained blocks of training lasting anywhere between three to eight weeks are typically referred to as "mesocycles" with each individual week being considered a "microcycle" (Mujika et al., 2018). Furthermore, when completing continuous progressive training, increases in fatigue are likely, warranting careful consideration of recovery. In RT, "recovery" is often referred to as the ability to meet or exceed performance in a particular activity following training (Bishop et al., 2008). Thus, if an athlete experiences inadequate recovery, there may be a temporary reduction in force production (Brown et al., 1997), performance (Burt & Twist, 2011), and a potential increased risk of injury (Cheung et al., 2003), justifying the need to balance training stress and recovery.

The inclusion of "deload" weeks between mesocycles of training is one proposed strategy for fatigue management (Bell et al., 2022); however, the way microcycles are constructed may influence recovery as well. Notably, fatigue may be dependent on the configuration of training; specifically, influenced by the manipulation of variables such as volume (Israetel et al., 2020), load (Redman et al., 2021), and proximity to muscular failure (Refalo et al., 2023). Additionally, exercise selection, range of motion, and whether there is an emphasis on the concentric and/or eccentric phase can influence fatigue (Nosaka & Newton, 2002). Outside of program design, additional consideration must be given to variables such as adequate sleep (Bird, 2013), nutrition (Beck et al., 2015), and stress management (Bartholomew et al., 2008) which also influence fatigue management.

Managing these variables likely requires that monitoring of some form be carried out by athletes and/or coaches. However, the assessment of fatigue and recovery in practice is not a well-established process in strength and power sports, and some of the methods used in sports science literature may not be practical for most due to accessibility, cost, their lab-based nature, or the inherent risk and fatigue from the test itself (i.e., maximal performance tests) (Helms et al., 2020; Raeder et al., 2016). To improve the understanding of how strength coaches monitor and control fatigue, exploring their experiences warrants further investigation (Bell et al., 2022).

Therefore, the purpose of this research was to examine current practices of coaches who create RT programs through an anonymous survey, with a focus on short-term training plan construction. Specifically, the aim was to determine if coaches consider recovery between RT sessions, the importance they give to specific variables that influence fatigue, if, when and how they measure recovery, and how such measurements dictate subsequent changes to future training sessions within a microcycle. This information can provide a framework of existing monitoring practice for other practitioners, and for researchers to empirically evaluate.

Section 2: Methods

Experimental Approach to the Problem

An anonymous online survey was created with the purpose of identifying current practices of coaches responsible for RT programs with an emphasis on recovery and how this may relate to program design. Coaches of all experience levels whether they conduct coaching in person or online were recruited through social media (Instagram). The survey was available from March 30 to April 30, 2023.

Subjects

Inclusion criteria for participation were coaches of at least 18 years of age, involved in the design of RT programs, any level of coaching experience, and coaching either in person and/or online. A survey was considered complete and was included for analysis when at least 97% of the questions were answered. The first page of the survey began with information describing the purpose of the study as well as risks and benefits of participation. Due to the anonymous nature of the survey, participants were notified on the information sheet that by submitting the survey, they were consenting to participate. Additionally, participants were reminded that they were able to cease participation at any time by simply exiting the survey. The research was approved by Auckland University of Technology Ethics Committee, AUTEC Reference number 23/82.

Procedures

Coaches completed a survey consisting of up to a maximum of 48 questions (due to nesting, based on responses) that was created and distributed online using Qualtrics software (Seattle, WA, USA). Definitions for concepts were provided prior to starting the survey for clarity and consistency and are as follows:

- Recovery: the ability to return to baseline performance or beyond; specifically, between sessions
- Fatigue: physical and/or mental exhaustion resulting from exertion causing a deterioration in performance
- Readiness: the ability to meet the physical and/or mental demands required from a training session
- Microcycle: one week of training
- Mesocycle: a "block" of training typically between 3-8 weeks
- Volume: sets per muscle group and/or exercise (i.e., squat, bench, deadlift, patterns) per week
- Load: weight lifted - typically prescribed as percentage of 1RM
- Proximity to failure: repetitions remaining after set completion prior to momentary muscular failure (the inability to complete the concentric phase of a repetition without form deviation)

The survey consisted of four main sections; (a) demographics and background information; (b) opinions on the importance of factors regarding recovery; (c) thoughts on recovery during program design; (d) ways to measure recovery during a microcycle. Background information included questions on the category and training level of individuals coached, coaching experience, and coaching modality (in person and/or online). The section with the opinions on the importance of factors relating to recovery included questions pertaining to program design, sleep, nutrition, stress management, and supplements in addition to whether coaches discussed recovery with their athletes. Answers were given as the importance placed on the questioned topic as: (a) none at all, (b) a little, (c) a moderate amount, (d) a lot, and (e) a great deal. The thoughts on recovery during program design section consisted of questions

related to practices of designing a microcycle of training; specifically, whether or not they used introductory and/or deload microcycles, consideration of individual exercises/movements and their potential impacts on recovery, the role that volume, load, and/or proximities to failure may play on recovery and how such evaluations influence microcycle construction. The section on ways to measure recovery included questions on if/how coaches measure recovery and if/how changes to a microcycle are made based on said monitoring. Additionally, a question regarding the implementation of additional recovery methods outside of training was included.

Statistical Analyses

Only completed questionnaires were analysed. Missing data checks were completed to verify data integrity. Descriptive data were presented as number (n) and percentages (%). All statistical analyses were performed using JASP 0.17.1.0 for Windows (JASP, Inc. Amsterdam, Netherlands).

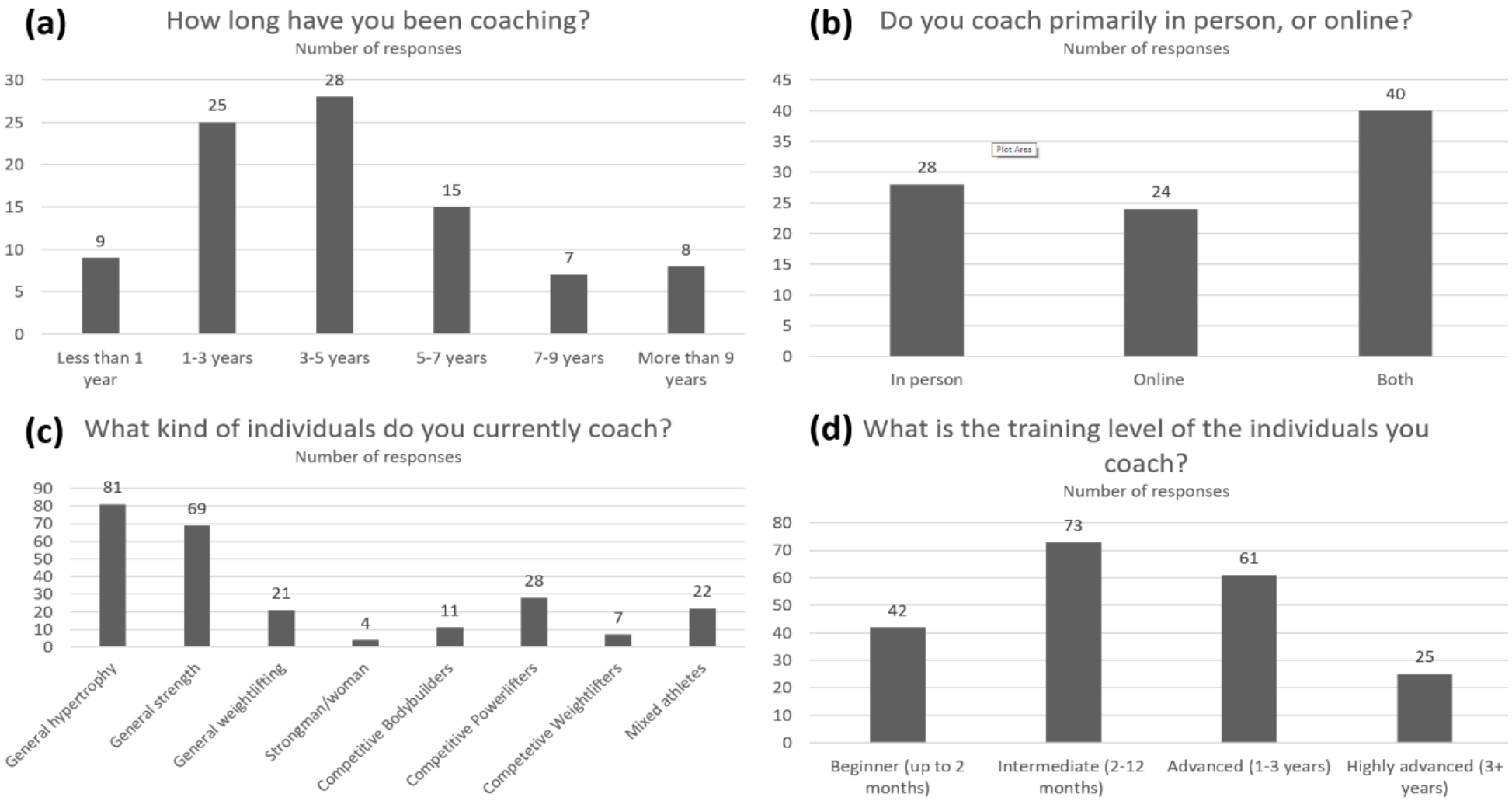
It was possible to select multiple answers for some questions; therefore, the response for some questions could add up to more than 100%. Text answers to "other, please specify" were grouped into common themes/responses by the primary investigator (CS).

Section 3: Results

Characteristics

A total of 148 responses were initially collected; however, after analysing for completion (97% of questions answered), 92 responses were left and included for analysis. Relevant participant characteristics are presented in Figure 3-1.

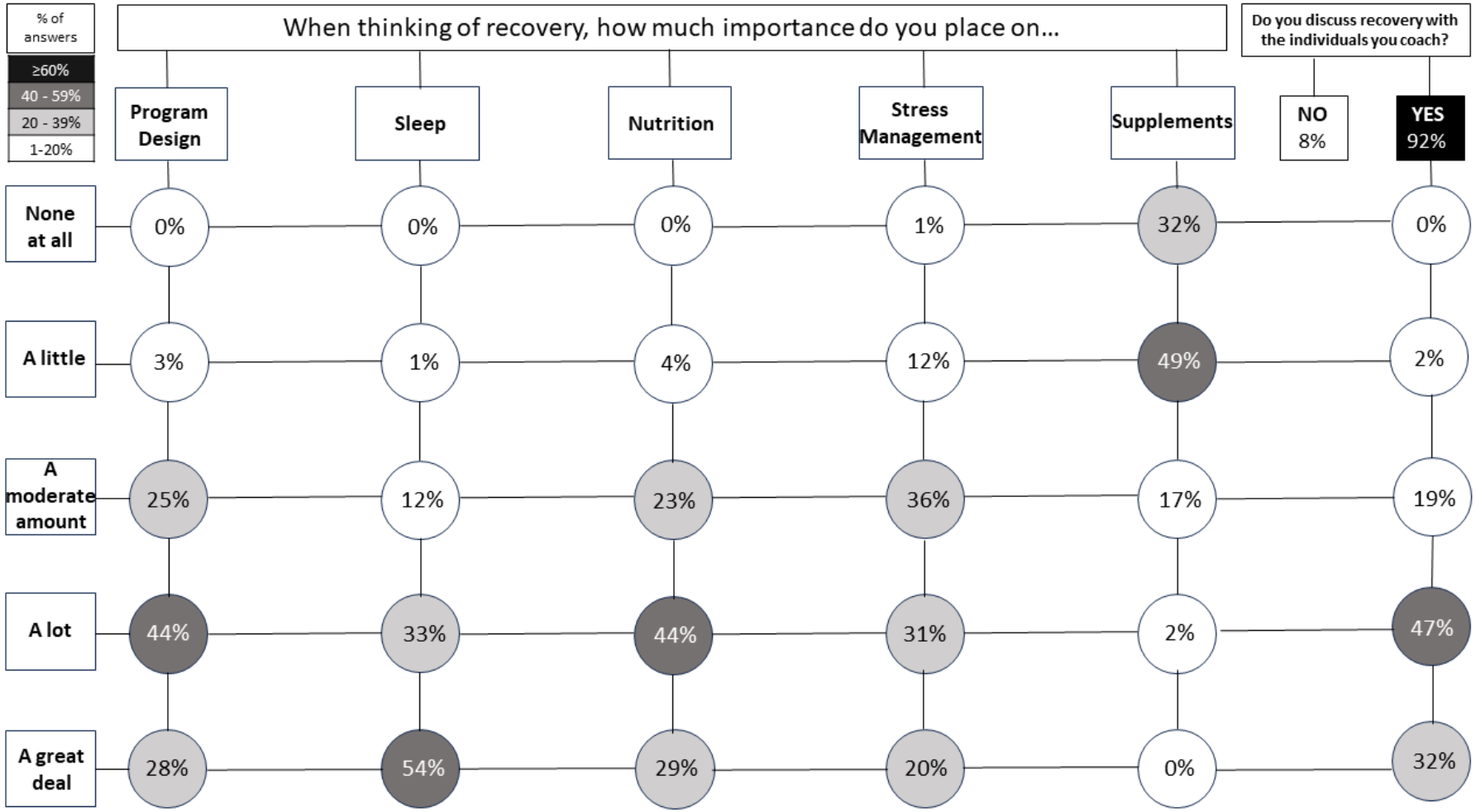
Figure 3-1 Participant Characteristics



Importance Placed on Recovery Variables

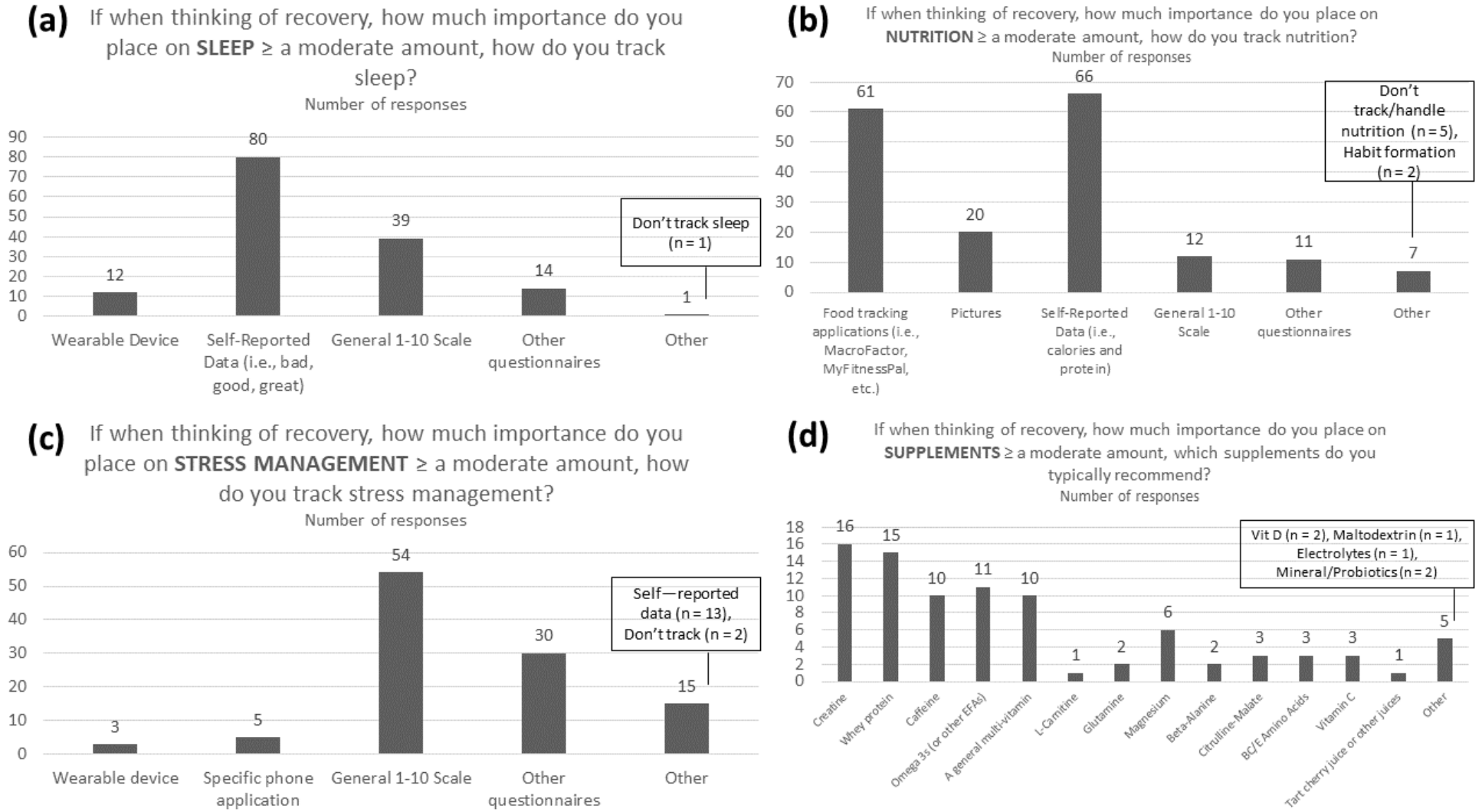
In regards to recovery, for the level of importance placed on "x" variable, the greatest response frequency for program design was "a lot" (44%, n = 40), for sleep, "a great deal" (54 %, n = 50), for nutrition, "a lot" (44%, n = 40), for stress management, "a moderate amount" (36%, n = 33), and for supplements, "a little" (49%, n = 45). The levels of importance placed on recovery variables are presented in Figure 3-2.

Figure 3-2 Importance placed on recovery variables



For those who responded “a moderate amount” or greater regarding the level of importance of variables, follow up questions were asked about how each corresponding variable was tracked. The most frequently reported method for tracking sleep (88%, n = 80) and nutrition (75%, n = 66) was self-reported data, with stress management being tracked on a general 1-10 scale (68%, n = 54). For supplements, respondents were asked which supplements they typically recommended with creatine being most frequent (89%, n =16). The data are presented in Figure 3-2 in detail.

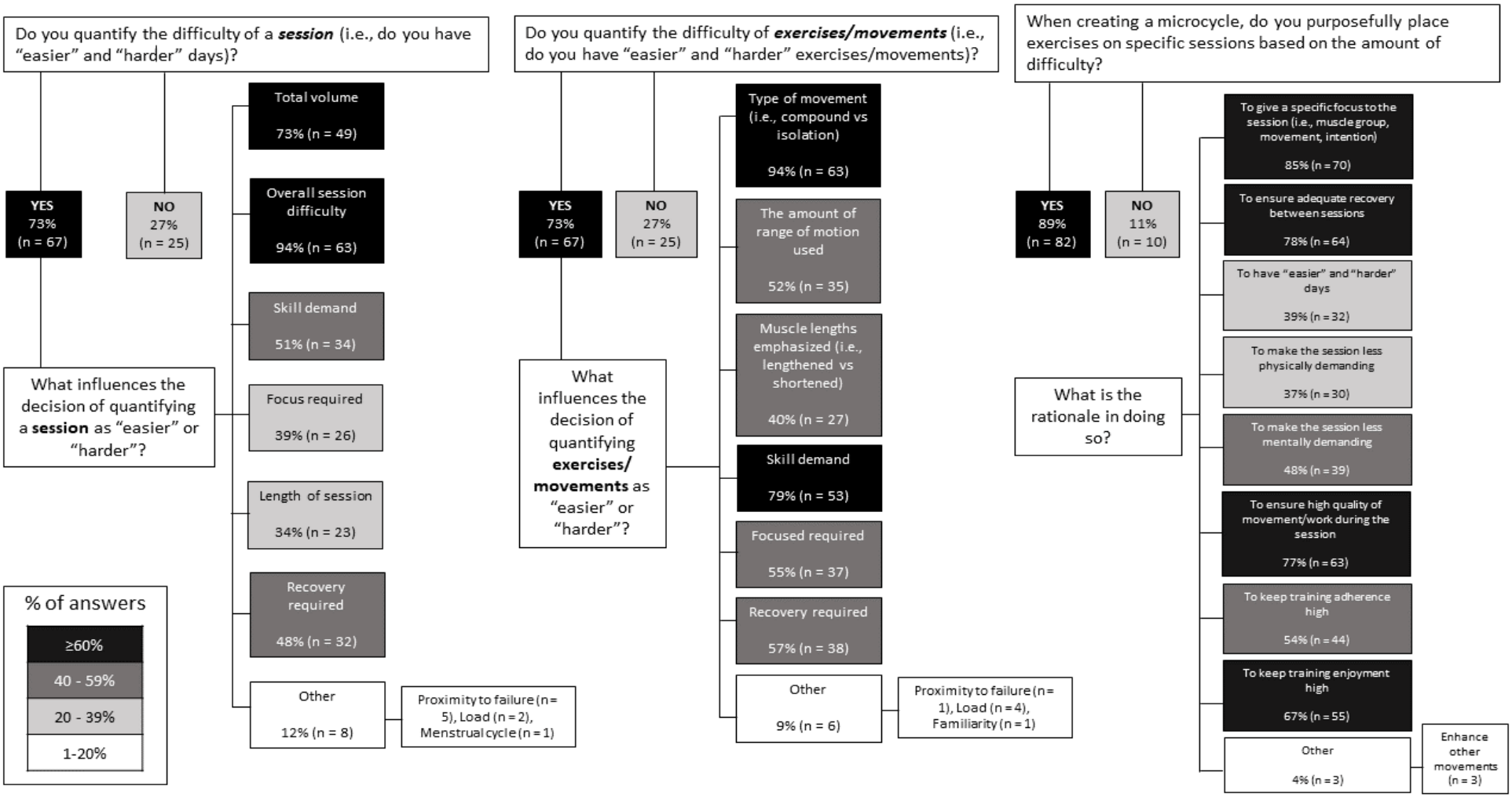
Figure 3-3 Tracking and monitoring of recovery variables



Influence of Recovery on Microcycle Construction

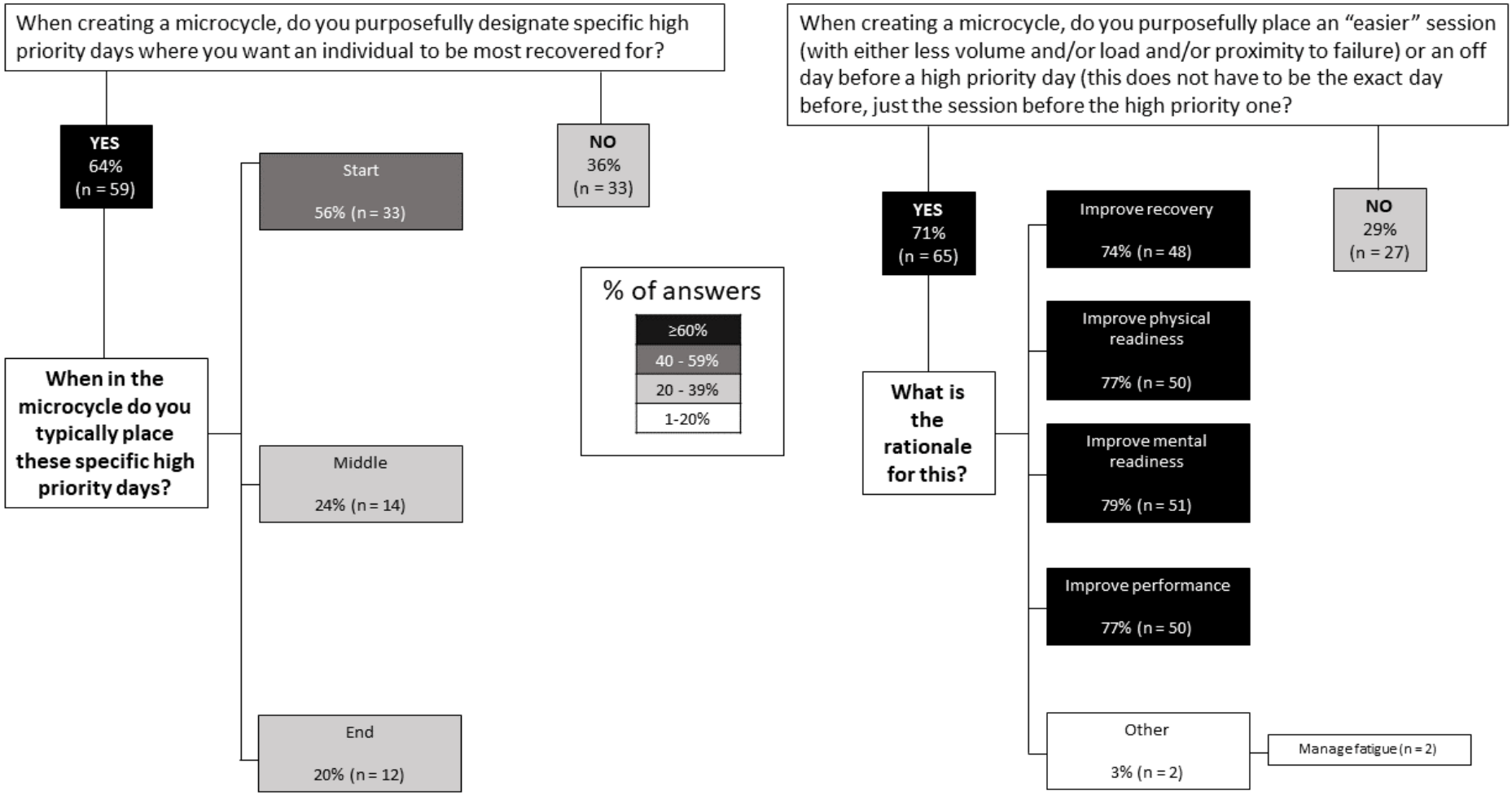
73% (n = 67) of coaches responded yes to quantifying the difficulty of a *session* (i.e., "easier" and "harder" day) followed by a question asking what determines the level of difficulty with 94% (n = 63) of respondents selecting overall session difficulty. Similarly, 73% (n = 67) responded yes to quantifying the difficulty of *exercises/movements* with the most frequent determining factor being the type of movement (i.e., compound vs isolation), (94%, n = 63). 89% (n = 82) responded yes to purposefully placing exercises in specific sessions based on the amount of difficulty when creating a microcycle, with the main rationale to give a specific focus to the session (i.e., muscle group, movement, intention; 85%, n = 70). These results are presented in Figure 3-4.

Figure 3-4 Difficulty of session, exercises, movements, and influence on microcycle construction



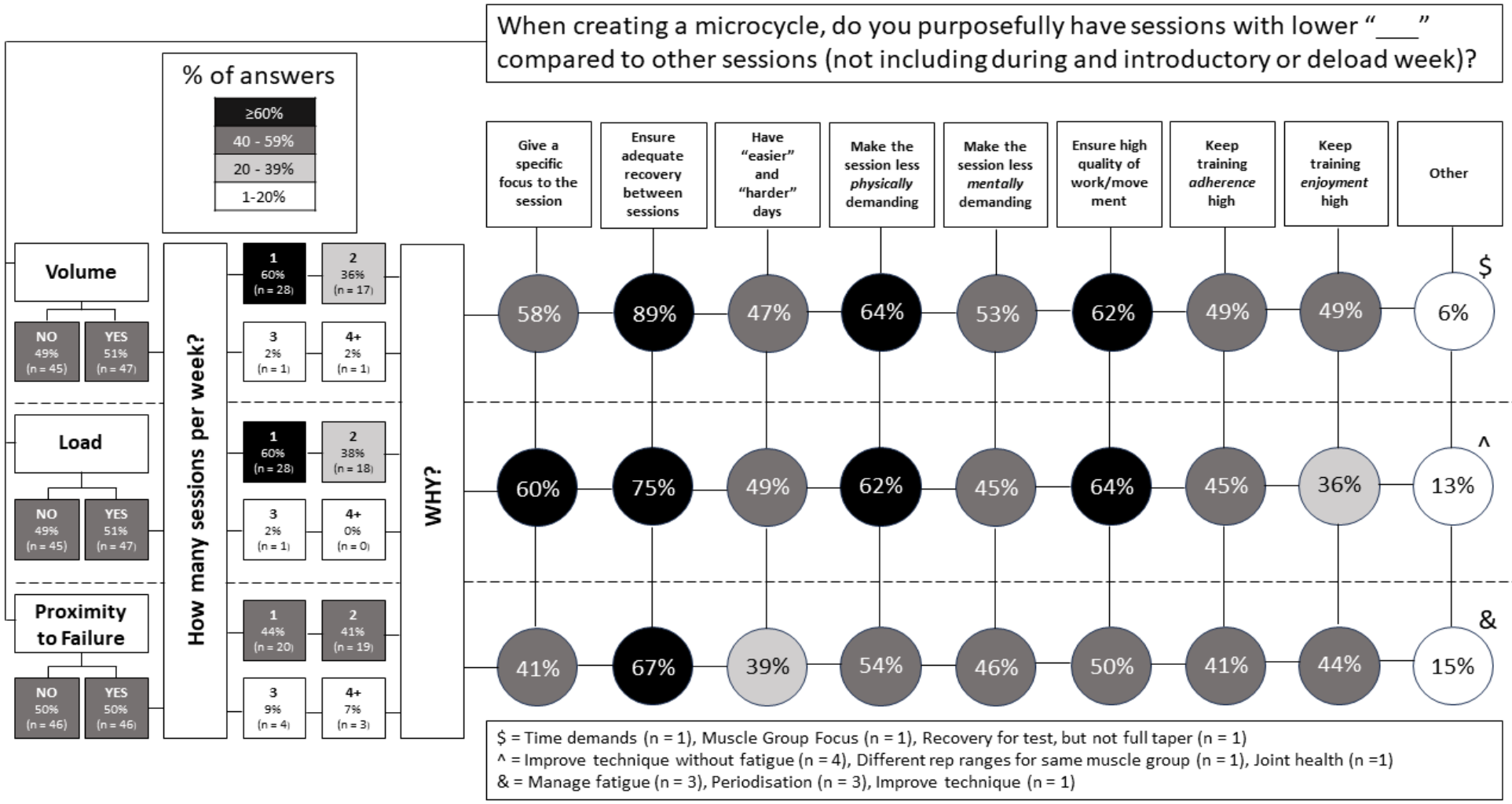
64% (n = 59) of coaches responded yes to purposefully designating high priority days where they want their athletes to be the most recovered, which was most frequently placed at the start of a microcycle (56%, n = 33). Moreover, 71% (n = 65) answered yes to placing an "easier" session or an off-day prior to the high priority day with the main rationale being to improve mental readiness (79%, n = 51). For more information, see Figure 3-5.

Figure 3-5 High priority days and easier sessions



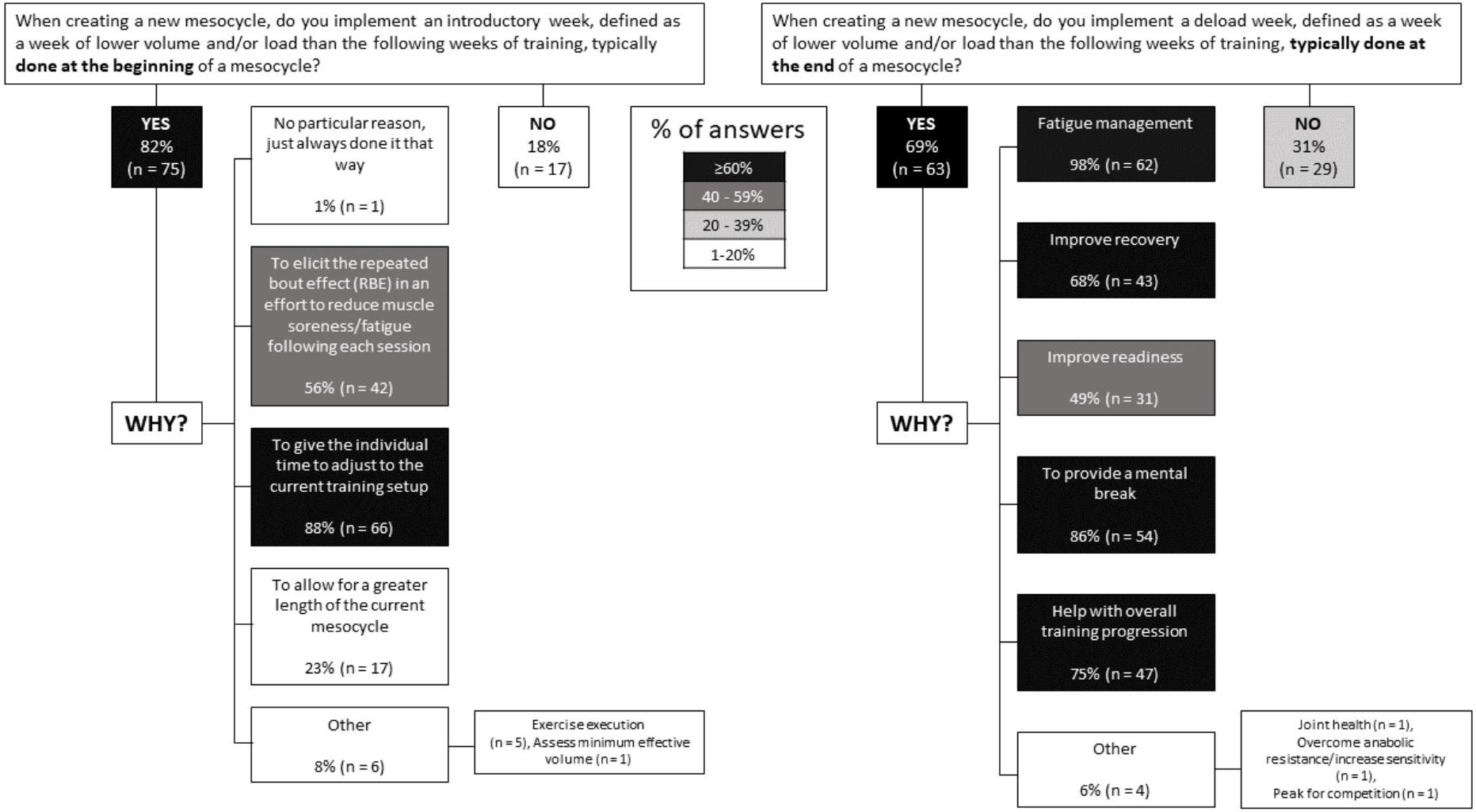
Roughly half of the time, coaches stated that they purposefully include sessions with lower volume (51%, n = 47), load (51%, n = 47) and proximity to failure (50%, n = 46), typically for one session per week (60, 60, and 44%, respectively). The most common rationale was to ensure adequate recovery between sessions, with rates of 89, 75, and 67% of the time for each corresponding variable. These data are presented in Figure 3-6.

Figure 3-6 Sessions with lower volume, load, and proximity to failure



82% (n = 75) answered yes to including an introductory week at the beginning of a mesocycle with the main rationale being to give the individual time to adjust to the current training setup (88%, n = 66). Additionally, 69% (n = 63) of respondents implemented deloads at the end of a mesocycle with the main reason being management of fatigue (98%, n = 62). For more information, see Figure 3-7.

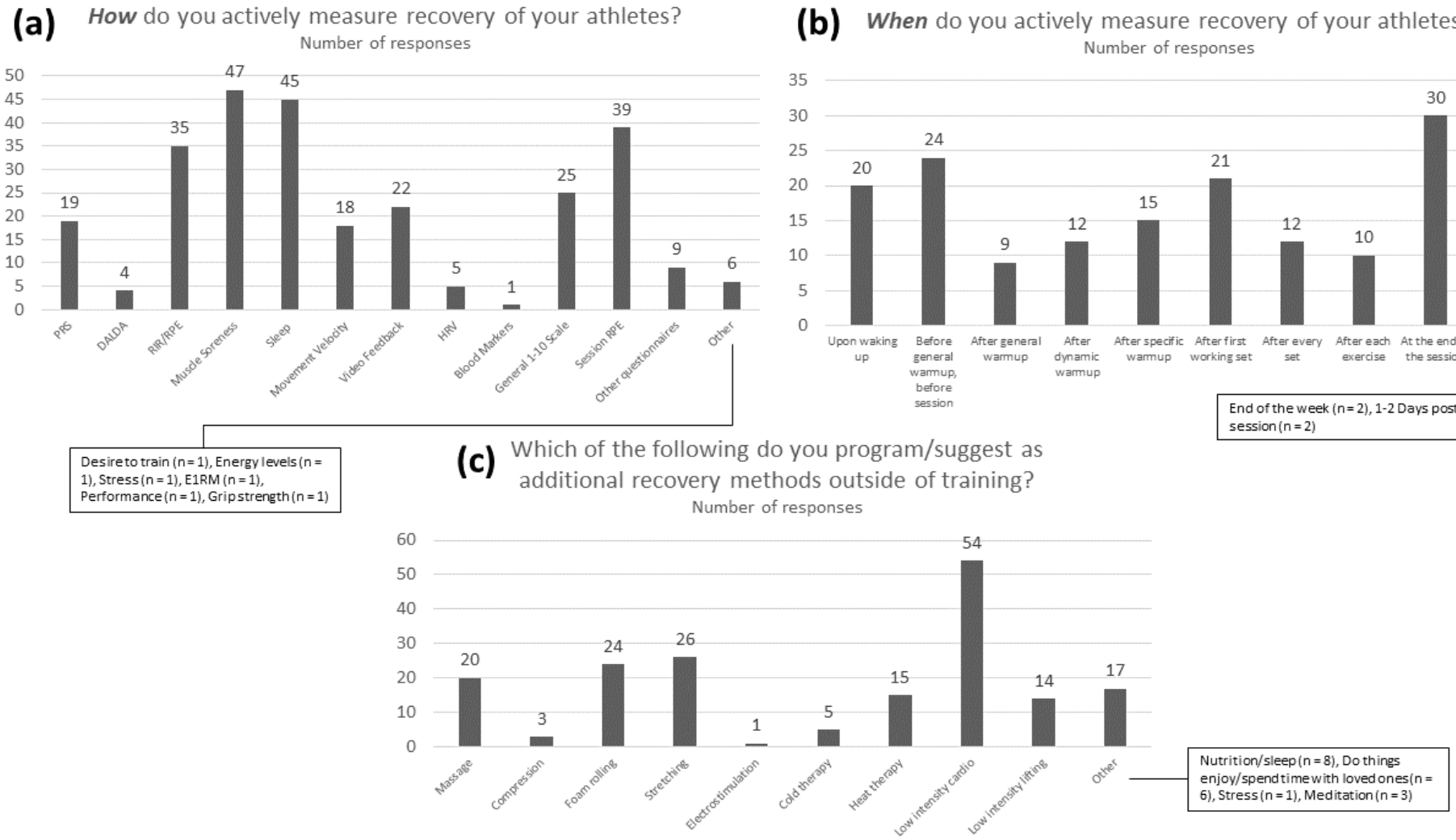
Figure 3-7 Introductory and deload weeks



Measuring Recovery in Practice

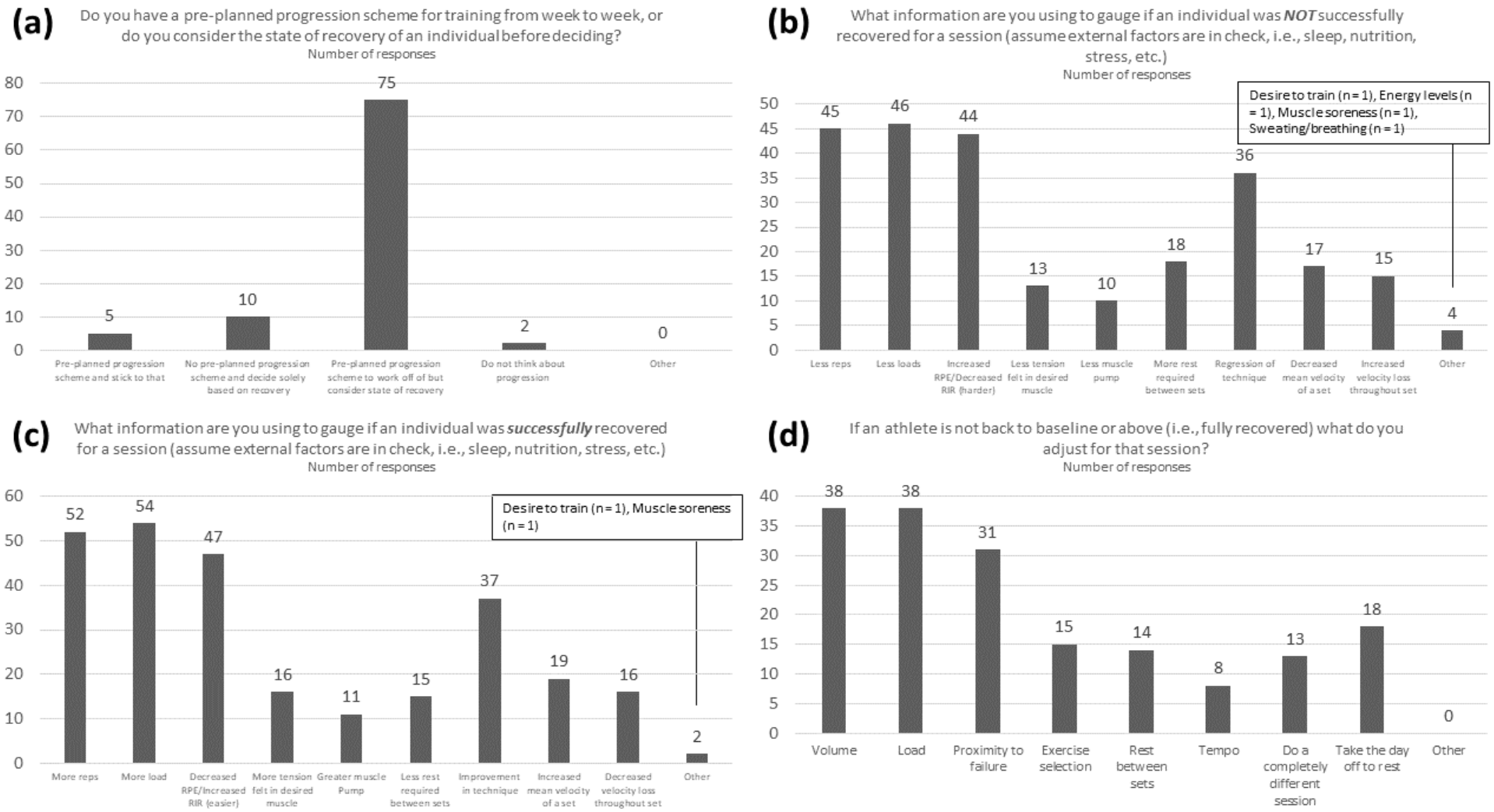
61% (n = 56) of coaches actively measure their athletes' recovery with muscle soreness the most frequently reported metric (84%, n = 47) and measurements mostly collected at the end of the training session (54%, n = 30). 65% (n = 60) suggested/implemented additional methods to enhance recovery outside of training, with low intensity cardiovascular training being most common (90%, n = 54). The results for how and when recovery was measured and the additional methods to enhance recovery are presented in Figure 3-8.

Figure 3-8 Time and means of measuring recovery and additional recovery methods



Respondents who actively measure recovery were presented a follow up question asking what information they used to gauge if an athlete was *not* successfully recovered. The most frequent responses were athletes training with lighter loads (82%, n = 46), fewer repetitions (80%, n = 45), and increased RPE/decreased RIR (i.e., "harder") (79%, n = 44). Conversely, most coaches gauged an athlete as *successfully* recovered when they trained with heavier loads (96%, n = 54) and more repetitions (93%, n = 52). 84% (n = 47) adjust training sessions when athletes are *not* successfully recovered with the primary adjustments coaches make equally distributed between reducing load or volume (both 81%, n = 38). Within a microcycle, coaches primarily used pre-planned progression schemes but considered the state of athlete recovery prior to making decisions (82%, n = 75). Information used to gauge athletes' recovery and subsequent training session adjustments are presented in Figure 3-9.

Figure 3-9 Gauging recovery and subsequent influence on microcycle construction



Section 4: Discussion

This anonymous survey of hypertrophy and strength focused coaches provides the first examination of the perceptions coaches have on recovery, primarily related to RT program design with further data on other aspects of recovery. Given there is a relative dearth of empirical data on best practice for these sports, a better understanding of common coaching practice may facilitate better understanding between sports scientists and coaches, ultimately improving both research and practice (Bell et al., 2022; Grgic & Mikulic, 2017; Pritchard et al., 2016). Notably, sleep, RT program design and nutrition were the primary variables considered and modified by coaches to influence recovery. In terms of importance, sleep was the most commonly modified variable with 54% of coaches attributing it with the highest level of importance (a great deal), followed equally by program design and nutrition, both of which 44% of coaches placed "a lot" of importance on. Importantly, these beliefs have empirical support, as prior research indicates the importance of sleep (Craven et al., 2022; Saner et al., 2020) periodization (Mujika et al., 2018), and nutritional manipulation (Beck et al., 2015) for recovery.

Coaches primarily use self-reported data (88%) to track athletes' sleep, typically gauged on a spectrum of "bad-great" rather than objective data from wearable devices (13%), with some coaches using other subjective methods such as 1-10 scales (43%) and questionnaires (15%) indicating coaches believe that subjective data can be useful for assessing sleep quality. Program design was given "a lot", "a great deal" or a "moderate amount" of importance by 97% of coaches combined, indicating coaches believe well thought out plans for training are important when it comes to managing fatigue. These findings are aligned with the research on periodization of training where there is a balancing act to promote adaptation while managing fatigue (Mujika et al., 2018; Turner, 2011). This importance placed on an appropriately designed program may suggest that one cannot "out-recover" a poorly designed program. Specifically, if variables are not tailored to the individual capacities and needs of an athlete, the

success of the program may be inhibited, regardless of the purported application of scientific theory.

Nutrition exhibited almost identical frequencies to program design with “a lot” of importance being most common (44%), proposing that coaches are in agreement with research regarding the influence of nutrition on exercise performance and recovery (Beck et al., 2015). Nutrition information was primarily tracked by self-report (75%) and food tracking applications (69%), seemingly advocating that quantitative data is most favoured by coaches potentially due to the sensitivity of such data and subsequent effects on performance and recovery. This may be true for all levels of athletes, but even more so for weight class-based strength athletes and bodybuilders who must periodically lose body mass and strategically allocate energy. Additionally, for those who wish to maximize hypertrophy, a calorie surplus is suggested to create a suitable environment for such growth (Slater et al., 2019), further presenting the utility of monitoring nutrition.

Coaches rated stress management at relatively high importance with the most frequent answer being “a moderate amount” (36%) and tracking done primarily by a general 1-10 scale (68%) and other questionnaires (36%). Due to the complexity of stress, simple 1-10 scales may be easiest for both the athlete and coach to use. Importantly, determining when stress is outside of the norm for an individual may be the most useful approach, which simple scales likely suit best. Interestingly, most coaches deemed supplements of little (49%) to no importance (32%) for recovery. While some supplements show promise for being an effective ergogenic aid (Jozo Grgic et al., 2022), in regards to recovery relative to other variables, they may not play as important of a role. These findings suggest that coaches believe priority should be given to the above-mentioned variables and that coaches ensure they are appropriately managed before looking towards supplements for recovery. Finally, and of importance, 92% of coaches discuss recovery with their athletes, highlighting the overall value of communication and education in the coach/athlete relationship.

Most coaches that quantified the difficulty of sessions (73%) did so by evaluating overall session difficulty (94%) as opposed to each individual exercise. Using session difficulty to help determine where sessions should be placed within a microcycle, with a focus of not putting difficult sessions too close together, may be a rationale for this type of monitoring. Total volume (73%) was the second most influential factor, which may be due to the performance impairment and increases in muscle damage which often follow high volume sessions (Bartolomei et al., 2017), warranting careful consideration from coaches. The same number of coaches (73%) considered the difficulty of exercises/movements when evaluating session difficulty, which was primarily influenced by the type of movement (94%). Multi- versus single-joint classifications, together with the perceived skill demand (79%) of a movement indicate that coaches feel movements involving more musculature which mentally challenge the athlete likely increase overall session difficulty. This is in agreement with previous literature which reported greater impairment of functional performance and delayed recovery of muscle edema after the leg press compared to knee extensions (Dourado et al., 2023). Similar frequencies were seen for recovery (57%) and focus required (55%), proposing that coaches believe exercises that are more difficult may require more effort both physically and mentally and therefore greater recovery times (Pareja-Blanco et al., 2020). The quantification of difficulty of exercises seems to greatly influence the decision on where they are placed within a microcycle (89% yes). Rationales for these decisions were to give a specific focus to the session (85%), ensure adequate recovery between sessions (78%), and keep the quality of work high (77%). Additionally, 64% of coaches responded yes to specifically designating high priority days where they want their athletes to be recovered, typically placed at the start of the microcycle (56%). This was often preceded by either an easier or off day (71%) to help facilitate recovery (74%), improve physical (77%) and mental (79%) readiness and performance (77%). Ultimately, data suggest that coaches believe in making purposeful and strategic decisions in an attempt to ensure adequate recovery is achieved and improve performance, especially at the beginning of the week where exercises and/or muscle groups that are most difficult and/or important to the athlete may be placed. Importantly, these answers were given with consideration to the difficulty of the exercises exclusively, but in practice, manipulation of

other variables (volume, proximity to failure, etc.) may influence the overall fatigue induced per exercise which warrants attention.

82% of coaches responded yes to including an introductory week at the beginning of a mesocycle with the main reasons being to give the athlete time to adjust to the current training setup (88%) and to elicit the repeated bout effect to reduce muscle soreness/fatigue (56%). When designing a new cycle of training, new exercises are often implemented which can induce greater muscle damage, affecting subsequent recovery time and performance (Byrne et al., 2004; Clarkson et al., 1992). In an effort to avoid this, coaches believe that a week of lower volume and/or load than the following weeks of training can be utilized to elicit the repeated bout effect to better prepare athletes for subsequent sessions, which is in agreement with previous literature (Chen et al., 2007; Nosaka et al., 2001). Similarly, at the end of a training cycle, 69% of coaches utilize deload weeks of lower volume and/or load with the primary aim of managing fatigue (98%). Additional reasons include providing a mental break (86%), to help with overall training progression (75%) and improve recovery (68%). This is in agreement with recent data from a qualitative interview study on coaches' beliefs about deloads where they indicated that a flexible and individualized approach be taken to manage fatigue, improve recovery, and assist in desired training outcomes (Bell et al., 2022).

Roughly half of coaches responded yes to purposefully having sessions with lower volume (51%), load (51%), and proximity to failure (50%). For all three variables, the main reason was to ensure adequate recovery between sessions (89%, 75%, and 67%, respectively). Coaches' concerns regarding recovery demands were greater for volume than for load and proximity to failure which align with previous literature suggesting that high volume exercise requires greater time to recover from compared to high intensity (Bartolomei et al., 2017). Including one session per week with lower volume and load was most frequent (60%) whereas one (44%) and two (41%) sessions for lower proximity to failure were favoured by coaches. Choosing two sessions of lower proximity to failure within a week may be due to popular, recent, and ongoing discussions regarding training to failure with seemingly equivocal data or rather, a variety of interpretation and proper application (Refalo et al., 2023; Robinson et al.,

2023). Nonetheless, coaches believe that all of these variables are likely important to consider and adopting an individualized approach with attention given towards subsequent effects on recovery and performance is suggested.

The majority of coaches (61%) currently monitor the recovery of their athletes with the most common methods being via muscle soreness (84%) and sleep (80%). These responses are understandable, as the negative effects of elevated muscle soreness and insufficient sleep are well documented (Craven et al., 2022; Peake, Neubauer, et al., 2017; Saner et al., 2020). Additionally, session rating of perceived exertion (sRPE, 70%) and the repetitions in reserve-based rating of perceived exertion scale (RIR/RPE, 63%) were frequently cited methods of monitoring recovery. The utility of sRPE is well documented; specifically, it is a valid representation of higher workloads, intensities, and greater physiological stress responses and its simplicity allows clear and concise ratings for overall session difficulty to be summed, recorded, and compared to other sessions (Haddad et al., 2017). As for RIR/RPE, these values may provide more specific insight for individual exercises and/or sets allowing for precise monitoring of changes in force production capability, giving some insight to intra-session recovery in a practical and reliable manner (Helms et al., 2020). The timing of these measurements varied from at the end of the session (54%), before the session (43%), after the first working set (38%), and even upon waking (36%), suggesting that coaches believe there are options and potentially, utility in taking measurements at multiple timepoints to understand and approach recovery in a multi-faceted manner.

Most coaches (82%) responded that they have a pre-planned progression scheme from week to week, but also consider how recovered the athlete is as opposed to having a rigid, unchanging pre-planned progression (5%) or going off recovery status alone (11%). Constructing a mesocycle is typically done under certain assumptions and theoretical models derived from the scientific literature. While this provides an actionable starting place, individuals may respond differently to the same program due to heritable factors and differences in environment that influence training outcomes (Bamman et al., 2007; Hubal et al., 2005). Essentially, there is no “perfect” program that applies to all, even when based on scientific

literature. Thus, any theoretical training framework likely should be informed with additional data on recovery and other potentially useful individual metrics which may help athletes succeed in training. Coaches used several primary pieces of training information, roughly equally, to gauge both successful and unsuccessful recovery including the number of repetitions performed, load used, and RIR/RPE, suggesting that specific and easy to use metrics are favoured. Typically, athletes should be able to maintain if not improve performance from week to week (Kellmann, 2010), so changes in these variables on a week-to-week basis may give insight that insufficient recovery occurred. Importantly, the consistent inability to perform as expected over mid-term time frames (micro- to mesocycle length time frames) should be of concern, as daily fluctuations are common and may not accurately capture true levels of recovery (Helms et al., 2020). Changes in technique were also frequently cited by coaches and can be used as another method to monitor recovery that is easy to track and compare. For example, taking video to assess exercise form is a common practice and can be used with other variables (i.e., RIR/RPE) to help give a more comprehensive understanding of performance (Cochrane et al., 2022).

81% of coaches cited making changes to volume and/or load with 66% adjusting RIR/RPE if an athlete was not sufficiently recovered for the session. Attempting to do more than may be feasible could put an athlete at risk of compounding levels of fatigue or worse, injury (Cheung et al., 2003). Therefore, coaches feel that making appropriate adjustments can allow the athlete to maintain progress, practice the skill of lifting, and importantly, stay healthy enough to ensure career longevity. With appropriate training program design, autoregulation, sleep, nutrition, and stress management techniques, additional methods to enhance recovery can be considered but coaches did not see them as replacements or equivalent to these primary variables. The most frequently mentioned recovery modality outside of these primary factors was low intensity cardiovascular training (90%). Indeed, current research suggests that AR via low volume, intensity, and/or duration cardiovascular training for the same muscle groups which were recently trained may improve recovery via enhanced blood flow and reductions in muscle edema (Clarkson et al., 1992; Peake, Roberts, et al., 2017). Coaches believe that this

method is easy to implement, can be paired with other without interference, and could plausibly be used to decrease stress, as low intensity leisure activities provide an opportunity to spend time with loved ones and can take the form of enjoyable activities.

Section 5: Practical Applications

This research provides novel insights into perceptions coaches have on recovery. Sleep, RT program design and nutrition were the primary variables considered and modified by coaches to influence recovery. Coaches primarily track sleep and nutrition via self-reported data, but a variety of methods may be used depending on the goals and resources available. Regardless of modality used, having some form of communication and education regarding recovery may be valuable for the coach/athlete relationship. Most coaches quantify the difficulty of sessions based on a comprehensive suite of variables covering effort given and total volume completed to ensure difficult sessions are not placed in proximity to one another. Coaches also quantified the difficulty of exercises/movements; specifically, those involving more musculature which mentally challenge the athlete.

While these specific coaching practices have not been empirically validated, the principles which underly them have been. Therefore, knowledge of these program design frameworks can be used by other coaches attempting to ensure sufficient recovery, to give a focus to sessions, and to maintain a quality of work. High priority sessions and/or movements were typically placed by coaches at the beginning of a microcycle, preceded by an easy/off day to increase the likelihood of high performance. Much like deloads, which are a post-mesocycle recovery tool used by coaches only explored recently in the literature, introductory weeks can also be implemented by coaches at the beginning of a mesocycle. While similar in conception to deloads, introductory weeks are used to help athletes adjust to a new mesocycle in which new exercises, higher volumes, or higher intensity will be used, by eliciting the repeated bout effect to reduce excessive muscle soreness/fatigue in response to such novel training.

In addition to the fatigue management techniques at the start and end of micro/mesocycles, coaches also strategically position easier sessions within microcycles.

Specifically, sessions with lower volume, load and proximity to failure are positioned in an attempt to improve recovery and performance for subsequent sessions of importance. To ensure the success of such session placement strategies, coaches monitor recovery via sleep, muscle soreness, sRPE, and RIR/RPE at various timepoints. Such monitoring indicates coaches are open to adjusting and autoregulating training within the week. However, such autoregulation seems to occur within an existing framework, as coaches primarily reported having a pre-planned progression scheme, but while also making decisions on how to adjust it based on athlete recovery. Given the low relative importance coaches placed on factors outside of those mentioned, it seems appropriate that additional recovery methods with empirical support – such as low intensity cardiovascular training - should only be implemented once these factors have been attended to, with modest expectations regarding their ability to decrease stress and enhance recovery.

Chapter 4 Investigating Objective and Subjective Monitoring Metrics for Resistance Training Relevant Recovery and Performance Prediction

Prepared for the Journal of Strength and Conditioning Research

Prelude

Chapter 3 illustrated that coaches consider sleep, program design, and nutrition as primary variables that influence recovery and track this information primarily via self-reported data. Further, most coaches quantify the difficulty of sessions based on a variety of variables such as effort given and total volume. These variables influence the placement of sessions within a microcycle such that they avoid placing difficult/high priority sessions in close proximity to one another. In practice, lower volume, load, and proximity to failure sessions, or even training cessation, may occur prior to important sessions to ensure adequate recovery and maximise performance on those days. Thus, the purpose of Chapter 4 was to examine which monitoring metrics could effectively assess recovery and predict performance. Given that the importance of recovery was established both in the literature and by the practice of coaches, this chapter examined the relationship between objective and subjective recovery metrics with RT performance to provide better tools for future research and practice.

Section 1: Introduction

When designing a RT program, a common aim is to enhance performance. This necessitates imposing stress on the body to elicit meaningful changes; however, such intentional stress often brings about fatigue. Thus, striking a balance between stress, fatigue, and recovery is vital for maximising performance (Bird, 2013). Fatigue, characterised as physical and/or mental exhaustion leading to diminished performance (Plisk & Stone, 2003), is an anticipated outcome of training; however, insufficient recovery can result in a temporary decrease in the ability to generate force (Brown et al., 1997), decreased performance (Burt & Twist, 2011), and a higher likelihood of injury (Cheung et al., 2003). Different exercise modes induce varying

physiological responses which impact the time course and ability to recover. Further, the magnitude of these responses is dependent on the configuration of a training program involving the manipulation of the primary variables of volume (Bartolomei et al., 2017) and proximity to failure (Morán-Navarro et al., 2017; Santos et al., 2018). Due to the complexity involved in the recovery process, some form of assessing/monitoring is warranted.

Individual responses to training outcomes (Bamman et al., 2007) and recovery (McLester et al., 2003) are widely documented; however, when program-design is tailored to the individual, adaptation to training can be improved even in highly experienced athletes (Helms et al., 2020). Importantly, to maximise results this process should be continually adapted based on individual responses, evolving needs, and changing states of readiness and recovery (Kiely, 2012). Therefore, it is important to choose methods of monitoring and assessing recovery that accurately depict information coaches and athletes need when evaluating programming (Flatt et al., 2019). For example, HRV is often viewed as an effective tool to periodise training (Kiviniemi et al., 2010) and determine training load and recovery status (Nakamura et al., 2015; Plews et al., 2013); however, success with this method typically relates to endurance athletes and not always RT (De Oliveira et al., 2019; Flatt et al., 2019).

While certain metrics such as maximal performance assessments may give insight to recovery, they come with inherent risks and may even delay recovery by accumulating more fatigue, potentially interfering with the recovery process. Simpler non-invasive and non-fatiguing assessment tools that provide a surrogate for fatigue can provide valuable monitoring. Such tools are common in the sports science literature, but unfortunately many techniques may be impractical for many due to accessibility, cost, and their dependency on laboratory settings. Promising non-fatiguing markers of recovery post-RT have been documented such as subjective scales like the PRS where scores were lower after high-volume muscle damaging resistance exercise and significantly and inversely related ($p < .05$, $r^2 = .58$) with the muscle damage biomarker creatine kinase (CK) (Sikorski et al., 2013), the CMJ where vertical jump height decrement prior to the session was correlated with decreases in back squat volume ($r^2 = .65$) (Watkins et al., 2017), and barbell velocity at varying loads (Jukic et al., 2023). However, the

evaluation of fatigue and recovery within the context of RT is not a firmly established practice. Thus, understanding which variables/measurement tools can reasonably detect variations in RT-relevant performance is important in judging their practical utility. Since performance is not unidimensional, providing insight on disparate outcomes (i.e., maximum repetitions or jump height as a proxy for explosive power), would provide a more comprehensive understanding of recovery.

Therefore, the aim of this study was to explore the ability of different monitoring metrics to assess recovery and predict RT-relevant performance. Specifically, we examined objective metrics such as movement velocity at high and moderate loads, plyometric performance, HRV, as well as subjective metrics such as muscle soreness, sleep quality, stress, and mood while assessing their ability to predict upper and lower body repetition and power performance, under varying states of fatigue. We hypothesised that plyometric performance, PRS, and muscle soreness measured via a visual analogue scale (VAS) would predict repetition performance and that low load velocity performance and PRS would predict power performance.

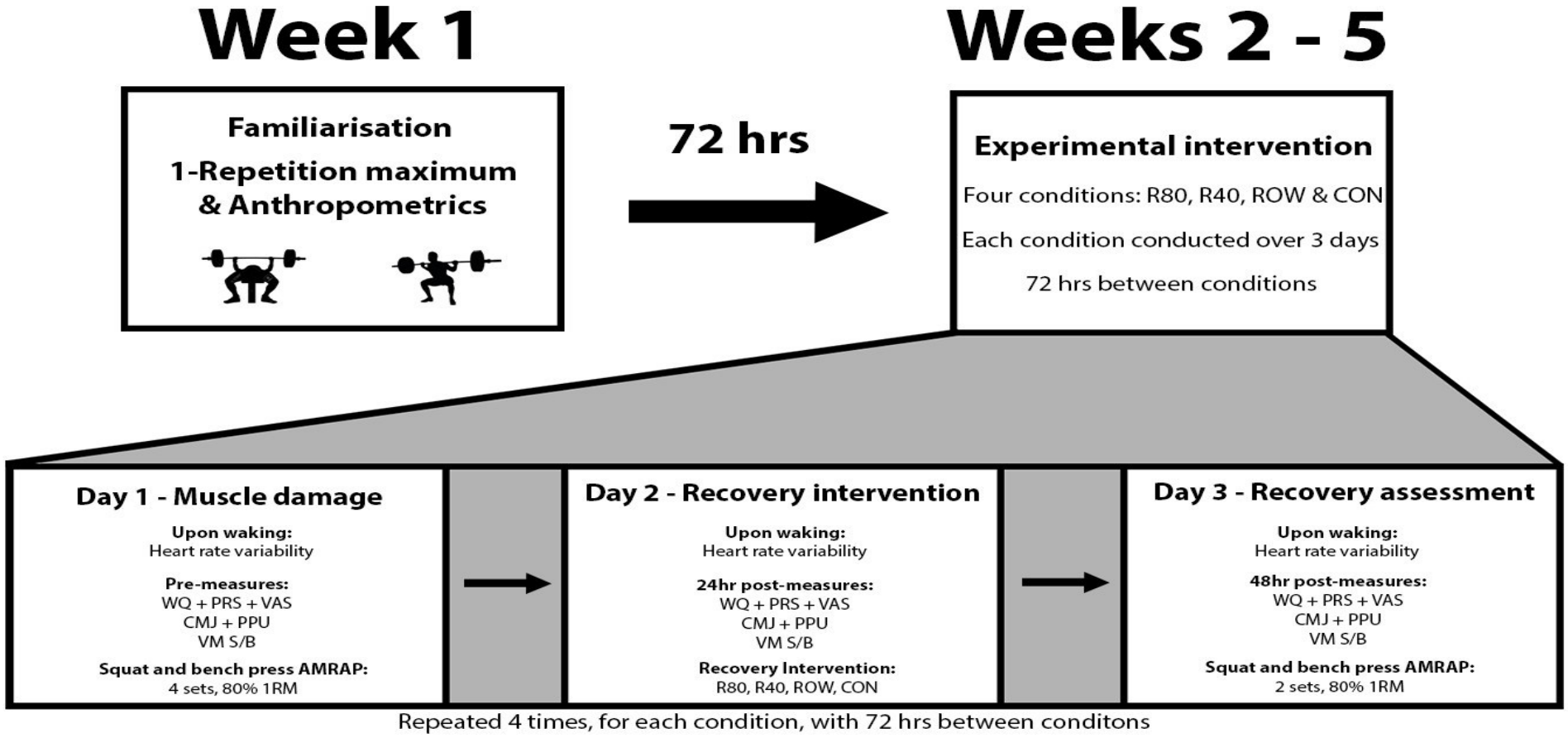
Section 2: Methods

Experimental Approach to the Problem

This study featured a randomised crossover design, where resistance trained males provided repetition and power performance, and a variety of fatigue measurements, across timepoints (under various states of fatigue) within four experimental conditions of recovery. The data collection was part of a larger investigation exploring the effects of different AR modalities; however, for the present research our focus was on assessing relationships between various objective and subjective resistance-training relevant monitoring metrics and performance (i.e., across experimental conditions and timepoints). To represent performance, barbell back squat repetition performance and CMJ were used for the lower body while barbell bench press repetition performance and PPU were used for the upper body. The following metrics were assessed to determine if they had any relationship with performance recovery: two

forms of velocity recovery with the barbell back squat and bench press, HRV, subjective measures of fatigue, muscle soreness, sleep quality, stress and mood, muscle soreness in an isometric position, and PRS. A timeline of events can be seen in Figure 4-1.

Figure 4-1 Timeline of events



R80 4 sets x 1 repetition x 80% one repetition maximum (*1RM*), *R40* 4x2x40% 1RM, *ROW* 20 minutes light rowing, *CON* passive recovery control, WQ wellness questionnaire, PRS perceived recovery status, VAS visual analogue scale, *CMJ* countermovement jump, *PPU* plyometric push up, *VM* velocity measure, *S* squat, *B* bench

Participants

An a priori power analysis was conducted for sample size estimation to determine the minimum sample size required to test the study hypothesis. Results indicated the required sample size to achieve 90% power for detecting a large effect, at a significance criterion of $\alpha = .05$, was N = 13. Only one participant had to withdraw from the study due to scheduling issues as a result of the COVID-19 lockdowns; however, they still completed one arm of testing which was included for analysis. Thirteen resistance trained males completed this study, who were free of injury and could barbell back squat at least 1.5x and bench press 1x body mass: age (27.31±4.14 years), height (178.98±5.63 cm), body mass (89.11±8.36 kg), training age (8±3.82 years), squat 1RM (169.81±23.85 kg), bench press 1RM (123.27±15.64 kg), estimated deadlift 1RM (185.77±30.81), Wilks (Vanderburgh & Batterham, 1999) score (308.87±37.53). Informed consent was provided before beginning the study and ethics approval was given by the Auckland University of Technology Ethics Committee (20/54).

Procedures

The study consisted of 5 weeks of experimentation, separated into one week of familiarisation and preliminary measurements, and four weeks of condition-specific procedures (i.e., one week each). The conditions consisted of i. four sets of one repetition with 80% of 1RM (R80), ii. four sets of two repetitions with 40% of 1RM (R40), iii. 20 minutes of light rowing at 50-60W (ROW), and iv. a PR control (CTRL). Prior to commencing the experimental procedures, participants were allocated to an order of crossover arms using a modified Latin Square approach. Each arm consisted of three days of experiments: 'baseline' measurements and a subsequent fatiguing session, and two follow up measurement sessions in parallel to the condition specific recovery modality. All measures completed on day one prior to the fatiguing session (repetitions to failure) were referred to as "PRE" baseline measurements, "24hr" on day two, and "48hr" on day three for each respective exercise and recovery metric. Between crossover arms, participants were instructed to maintain their normal routine and avoid anything

substantially fatiguing (i.e., new exercises, 1RM attempts, repetitions to failure, etc.). On day one of each crossover arm, and for testing occurring during familiarization, participants arrived with 72 hours of rest from any training. The same standardized dynamic warmup was completed prior to every session.

Week 1: Familiarisation and Baseline Measures

During the first week, participants attended familiarization where they were habituated with CMJ, PPU, squat and bench press repetition and velocity procedures as well as the Likert scales that would be used daily for recording various recovery values. During this week, 1RM and anthropometrics were also measured during a session preceded by 72 hrs rest. Body mass and height were recorded using an electronic column scale and wall-mounted stadiometer (Seca Ld, Hamburg, Germany).

One-Repetition Maximum Testing:

Pretesting, participant estimated one repetition maximum (E1RM) was determined based on the most recent and heaviest squat and bench press training log records, to be used in estimating ranges of loading for forthcoming 1RM attempts. All lifting (including subsequent experimental sessions) was completed using a 20 kg barbell (Rogue, Columbus, Ohio, USA) and calibrated metal weight plates (Viking, Wellington, New Zealand). Participants were allowed to wear lifting belts, shoes, knee sleeves and wrist wraps, which was kept consistent during 1RM and repetition testing.

After the standardized dynamic warm up, a specific warm-up for the back squat consisting of up to 10 repetitions with the barbell, three repetitions with 20, 40, and 60% E1RM, one repetition with 80 and finally 90% of E1RM were completed with three minutes of rest between sets. Following the 90% E1RM warm up, 1RM attempts were selected based on barbell velocity, the participant's repetitions in reserve-based rating of perceived exertion (RIR-based RPE) (Zourdos 2016), and discussions between the participant and researchers. Three to five minutes rest were given between each 1RM attempt with a maximum of five attempts permitted

to obtain a true 1RM. Once the squat 1RM was acquired, 10 minutes of rest was given before the bench press was performed following the same procedures with additional instruction to lightly touch the chest with the barbell for a repetition to count. During the attempts, velocity was recorded for each repetition using a linear position transducer (GymAware Power Tool; Kinetic Performance Technologies, Canberra, Australia) attached to the right side of the barbell to aid in attempt selection of the 1RM. The final 1RM and velocity values for each movement were subsequently used for determining the load for repetitions to failure, v75, and to help determine v1 in the following weeks (described in more detail below).

Weeks 2 to 5: Experimental Measurements

For each of the three experimental days, participants reported to the laboratory, and performed a selection of measurements followed by either multiple sets of maximum repetitions at 80% 1RM for squat and bench (as many reps as possible [AMRAP]; days 1 and 3/PRE and 48hr) or the recovery intervention (day 2/24hr). Several measurements were repeated directly proceeding the AMRAP on day one (CMJ for squat, PPU for bench, and v1 and v75 for both) for other analytical processes and excluded from these analyses. Several other measurements (e.g., HRV, soreness) were recorded at specific times preceding or during warmup, as discussed below.

HRV:

Prior to the start of the study, a five-day rolling average HRV was collected to establish a baseline, measured using the HRV4 Training phone application (Plews et al., 2017). Participants were instructed to obtain HRV measures every day immediately upon waking, after using the bathroom, in a relaxed position before consumption of food or liquids. The root mean square of successive differences between normal heartbeats (RMSSD) was examined as suggested in previous literature (Hautala et al., 2001; Plews et al., 2017), and recorded for each of the mornings of the three experimental days (for each condition) for our analyses.

Subjective Measures:

Upon entering the lab prior to any warmup or exercising, subjective measures of fatigue, muscle soreness, sleep quality, stress, and mood were assessed using a Wellness Questionnaire (McLean et al., 2010). Descriptions of each variable were given and related to a one-to-five scale with one typically being “much worse”, three “normal”, and five “much better”. Subsequently, muscle soreness was recorded via a 100mm VAS (Lee et al., 1991) with anchors of “no soreness” and “extreme soreness” in two positions: (1) in a squat position with 90 degrees of knee flexion and top of the thigh parallel to the floor and (2) in a push-up position with chest just above the floor so that the respective muscles for each movement were under tension (Roberts et al., 2014). PRS (Laurent et al., 2011) was collected on each experimental day at two time points: (1) immediately upon arrival to the lab prior to any exercise (PRS cold) and (2) after the dynamic and specific warm up, prior to repetitions to failure (PRS warm). In this 0-10 scale 10 signifies “very well recovered” and 0 signifies “very poorly recovered”. Typically, on the side of the scale, there are score ranges that indicate whether the rater expects reduced, normal, or improved performance; however, in an attempt to eliminate any potential influence on performance, this portion of the scale was not shown to participants.

Power Testing:

To represent power production, CMJ and PPU were measured via a force-plate (AMTI, Watertown, MA, USA). For each movement, participants were asked to “position themselves on the force plate” once recording began, followed by a command of either “jump” or “push” to initiate the repetition. For the CMJ, participants were instructed to place and keep their hands on their waist while completing a small and quick countermovement before jumping as high as they could, landing on the force plate. For the PPU, participants went into a push-up position and were instructed to complete a small and quick countermovement, push as far away from the force plate as possible, land, and return to the starting position. A total of three jumps/push-ups were completed for each participant with the same positioning, with the raw force-time data for each repetition recorded for analysis. While PPU and CMJ are often used to reflect low load power performance (Morán-Navarro et al., 2017), we determined from piloting that the PPU

required more force output than bench press against v1 load, and thus the latter was selected as the bench low-load power performance measure in tandem to CMJ for the lower body.

Velocity Testing:

V1 was collected at the beginning of each arm. To find v1 load, velocity data gathered during the warms up of 1RM testing on week 1 was viewed to give an estimate of what load to use. For example, if 40kg elicited 1.1m/s during the 1RM warmups, the first set was completed at ~50kg to begin finding the appropriate load. A successful v1 load was achieved when the average velocity of three repetitions was 1 ± 0.03 m/s (0.97 – 1.03 m/s). If not obtained on the first set, the load was adjusted up or down per the mean velocity. All v1 loads were successfully obtained in no more than three attempts. This load was kept the same during the respective crossover arm but re-assessed on day 1 of each new arm and viewed as an individual time point. Two minutes of rest were given between v1 attempts and three minutes before v75 repetitions.

AMRAP

AMRAPs were performed for both squat or bench press in random order, completed with 10 minutes of rest between exercises, and four minutes of rest after the preceding measurement (i.e., v75). Loading parameters were calculated from their preceding 1RM attempts. These performances represented both a performance outcome, and a fatiguing protocol. The same protocol from day one was followed for day three with the only exception that two sets to failure (as opposed to four) were completed for the squat and bench press. During their attempts, participants were instructed to lower the barbell at a self-selected velocity and perform the concentric as fast as possible in addition to pausing no more than two seconds between repetitions. Verbal encouragement from the same number of researchers was provided for every repetition during each session of the study, with their attempts supervised and spotted to ensure maximal effort. Maximum repetitions were recorded as the final completed repetition before volitional failure dictated by the participants as a 10 RPE (i.e., no repetitions left in reserve), as one of the primary outcome variables of interest in the study.

Data Analysis

For AMRAP measures for the squat and bench, the total repetitions for the first two sets of repetitions to failure completed at PRE and 48hr were used as dependent variables for statistical analysis. For power performance (i.e., CMJ and PPU), the raw force-time data was analyzed using a custom-built LabVIEW (National Instruments) analysis interface, which applied the flight time method to detect height attained. The mean height of the three repetitions exported by LabVIEW software was recorded for statistical analysis, used as both an independent (recovery metric for repetitions) and dependent (performance measure) variable based on its utility for strength and conditioning application more broadly. The velocity-time data for each of the 'velocity-based' assessments were analysed using the GymAware program to provide mean repetition velocity. The mean of three repetitions with v1 and two repetitions with v75 were used as independent variables in the subsequent statistical analyses, respective of the movement type (e.g., v75 for bench press, used for bench or push up models). For HRV, the RMSSD values recorded and given by the HRV 4 Training app on the morning of each session were used as an independent variable. Raw scale values from each session for wellness, PRS, and VAS were used as independent variables. When detecting associations with AMRAPs, the two timepoints of PRE and 48hr post were used for all variables. For the remaining outcomes, the three timepoints for all variables were PRE, 24, and 48hr post exercise.

Statistical Analysis

Statistical analyses were performed using R (The R foundation for Statistical Computing, Vienna, Austria version 4.1.3). Primarily, *lmerTest* (Kuznetsova et al., 2017) was used to fit the primary models, *ggeffects* (Lüdecke, 2018) to estimate marginal means, and various packages from the *easystats* (Lüdecke et al., 2022) framework used to evaluate assumptions and extract model coefficients and standardized effects (e.g., *performance*, *parameters*, and *effectsize*).

To address the primary aim of exploring relationships between monitoring metrics and performance, a selection of linear mixed effects models was used. This allowed the fixed effects

of various assessment metrics to be explored, while controlling for participant as a random effect and addressing the repeated measures aspects of time (PRE, 24hr and 48hr) and condition (recovery interventions). Four models were built, with squat and bench repetitions, CMJ, and PPU as the target variables. For the two repetitions models, recovery measures included wellness scores (fatigue, muscle soreness, sleep quality, stress, and mood), and PRS (warm and cold), with the corresponding movement-specific plyometric (CMJ or PPU), v1 and v75 (squat or bench), and VAS variables (squat or pushup) at PRE and 48hr post timepoints. For the CMJ and PPU models, the same collection of independent variables was used, with the exception of the plyometric variables themselves (entered as dependent variables, for these models) at PRE, 24, and 48hr post timepoints. The original models included VAS at rest as a predictor; however, due to elevated multi-collinearity (variance inflation factor = 6.44-10.87; correlation with VAS squat and pushup $r>.88$, $p<.001$), and low model contribution ($p>.84$), it was removed from the final models in favor of retaining movement specific VAS scores.

The explanatory strength of each of the four models was described via the conditional coefficient of variation (r^2), with raw and pseudo-standardized coefficients (*beta*) presented to estimate model association with the outcome variable, and relative contribution the model, respectively. The latter were interpreted using rule-of-thumb thresholds of *beta* <0.2 as very small, 0.2≤ *beta*<0.5 as small, 0.5≤ *beta*<0.8 as medium. 95% confidence intervals (CI) were calculated for coefficients, with p-values used to interpret statistical significance (set at an alpha of $p \leq .05$).

Section 3: Results

All models fit the data well (r2>.63), with the coefficients displayed in Tables 4-1 and 4-2. Descriptive statistics for all variables are displayed in Table 4-3.

Table 4-1 Descriptive statistics of all variables (mean± standard deviation)

	Timepoint		
Variable	Pre	24hr	48hr
Squat repetitions	13.49± 2.74	-	13.16± 2.86
CMJ (cm)	37.76± 7.75	35.31± 7.6	36.65± 7.89
Squat v1 (m/s)	0.99± 0.03	0.93± 0.04	0.95± 0.05
Squat v75 (m/s)	0.58± 0.08	0.52± 0.11	0.56± 0.09
Bench repetitions	15.49± 2.6	-	14.69± 2.92
PPU (cm)	15.07± 3.7	13.6± 2.51	14.36± 3.11
Bench v1 (m/s)	1± 0.03	0.94± 0.06	0.94± 0.06
Bench v75 (m/s)	0.46± 0.1	0.41± 0.1	0.44± 0.1
HRV (rMMSD)	64.18± 21.25	59.38± 23.56	62.4± 23.32
PRS cold (score)	7.94± 1.33	4.39± 1.48	5.06± 1.43
PRS warm (score)	7± 1.53	4.69± 1.61	5.47± 1.36
Squat VAS (mm)	10± 12.71	64.94± 23.32	48.65± 24.02
Push up VAS (mm)	4.94± 8.3	48.94± 23.45	37.25± 25.71
Fatigue (wellness score)	3.59± 0.99	2.71± 0.57	2.88± 0.75
Soreness (wellness score)	3.9± 0.79	1.84± 0.62	2.2± 0.86
Sleep (wellness score)	3.88± 0.82	3.45± 0.88	3.65± 0.77
Stress (wellness score)	3.22± 1.09	3.20± 0.99	3.12± 0.9
Mood (wellness score)	4.12± 0.8	4± 0.81	3.84± 0.8

CMJ-countermovement jump, *v1*-movement velocity against a load that elicited a 1m/s velocity, *v75*-velocity at 75% of one-repetition maximum, *PPU*-plyometric push up, *HRV*-heart rate variability, *PRS*-perceived recovery status, *VAS*-visual analogue scale

Table 4-2 Lower body coefficients

	Squat repetitions				CMJ			
Predictors	*Estimates*	*CI*	*std. Beta*	*p*	*Estimates*	*CI*	*std. Beta*	*p*
(Intercept)	2.94	-6.93 – 12.82	0	.555	23.82	13.25 – 34.38	0	**<.001**
HRV (rMMSD)	0	-0.02 – 0.02	0.03	.838	0.01	-0.00 – 0.03	0.14	.148
Fatigue (wellness score)	-0.4	-0.94 – 0.14	-0.24	.147	-0.01	-0.61 – 0.58	-0.01	.961
Soreness (wellness score)	-0.28	-0.88 – 0.33	-0.21	.365	0.38	-0.26 – 1.02	0.21	.242
Sleep (wellness score)	0.14	-0.41 – 0.70	0.07	.605	0.08	-0.48 – 0.65	0.03	.774
Mood (wellness score)	-0.81	-1.65 – 0.03	-0.42	.059	-0.22	-1.12 – 0.69	-0.08	.64
Stress (wellness score)	0.33	-0.23 – 0.90	0.21	.24	-0.25	-0.86 – 0.37	-0.11	.428
PRS cold (score)	0.51	0.14 – 0.87	0.63	**.007**	-0.13	-0.49 – 0.23	-0.13	.471
PRS warm (score)	0.14	-0.17 – 0.45	0.14	.377	0.08	-0.22 – 0.37	0.06	.621
Squat VAS (mm)	0.01	-0.01 – 0.04	0.22	.255	-0.01	-0.03 – 0.01	-0.15	.37
CMJ (cm)	0	-0.13 – 0.12	-0.02	.943	-	-	-	-
Squat v1 (m/s)	3.66	-6.08 – 13.41	0.1	.456	11.59	1.46 – 21.71	0.26	**.025**
Squat v75 (m/s)	10.79	1.54 – 20.04	0.57	**.023**	3	-3.83 – 9.82	0.13	.386
Random Effects								
σ^2	2.18				3.7			
τ_{00}	$4.61_{participant}$				$62.70_{participant}$			
Observations	95				143			
Marginal R^2 / Conditional R^2	.140 / .724				.024 / .946			

CI-confidence interval, *std. beta*-standardised beta coefficients, *HRV*-heart rate variability, *PRS*-perceived recovery status, *VAS*-visual analogue scale, *CMJ*-countermovement jump, *v1*-movement velocity against a load that elicited a 1m/s velocity, *v75*- velocity at 75% of one-repetition maximum

Table 4-3 Upper body coefficients

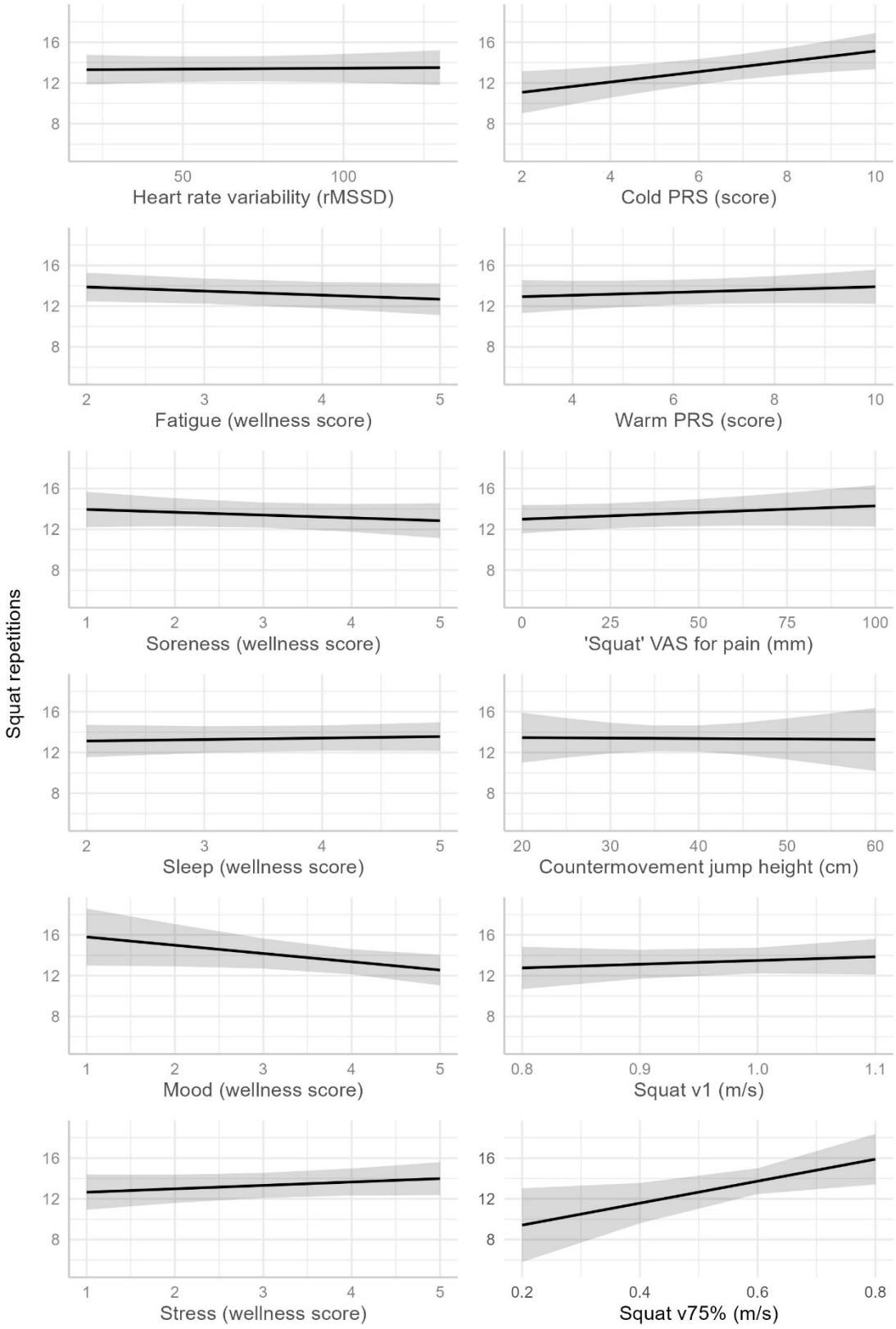
	Bench press repetitions				PPU			
Predictors	*Estimates*	*CI*	*std. Beta*	*p*	*Estimates*	*CI*	*std. Beta*	*p*
(Intercept)	6.83	-0.27 – 13.93	0	.059	3.53	-4.70 – 11.75	0	.398
HRV (rMMSD)	0.01	-0.00 – 0.03	0.19	.101	0.02	0.00 – 0.04	0.25	**.014**
Fatigue (wellness score)	-0.42	-0.90 – 0.07	-0.25	.093	0.37	-0.25 – 0.99	0.15	.239
Soreness (wellness score)	-0.56	-1.08 – -0.04	-0.43	**.034**	-0.23	-0.85 – 0.39	-0.13	.465
Sleep (wellness score)	-0.04	-0.55 – 0.46	-0.02	.862	-0.14	-0.72 – 0.45	-0.05	.643
Mood (wellness score)	-0.01	-0.77 – 0.75	-0.01	.978	0.49	-0.37 – 1.36	0.19	.26
Stress (wellness score)	0.08	-0.42 – 0.59	0.05	.741	-0.19	-0.80 – 0.42	-0.09	.547
PRS cold (score)	0.42	0.11 – 0.72	0.54	**.008**	0.09	-0.27 – 0.44	0.08	.635
PRS warm (score)	0.12	-0.16 – 0.39	0.12	.392	0.03	-0.27 – 0.33	0.03	.833
Push up VAS (mm)	-0.01	-0.04 – 0.01	-0.23	.17	0	-0.03 – 0.02	-0.05	.764
PPU (cm)	-0.17	-0.31 – -0.02	-0.36	**.023**	-	-	-	-
Bench v1 (m/s)	6	-0.80 – 12.81	0.22	.083	4.22	-3.95 – 12.40	0.11	.309
Bench v75 (m/s)	8.63	2.52 – 14.73	0.56	**.006**	8.42	1.03 – 15.81	0.4	**.026**
Random Effects								
σ^2	1.78				4.18			
τ_{00}	$4.95_{\text{participant}}$				$5.16_{\text{participant}}$			
Observations	96				144			
Marginal R^2 / Conditional R^2	.191 / .786				.167 / .627			

CI-confidence interval, *std. beta*-standardised beta coefficients, *HRV*-heart rate variability, *PRS*-perceived recovery status, *VAS*-visual analogue scale, *PPU*-plyometric push up, *v1*-movement velocity against a load that elicited a 1m/s velocity, *v75*- velocity at 75% of one-repetition maximum

Repetition Performance

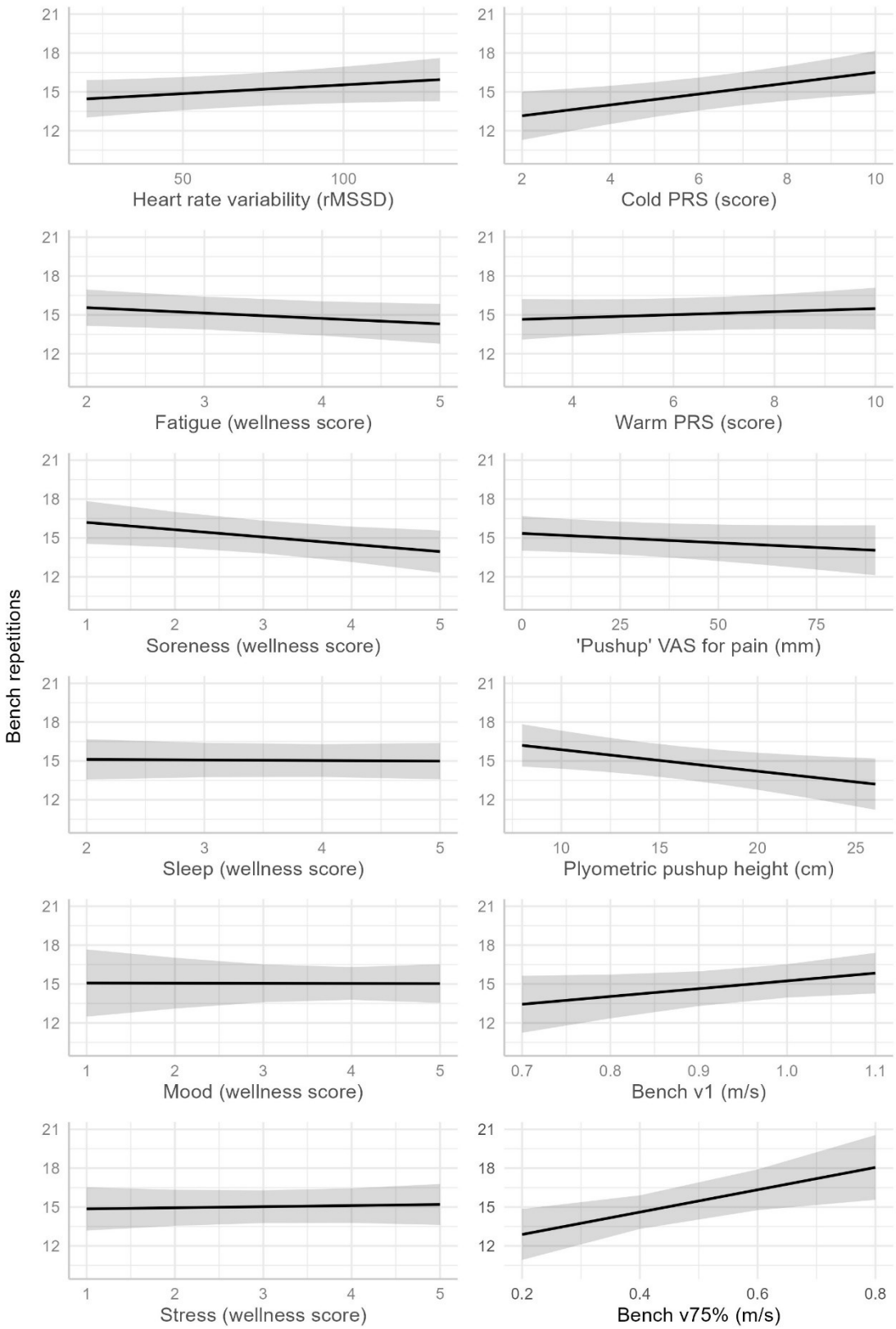
For squat repetitions, only PRS cold and v75 significantly contributed to the model ($p<.05$), with positive *medium* sized coefficients. Of the subjective measures, soreness and PRS cold both significantly contributed to the model ($p<.05$). The relationship with soreness was negative and *small*, and *medium* and positive with PRS cold. PPU and v75 were both statistically significant ($p<.05$). The former was negative, and *small*, with the latter positive, and *medium*. The predicted values from each model are presented in Figures 4-2 and 4-3, respectively.

Figure 4-2 Predicted values for squat repetitions and monitoring metrics



HRV-heart rate variability, *PRS*-perceived recovery status, *VAS*-visual analogue scale, *CMJ*-countermovement jump, *v1*-movement velocity against a load that elicited a 1m/s velocity, *v75*- velocity at 75% of one-repetition maximum

Figure 4-3 Predicted values for bench press repetitions and monitoring metrics

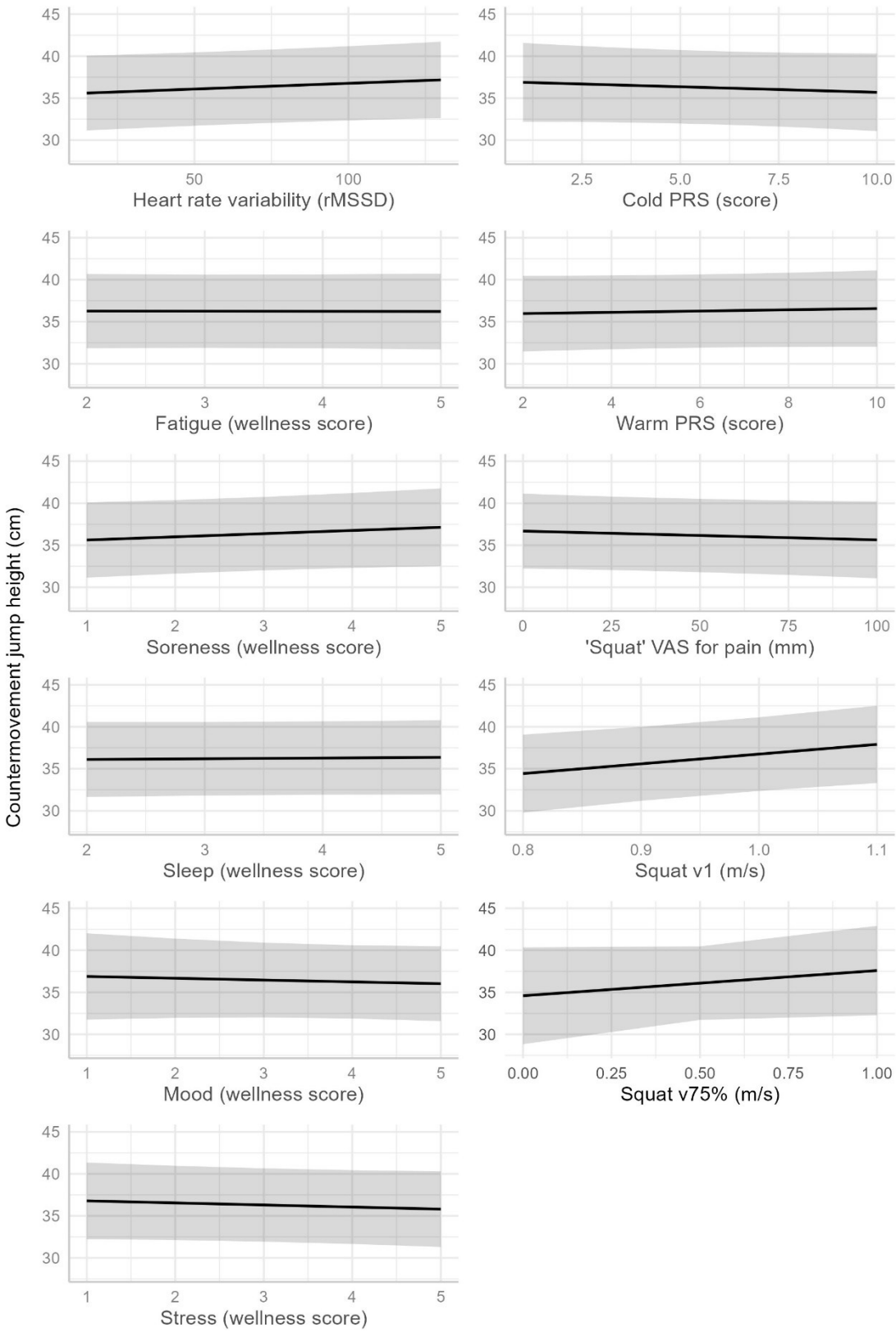


HRV-heart rate variability, *PRS*-perceived recovery status, *VAS*-visual analogue scale, *PPU*-plyometric push up, *v1*-movement velocity against a load that elicited a 1m/s velocity, *v75*- velocity at 75% of one-repetition maximum

Plyometric Performance

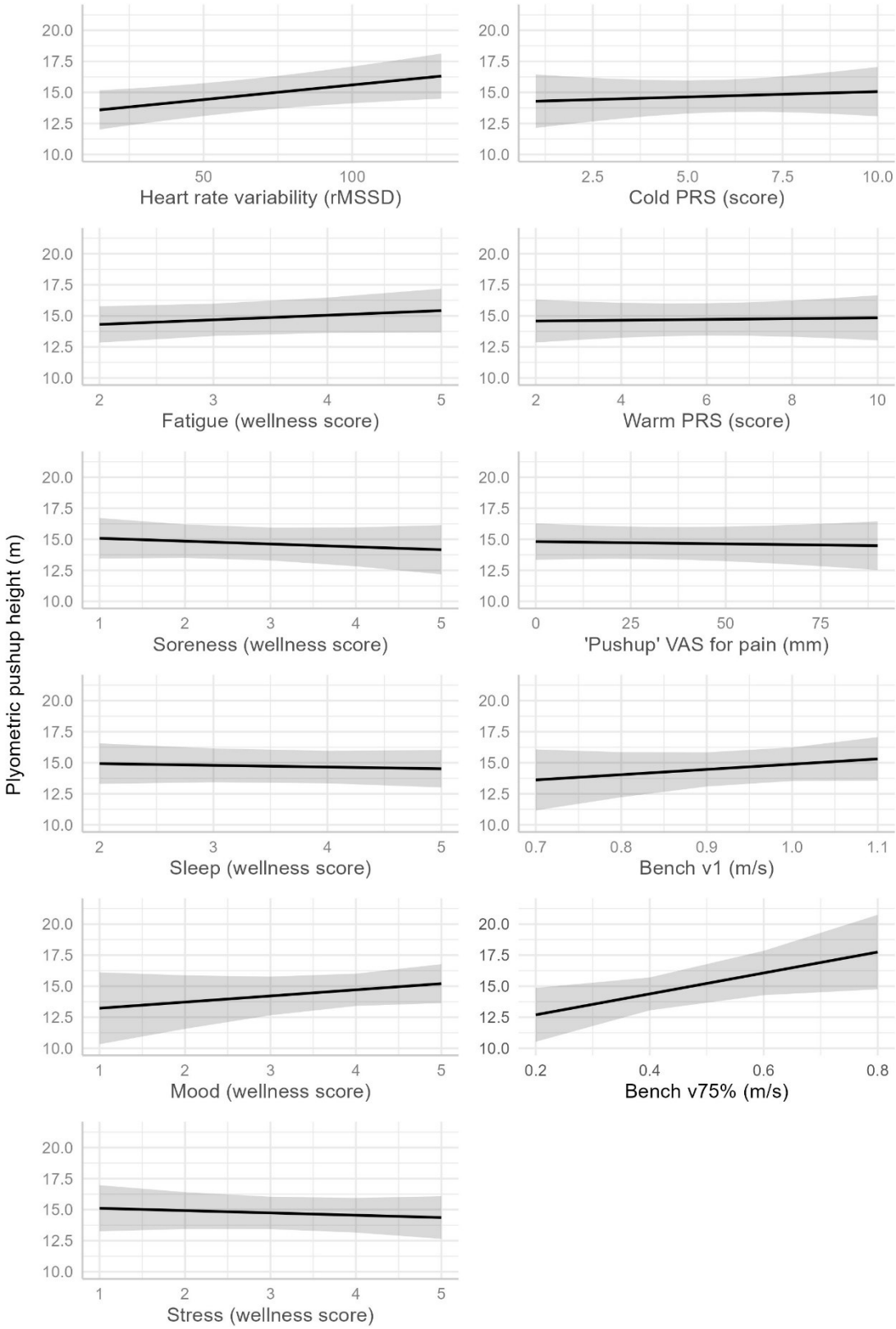
For CMJ, only the effect of v1 was statistically significant (p=.047), positive, and *small*. For PPU, both HRV and v75 contributed statistically (p<.05), and had positive, and *small* coefficients. The predicted values from each model are presented in Figures 4 and 5, respectively.

Figure 4-4 Predicted values for countermovement jump and monitoring metrics



HRV-heart rate variability, *PRS*-perceived recovery status, *VAS*-visual analogue scale, *CMJ*-countermovement jump, *v1*-movement velocity against a load that elicited a 1m/s velocity, *v75*- velocity at 75% of one-repetition maximum

Figure 4-5 Predicted values for plyometric push up and monitoring metrics



HRV-heart rate variability, *PRS*-perceived recovery status, *VAS*-visual analogue scale, *PPU*-plyometric push up, *v1*-movement velocity against a load that elicited a 1m/s velocity, *v75*- velocity at 75% of one-repetition maximum

Section 4: Discussion

This is one of the few studies to investigate the ability of different monitoring metrics to assess recovery and predict RT-relevant performance. Our aim was to determine which objective and subjective metrics were associated with upper and lower body repetition and power performance under varying states of fatigue. Our hypotheses were partially supported by our findings. Specifically, in support of our hypotheses, the following were statistically significant in measuring recovery: (i) squat repetition performance - PRS cold, (ii) bench press repetition performance - PRS cold and PPU, and (iii) CMJ - squat v1. Additionally, outside of our hypotheses, the following metrics were significant in measuring recovery: (i) squat repetitions – squat v75, (ii) bench repetitions – soreness, PPU, and bench press v75, and (iii) PPU – HRV and bench press v75. Therefore, these monitoring metrics may be useful for assessing recovery status for and lower body repetition and power performance.

PRS cold significantly predicted squat and bench press repetition performance such that when higher scores were given, indicative of greater recovery, better performance occurred. The PRS scale was initially developed to examine if an individual could subjectively estimate their level of recovery and subsequent sprinting performance, showing promise only in its ability to detect insufficient recovery and decreased performance (Laurent et al., 2011). Additionally, in follow up research, after engaging in high-volume muscle damage-inducing resistance exercise, there was a significant inverse relationship ($p < .05$, $r^2 = .58$) observed between PRS scores and CK (Sikorski et al., 2013). Thus, muscle soreness may influence perceived recovery. Our findings are in partial agreement as higher perceived soreness scores were associated with decreasing bench press repetition performance. Specifically, a one unit increase in soreness corresponds to approximately a half-repetition decrease in bench repetitions (-0.56); however, while PRS warm was not significant, higher PRS cold scores were associated with higher repetitions in bench and squat (0.42 and 0.51 repetitions for a one-unit increase). One

explanation for the lack of clear contribution of PRS warm is the effect of the preceding warmup (immediately following v75). After movement with significant loads, feelings of soreness or general discomfort may have been exacerbated, thus, influencing subsequent PRS scores and diverging from 'cold' readings. This is a notable finding, and worth considering if aiming to adopt PRS.

For the squat, PRS cold had the strongest association of the variables entered in the model (*beta*=0.63). Notably, Sikorski and colleagues' (Sikorski et al., 2013) training protocol consisted of three sets of 10-12 RM across nine exercises in one session (27 sets to failure) compared to just eight sets to failure in the present study. Thus, it is likely that due to a much greater volume of training, more fatigue was accumulated, requiring longer than the 48 hours of recovery given by Sikorski. Therefore, it's possible that the level of soreness observed had greater influence on the post-PRS scores in this prior investigation. Regarding other relevant performance metrics and their relationship with PRS, when examining the influence of proximity to failure on neuromuscular fatigue in RT, PRS does not always reflect lifting velocity (Refalo et al., 2023). Specifically, in Refalo and colleagues' investigation, lifting velocity fully recovered to baseline despite low PRS scores following six sets of barbell bench press with 75% 1RM performed to either momentary muscular failure, 1-RIR, or 3-RIR. Further, PRS scores were lower following failure than both 1- and 3-RIR at 24- and 48-hours post-exercise. Therefore, perceptions of fatigue may not always lead to or directly scale with decrements in performance or at the very least, the performance-perception relationships may differ on an individual basis and should be examined case-by-case. In the current study, however, PRS score was associated with squat and bench press repetition performance, which may highlight utility for individuals where repetition performance is of interest, such as those with hypertrophy or strength goals (Currier et al., 2023; Ralston et al., 2017; Schoenfeld & Grgic, 2018).

Average velocity on two repetitions at 75% 1RM was a strong predictor for repetition performance (*beta*=0.57), which is perhaps unsurprising given the proximity in load between the velocity metric and the repetitions test. Specifically, a 0.1 m/s increase in squat v75

corresponds to about a one repetition increase in squat repetitions (1.08). The confidence intervals were quite broad, however, so the actual association could vary in different situations (e.g., for 0.1 m/s change in v75, CI=0.15-2.00). This finding is aligned with previous research where v75 was significantly reduced 24 hours-post failure training and typically returned to baseline by 48 hours-post in the squat and bench press as observed by (Morán-Navarro et al., 2017). However, Moran-Navarro and colleagues only used v75 to create a time course of recovery while we used it to both measure recovery and predict subsequent repetition performance; therefore, providing novelty and additional support in favour of v75 as a monitoring metric for high loads barbell exercises. In further support of using low-repetition, moderate- to high-load performance as an acute performance predictor, in a case series, significant relationships were reported for all three participants between RIR-based RPE scores on their final warm up set at 85% 1RM and 1RM performance (Zourdos et al., 2015). While the present study's last warm up loads and performance measures differed from the previously published data, the present and previous work potentially support a similar application of using the RPE, RIR, or velocity of the last warm up to autoregulate load selection in the subsequent working set.

Bench press v75 significantly predicted PPU performance (beta=0.4) where a one unit increase in bench press v75 (0.1m/s) corresponds to an 0.84 cm increase in PPU height. Since the body mass load experienced in PPU likely renders it a force-dominant movement for many, its relationship with bench press v75 is unsurprising. For the lower body, squat v1 remained an indicator of performance against medium loads and significantly predicted performance in the CMJ. This is also unsurprising due to the similar low – moderate loads used in these exercises that are dependent on generating maximum force. Previously, high correlations between mechanical (velocity and CMJ height losses) and metabolic (lactate, ammonia) measures of fatigue were reported (Sánchez-Medina & González-Badillo, 2011). Given fatigue has conventionally been characterised by a reduction in the ability to generate force, ultimately leading to an inability to maintain performance at an anticipated level (Bigland-Ritchie & Woods, 1984; Enoka & Stuart, 1992), changes in movement velocity against a given load (i.e.,

v1) may objectively quantify neuromuscular fatigue. Therefore, v1 and v75 may be used as tools to measure neuromuscular fatigue. Specifically, these metrics may be integrated during the barbell specific warmup to give insight on fatigue and recovery.

HRV significantly predicted PPU performance. Data on the use of HRV for monitoring recovery in RT is equivocal; thus, this study provides important insight for its potential use. Flatt and colleagues (Flatt et al., 2019) reported no significant association between HRV, neuromuscular, and perceptual recovery following repetitions to failure in the barbell squat, bench press, and pull-down; however, they suggested that an individualised approach be taken due to varying timeframes of recovery between and within participants when examining different HRV metrics. For example, decrements in supine, but not standing RMSSD were observed at 24 hours and remained suppressed for 48 hours after a six-day overload microcycle of strength and high-intensity interval training; however, correlations between HRV measures and performance were weak or inconsistent (Schneider et al., 2019). Thus, HRV seems to be sensitive both to the method of data collection and individual differences suggesting that recorded values may not always accurately depict recovery or relate to changes in performance. Conversely, in the current study, increased HRV values were significantly related to increases in the PPU (*beta*=0.25) where a one unit increase in HRV corresponds with 0.02cm PPU height, thus, providing evidence in favour of use as an objective physiological metric to measure recovery and predict subsequent performance. Practically, given the relatively small difference in PPU height per unit and the large variation in HRV (~61.99± 22.71 on average across all three timepoints), individual responses and utility of this recovery metric may vary. Additionally, in the present study, participants were instructed to take HRV measurements in a relaxed position, which could include supine, side-lying, or seated positions providing more evidence for this method of data collection rather than standing. However, the present study only examined acute HRV recovery and performance, thus, long term adaptations and application are uncertain. Importantly, due to sensitivity of this data, HRV values should be viewed cautiously and together with other metrics to provide a more accurate assessment on whether training adjustments are appropriate thereby creating an individualised profile. Further,

since upper body power performance was the only outcome of significance, it is uncertain whether HRV can predict other types of performance, warranting future investigation.

Surprisingly, a significant negative relationship existed for the PPU and bench press repetitions (*beta*=-0.36) where a one unit increase in PPU height corresponds with -0.17 repetitions. This finding may be explained by different recovery time courses of different muscle fibres and subsequent performance outcomes (Pareja-Blanco et al., 2017); however, this is speculative, was not measured, and was not the objective of the current study. Nevertheless, this relationship further highlights the importance of approaching recovery with an individualised approach tailored to the specific outcomes of the individual as well as a pathway for future research. However, one possibility is that the inverse association at play is perhaps be a result of the order of testing that took place during the study. While participants may have been able to express recovery in explosive plyometric performance performed at the beginning of the session, the culmination of the combined efforts between the PPU and repetitions to failure (i.e., warmups) in addition to lingering fatigue from the previous two sessions may have impacted repetition performance. Interestingly, CMJ did not significantly predict repetition performance in the squat (*beta*=-0.02) as speculated. Watkins and colleagues (Watkins et al., 2017) reported that decrements in vertical jump height were correlated with the decrement in back squat volume performance; however, in that study, the RT protocol consisted of hang cleans, push presses, Romanian deadlifts, leg presses, and four sets to failure in the back squat while in our study, only eight total sets to failure were completed in the squat and bench press. Thus, with greater fatigue accumulation and subsequent recovery demands, decrements in performance could be more apparent. Therefore, future research is needed to determine the utility of CMJ to assess recovery.

The current study is not without limitations. Initially, it is important to note that this study exclusively focused on resistance-trained males and only used the barbell back squat and bench press exercises. Consequently, the findings may not be applicable to different populations or exercises. In addition, muscle damage was induced by completing four sets to volitional failure with 80% of 1RM, a method derived from previous research but somewhat arbitrary.

Therefore, the impact of different protocols producing varying degrees of damage on the results remains unknown, presenting a potential avenue for exploration in future studies. There was a lack of biochemical analyses in this study, thus, future research should attempt to include such analyses for a more comprehensive view on recovery. HRV was measured via a smartphone outside of the laboratory, therefore it is uncertain whether differences in collection took place, potentially influencing results. Finally, results in the current study may only be extrapolated to acute recovery and performance; thus, it is uncertain how chronic fatigue accumulation, performance, and adaptation would be affected, suggesting a path for future research.

In summary, the present study demonstrates that the following metrics may be useful for measuring recovery and predicting subsequent performance (expressed as metric – performance outcome): (i) PRS cold – squat and bench press repetitions, (ii) v75 – squat and bench press repetitions, and PPU, (iii) Squat v1 – CMJ, (iv) soreness – bench press repetitions (v) HRV – PPU, and (vi) PPU – bench press repetitions. Practically, these objective and subjective metrics present non-invasive, easy to implement, intuitive tools to comprehensively assess recovery between RT sessions.

Section 5: Practical Applications

If squat and bench press repetitions are of importance, PRS taken prior to exercise may accurately assess recovery and predict subsequent performance. These scores may provide the option to autoregulate the training session. For example, if scores are lower than expected or intended, decreases in load, volume, proximity to failure or a combination of these variables may be favoured. Conversely, if values are higher than expected or intended, potential increases in the stimulus could occur, resulting in a flexible template for training. Specifically, if squat repetition performance is of particular interest, on days where PRS scores are high, one may take advantage of this improved recovery and select a prioritised day/exercise. Alternatively, if recovery is worse than expected, rather than selecting a difficult session, an easier session may be performed instead in an attempt to avoid excess fatigue. Finally, due to the inverse

relationship between PRS and muscle soreness, perceived soreness values may also provide value in evaluating recovery and performance.

Velocity is a useful tool to measure recovery with specific interest given to squat v1 in predicting CMJ performance. Given the comparable low to moderate loads employed in these exercises relying on generating maximum force, squat v1 may give insight on expected CMJ performance. Additionally, v75 may provide a way to assess recovery against high loads as it is heavy enough to be specific to strength, but not too heavy as to induce fatigue. Specifically, this may be a useful metric to measure recovery for squat and bench press repetition and upper body power performance. Velocity, together with RIR-based RPE, may provide a more comprehensive view of recovery giving both objective and subjective feedback. Alternatively, for those who do not have access to velocity devices, RIR-based RPE alone may be adopted. Practically, velocity and/or RIR-based RPE of the last warm up set prior to the first working set can be monitored as a way to measure recovery and help determine subsequent load selection.

Finally, HRV may be useful in measuring recovery and power performance of the upper body. HRV is attractive to coaches and individuals as it provides a non-invasive physiological marker of recovery than can be easily obtained with inexpensive and intuitive mobile applications. This tool may be used to dictate volume and load prescription or session order based on morning RMSSD values in relation to baseline, thus, providing a more individualised approach to RT prescription. However, due to the variability in prior research, more data is needed on HRV before confident recommendations can be made. Therefore, due to the diverse nature of performance-specific recovery timeframes and individual differences, a multi-dimensional approach to assessing post-RT recovery with a variety of monitoring tools that are specific to the desired outcomes is recommended, as it may provide more accurate insights on athletes' recovery status and thus, subsequent expected performance.

Chapter 5 Implementation of a Low-Volume Power-Type Day to Improve Resistance Training Recovery and Performance in Well-Trained Males

Prepared for the Journal of Strength and Conditioning Research

Prelude

Chapters 2 and 3 outlined the importance of recovery and how this may influence RT microcycle construction. Then, Chapter 4 provided insight as to which monitoring metrics adequately measure recovery and may aid in predicting subsequent RT performance. However, to push the field forward in striving for better applied outcomes, further insight was needed regarding the impact of various types of AR on subsequent RT performance. To do so, the purpose of Chapter 5 was to compare the effect of three different AR methods – as well as PR - on RT-relevant performance following a damaging bout of RT, in order to better inform short term RT program design.

Section 1: Introduction

"Recovery" in RT is defined as the ability to meet or exceed prior performance (Bishop et al., 2008). Therefore, an inadequately recovered lifter may experience a temporary reduction in force production capability (Brown et al., 1997). Consequently, this can decrease performance (Burt & Twist, 2011) and may increase injury risk (Cheung et al., 2003). These factors emphasize the importance of balancing training stress with recovery. Rather than simply adopting PR strategies, various interventions have explored proactive means of improving recovery after exercise; for example, stretching (Herbert & Gabriel, 2002), electrostimulation (Bieuzen et al., 2014), wearing compression garments (Marqués-Jiménez et al., 2016), massage (Kargarfard et al., 2016), CWI (Leeder et al., 2012), cryotherapy (Costello et al., 2015), and foam rolling (D'Amico & Gillis, 2019). Despite promising results, the practical feasibility for many of these interventions is often lacking.

An arguably more practical approach is the use of AR methods, defined as any form of exercise/movement used to improve recovery, of typically lower volume, intensity, and/or duration. AR might be preferred over many alternative strategies since some evidence indicates reduced time course of recovery (Dupuy et al., 2018), and it is typically more practical and affordable. For example, compared to CWI, AR consisting of low intensity cycling had similar effects on the inflammatory response after a high-volume RT session for the lower body (Peake, Roberts, et al., 2017). Beyond the advantage of practicality, it is also worth noting that chronic CWI use may negatively impact the anabolic response to RT (Fyfe et al., 2019; Roberts et al., 2015). However, further study is required due to the limited data on AR to enhance our theoretical understanding of its function and application.

There are several studied types of AR for RT. Common iterations include performing upper body exercises after damaging lower body exercises (Abaidia et al., 2017), training the same muscle group with very load loads after damaging sessions (Bartolomei et al., 2019), and placing low volume "power-type" exercises after a hypertrophy session to promote recovery before a strength session (Zourdos et al., 2016). Theoretically, these AR modalities might improve recovery in two ways: 1) facilitating recovery and/or 2) by "priming" subsequent performance. Indeed, albeit limited in scope, existing research suggests that low-volume, power-type training may improve RT performance in the subsequent 24-48 hours (Tsoukos et al., 2018). Nonetheless, these various methods have not been directly compared to one another.

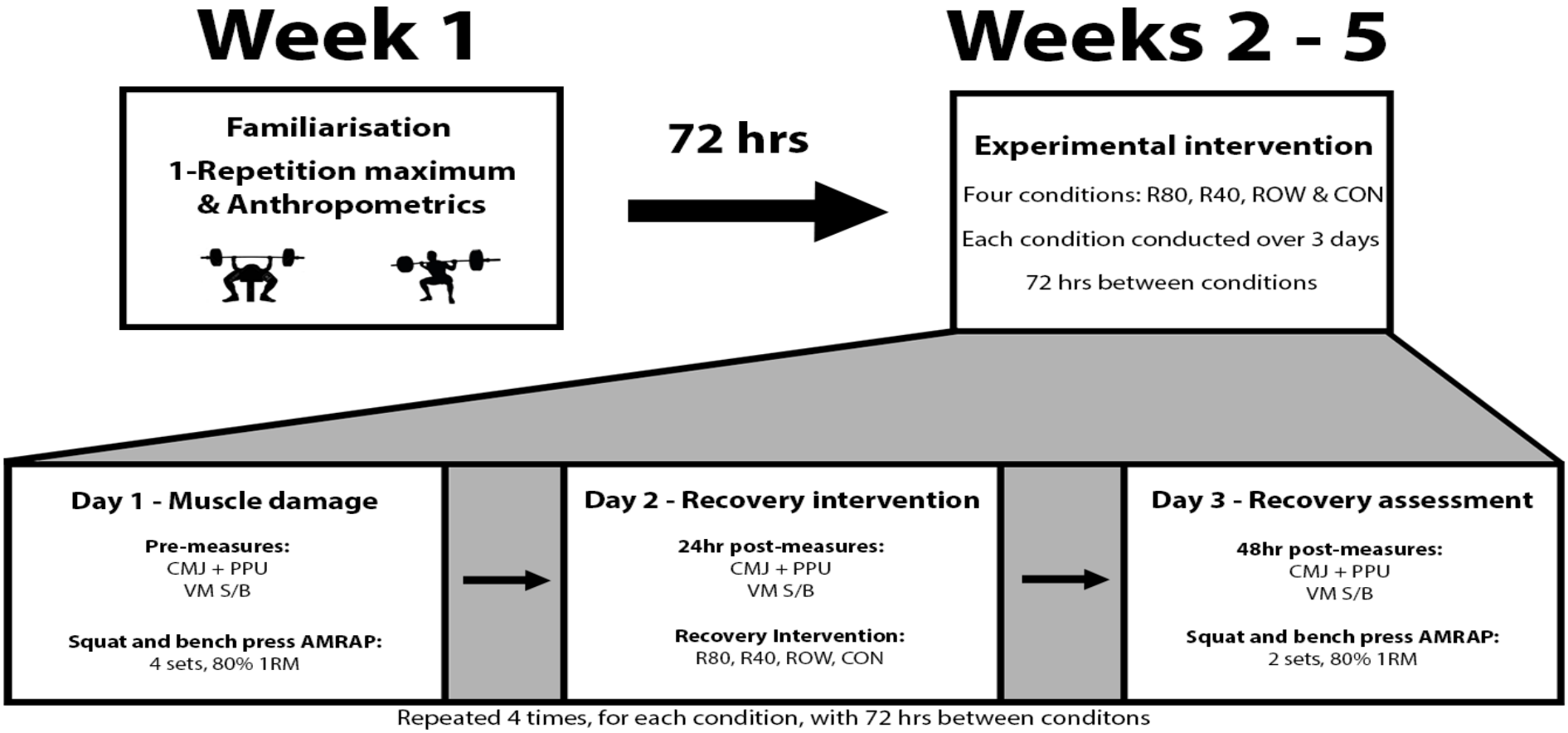
We aimed to compare the effect of four different AR methods on RT-relevant performance following a damaging bout of RT. Specifically, we compared a PR control, low intensity aerobic training on a rowing machine, and two power-type sessions with lower and higher loads, respectively, and assessed their impact on squat and bench press repetition performance and additional indices of strength and power. Based on the limited extant research, we hypothesized that the lower load power-type session would promote post-RT recovery most efficiently for power-type performance measures and that the higher load session would promote post-RT recovery most efficiently for repetition and higher load velocity performance, by providing both AR and a priming effect.

Section 2: Methods

Experimental Approach to the Problem

A randomized crossover examination with repeated measures of the effects of four different recovery modalities on repetition and power performance in the upper and lower body was performed in trained males. Barbell back squat repetition performance, CMJ, and two forms of velocity recovery with the barbell back squat were used to characterize performance, and thus examine "recovery", of the lower body. Likewise, barbell bench press repetition performance, PPU, and two forms of velocity recovery with the barbell bench press were used for the upper body. Each participant underwent all four conditions; two of which consisted of AR variations of low-volume power-type RT, in addition to an AR light intensity cardio session on a rower machine and finally, a PR control where no additional exercise was completed. Testing during each arm of the crossover took place across three consecutive days at the same time of day. A timeline of events can be seen in Figure 5-1.

Figure 5-1 Timeline of events



R80 4 sets x 1 repetition x 80% one repetition maximum (*1RM*), *R40* 4x2x40% 1RM, *ROW* 20 minutes light rowing, *CON* passive recovery control, *CMJ* countermovement jump, *PPU* plyometric push up, *VM* velocity measure, *S* squat, *B* bench

Participants

Thirteen resistance trained males completed this study. In order to participate, individuals needed to be able to squat 1.5x and bench 1x body mass and be free of injury. The participant characteristics expressed as means and standard deviations: age (27.31±4.14 years), height (178.98±5.63 cm), body mass (89.11±8.36 kg), training age (8±3.82 years), squat 1RM (169.81±23.85 kg), bench press 1RM (123.27±15.64 kg), estimated deadlift 1RM (185.77±30.81), Wilks score (308.87±37.53). Informed consent was provided before beginning the study and ethics approval was given by the Auckland University of Technology Ethics Committee (approval number: 20/54).

Procedures

The research spanned a period of five weeks, with one week dedicated to familiarization and preliminary measurements, followed by four weeks of specific procedural conditions, with each condition lasting one week. Before initiating the experimental procedures, participants were assigned to a sequence of crossover arms using a modified Latin Square approach. These arms consisted of various interventions: i. four sets of one repetition with 80% of 1RM (R80), ii. four sets of two repetitions with 40% of 1RM (R40), iii. 20 minutes of light rowing at 50-60W (ROW), and iv. a PR control (CTRL). Two minutes of rest were given between sets for R80 and R40. Participants provided RIR-based RPE values after each set for R80 and R40 while 6-20 Borg RPE scores (Borg, 1998) were given every five minutes during ROW. Participants were required to report to the lab for 24hr post power and velocity testing even during the CTRL session.

Each arm involved a three-day experimental process, including baseline measurements, a subsequent fatiguing session, and two follow-up measurement sessions concurrent with the specific recovery modality. Measurements taken on day on before the fatiguing session (as many reps as possible [AMRAP]) were labelled as “PRE” baseline measurements, “24hr” measurements were conducted on day two, and “48hr” measurements were taken on day three

for each corresponding exercise and recovery metric. Participants were instructed to maintain their normal routine and avoid significantly fatiguing activities (such as new exercises, 1RM attempts, AMRAPs, etc.) between crossover arms. On the first day of each crossover arm and during the familiarization testing, participants arrived with a 72-hour rest period from any training, and a standardized dynamic warm-up was completed before each session.

Week 1: Familiarization and Baseline Measures

In the first week, participants engaged in a familiarisation period where they became acquainted with the procedures for the CMJ, PPU, squat and bench press repetitions and velocity. Body mass and height were recorded using an electronic column scale and wall mounted stadiometer (Seca Ld, Hamburg, Germany). Finally, participants were familiarized with the rower (Concept 2 Model D Rower) where proper set up and technique were practiced.

One-Repetition Maximum Testing.

After 72 hours without training, participants began the study by completing 1RM testing. Participants E1RM was determined based on the most recent and heaviest squat and bench press training log records, to be used in estimates ranges of loading for 1RM attempts. All lifting (including subsequent experimental sessions) was completed using a 20 kg barbell (Rogue, Columbus, Ohio, USA) and calibrated metal weight plates (Viking, Wellington, New Zealand). Participants were allowed to wear lifting belts, shoes, knee sleeves and wrist wraps, which was kept consistent during 1RM and repetition testing.

Following the dynamic warmup, a specific warm-up for the back squat consisting of up to 10 repetitions with the barbell, three repetitions with 20, 40, and 60% of E1RM then one repetition with 80 and then 90% of E1RM were completed with three minutes of rest between sets. After the last warm up with 90% E1RM, 1RM attempts were determined based on barbell velocity, a RIR-based RPE (Zourdos et al., 2016) given by the participant, and consultation with the participant and other researchers. Three to five minutes rest were given between 1RM attempts. A maximum of five attempts were allowed to obtain a true 1RM. Once obtained, 10

minutes of rest were given before the same procedures were followed for the bench press. Participants were required to lightly touch the chest with the barbell for a repetition to count. During the attempts, velocity was recorded for each repetition using a linear position transducer (GymAware Power Tool; Kinetic Performance Technologies, Canberra, Australia) attached to the right side of the barbell to assist in attempt selection during the 1RM session and v1 on the upcoming weeks. The final 1RM values for each movement were subsequently used for determining loads for v1, v75, AMRAPs and AR protocols (R80 and R40) in the following weeks (described in more detail below).

Weeks 2 to 5: Experimental Measurements

On each of the three experimental days, participants reported to the laboratory and underwent a series of measurements. Subsequently, they either performed multiple sets of AMRAPs with 80% of 1RM for the squat and bench (days 1 and 3/PRE and 48hr) or the recovery intervention (day 2/24hr). Following the AMRAPs on day one, certain measurements (CMJ, PPU, v1, and v75 for both) were repeated for additional analytical purposes but were excluded from the present analyses.

Power Testing:

To quantify power production, the CMJ and PPU were assessed using a force plate (AMTI, Watertown, MA, USA). Participants were instructed to position themselves on the force plate upon the start of recording and were given commands of either “jump” or “push” to initiate the respective repetition. For the CMJ, participants were directed to place and maintain their hands on their waist, execute a small and rapid countermovement, and then jump as high as possible, landing back on the force plate. In the case of the PPU, participants assumed a push-up position, performed a brief and swift countermovement, pushed themselves as far away from the force plate as possible, landed, and returned to the starting position. Recording ceased once the participant completed the repetition and settled. Each participant completed a total of three jumps and push-ups each exercise, maintaining the same positioning for consistency. The raw force-time data were recorded for subsequent analysis. While both the CMJ and PPU are

commonly utilized to assess low load performance (Morán-Navarro et al., 2017), pilot testing revealed that the PPU imposed greater demands than bench press v1. Consequently, v1 for the bench press was chosen as the measure for low load performance, with CMJ serving as the counterpart for lower body assessment.

Velocity Testing:

V1 data were collected at the initiation of each arm. Estimates were derived from velocities recorded during the warm-ups of the 1RM testing in week one and were utilized to determine the actual load. A successful v1 was achieved when the average velocity of three repetitions fell within the range of 1m/s ± 0.03(0.97-1.03 m/s). If this criterion was not met on the first set, the load was adjusted either upward or downward based on the mean velocity. All v1 loads were successfully attained within a maximum of three attempts. This load remained constant throughout the corresponding crossover arm but was reassessed on day one of each new arm, treating it as an individual time point. A two-minute rest interval was observed between v1 attempts, followed by three minutes of rest before v75 repetitions.

AMRAP:

AMRAPs were conducted for both squat and bench press in a random order, interspersed with 10 minutes of rest between exercises and four minutes following the preceding measurements (i.e., v75). The loading parameters were derived from the preceding 1RM attempts. These performances served as both an indicator of overall performance and a fatiguing protocol. The same protocol employed on day one was replicated on day three, with the only deviation being that two sets of failure (as opposed to four) were completed for both the squat and bench press. Participants were instructed to lower the barbell at a self-selected velocity and execute the concentric phase as rapidly as possible, with no more than a two-second pause between repetitions. Verbal encouragement from an equal number of researchers was consistently provided for each repetition during every session of the study. The attempts were closely supervised and spotted to ensure maximal effort. The maximum repetitions were recorded as the final completed repetition before volitional failure, as determined by the

participants reaching a 10 RPE (i.e., no repetitions left in reserve), representing one of the primary outcome variables of interest in this study.

Data Analysis

In the analysis of AMRAP measures for the squat and bench press, the total repetitions from the first two sets of repetitions to failure completed at PRE and 48hr were employed as dependent variables for statistical examination. For power performance assessments (i.e., CMJ and PPU), raw force-time data were analysed using a custom-built LabVIEW (National Instruments) analysis interface. This interface utilized the flight time method to identify the height attained during each movement. The mean height of the three repetitions exported by the LabVIEW software served as a recorded value for statistical analysis. Velocity-time data for the "'velocity-based' assessments were analysed using the Gymaware program to determine mean repetition velocity. The mean of three repetitions with v1 and two repetitions with v75 were used as dependent variables in subsequent statistical analyses. Beyond the AMRAPs, the timepoints for all variables were at PRE, 24, and 48hr post exercise.

Statistical Analysis

Statistical analyses were performed using JASP 0.17.1.0 for Windows (JASP, Inc. Amsterdam, Netherlands) and R (The R foundation for Statistical Computing, Vienna, Austria version 4.1.3). Notably, *lmerTest* (Kuznetsova et al., 2017) and various packages from the *easystats* (Lüdecke et al., 2022) framework (e.g., *performance*, *parameters* and *effect size*).

To address our aim, a linear mixed effects model (estimated using REML and nloptwrap optimizer) which allowed the specification of both random and fixed effects, on the outcome's variables of bench and squat repetitions, countermovement jump and plyometric push up, and velocity at v1 load and v75 for bench and squat. Specifically, participant was entered as a random effect, with exercise condition (R80, R40, ROW, or CTRL), time (PRE, 24, and 48 hours) and their interaction each entered as fixed effects, for the corresponding outcome variable. Model fit was reported as conditional R^2. An analysis of variance was applied to the

model to extract standardized effects (partial eta squared; n_p^2) and to test for the significance of the fixed effects and their interaction, including contrasts on estimated marginal means (using the Tukey method for multiple comparisons, where appropriate). Qualitative magnitude of effect was interpreted following Field's (Field, 2013) recommendations (very small = <.01, small <.06, medium = <.14, large = >.14). 95% confidence intervals (CI) and p-values (set at an alpha of $p \leq .05$) were computed using a Wald t-distribution approximation.

Section 3: Results

The following model fits are reported as conditional R^2: squat repetitions =.76, bench repetitions =.83, CMJ =.96, squat v1 =.54, squat v75 = .73, PPU = .76, bench v1 =.52 and bench v75 =.85.

Repetition Performance

The main effect of time was statistically significant (p=0) and medium (n_p^2 =.11) for bench press repetitions. The main effect of period was statistically significant for squat (p=0, large n_p^2 =.19) and bench (p=0, large n_p^2 =.26) repetitions. Data are presented in Table 5-1 and Figures 5-2 and 5-3 in detail.

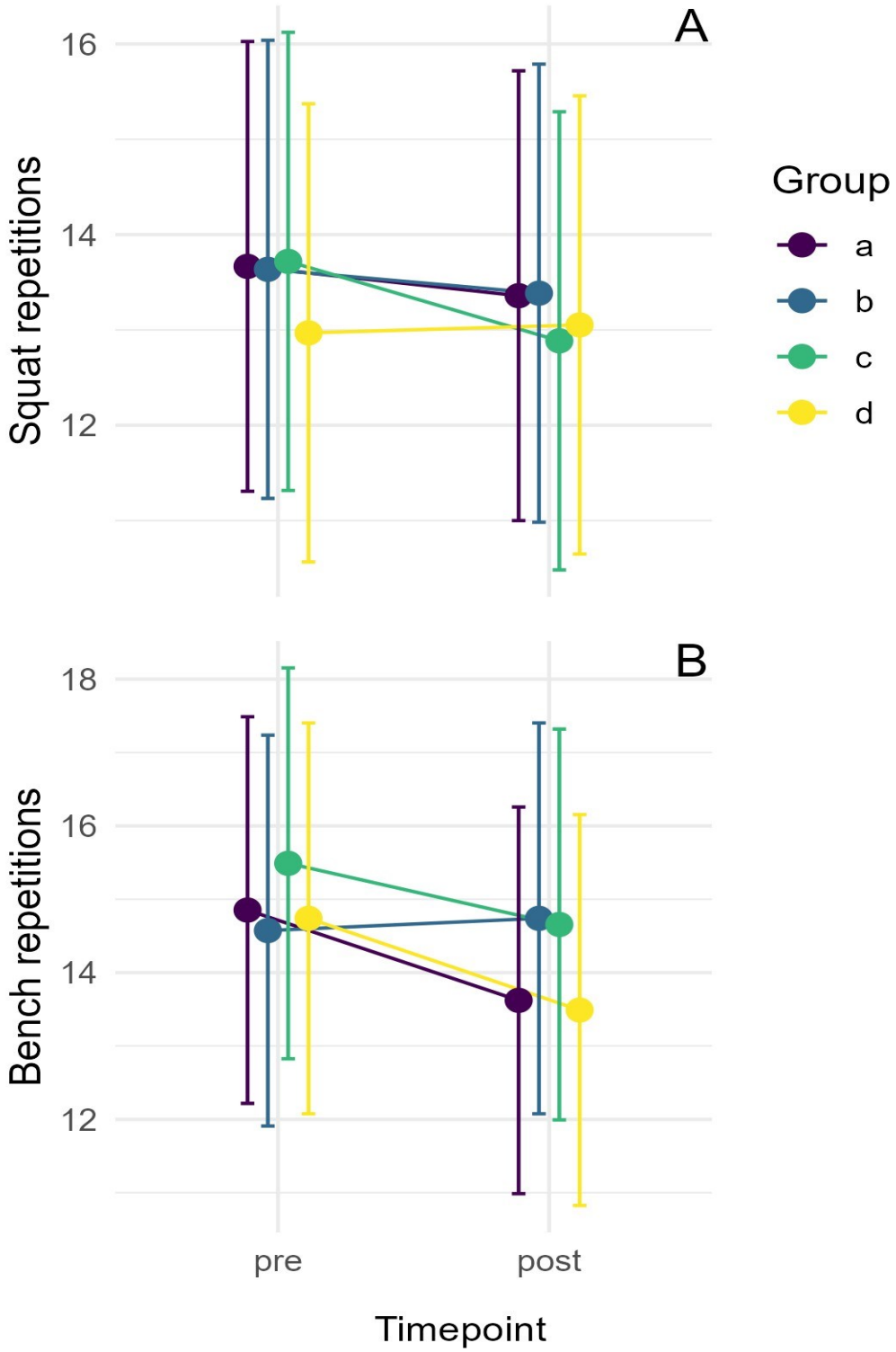
Table 5-1 Repeated measures ANOVA for performance outcomes

	Condition			Time			Order			Period			Cond: Time		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Squat repetitions	0.57	0.64	0.02 (0; 0.09) *small*	1.10	0.30	0(0; 0.11) *small*	2.37	0.14	0.45(0; 0.71) *large*	5.82	0	0.19(0.04; 0.33) *large*	0.36	0.78	0.01(0; 0.07) *small*
CMJ	3.6	0.02	0.08(0; 0.18) *medium*	21.05	0	0.26(0.13; 0.38) *large*	0.20	0.89	0.06(0;0.27) *medium*	5.24	0	0.17(0.02; 0.22) *medium*	0.62	0.72	0.03(0; 0.06) *small*
Squat v1	0.32	0.81	0(0; 0.04) *very small*	45.24	0	0.43(0.3; 0.53) *large*	0.85	0.50	0.22(0; 0.54) *large*	1.22	0.30	0.03(0; 0.09) *small*	2.14	0.05	0.1(0; 0.17) *medium*
Squat v75	0.66	0.58	0.02(0; 0.06) *small*	13.76	0	0.19(0.07; 0.31) *large*	0.42	0.74	0.12(0; 0.41) *medium*	0.79	0.50	0.02(0; 0.07) *small*	1.20	0.31	0.06(0; 0.11) *small*
Bench repetitions	2.72	0.05	0.1(0; 0.22) *medium*	9.06	0	0.11(0.01; 0.25) *medium*	0.64	0.61	0.17(0; 0.48) *large*	9.01	0	0.26(0.09; 0.4) *large*	1.60	0.20	0.06(0; 0.16) *medium*

PPU	2.35	0.08	0.06(0; 0.14) *small*	12.12	0	0.17(0.06; 0.28) *large*	0.25	0.86	0.08(0;0.32) *medium*	15.44	0	0.28(0.14; 0.39) *large*	0.61	0.72	0.03(0; 0.06) *small*
Bench v1	3.42	0.02	0.08(0; 0.17) *medium*	27.84	0	0.32(0.18; 0.43) *large*	0.36	0.78	0.19(0; 0.41) *medium*	0.26	0.85	0(0; 0.03) *very small*	1.35	0.24	0.06(0; 0.12) *medium*
Bench v75	0.04	0.99	0(0;0) *very small*	14.30	0	0.19(0.08; 0.31) *large*	1.35	0.32	0.31(0; 0.62) *large*	0.94	0.42	0.02(0; 0.08) *small*	0.43	0.02	0.02(0; 0.04) *small*

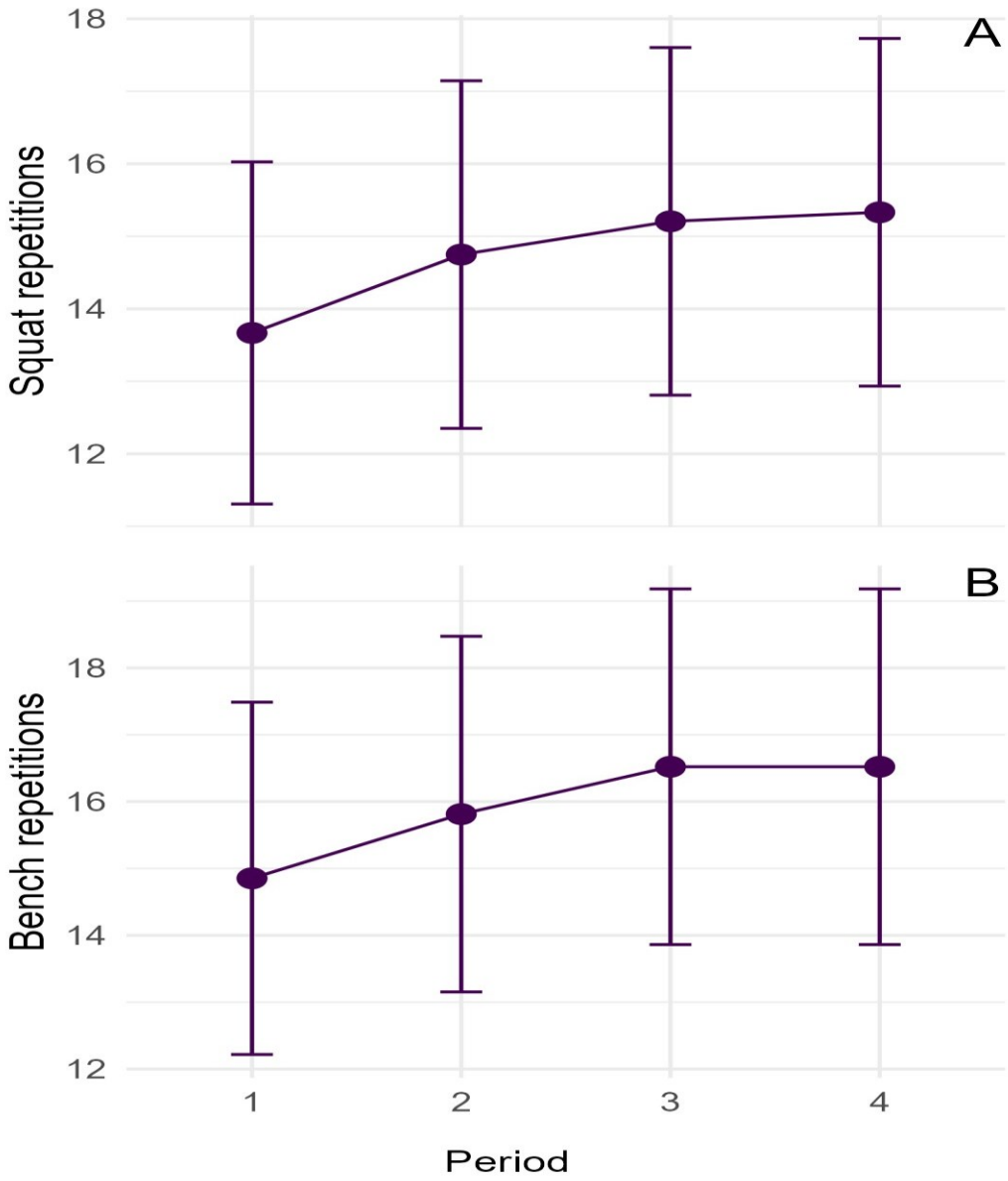
CMJ Countermovement jump, *V1* movement velocity against the load that elicits 1 m/s, v75 movement velocity against 75% of 1RM, PPU plyometric push up

Figure 5-2 Squat and bench press repetitions across time and groups



Data represented as mean± standard deviation. Group A: R80 – 4 sets, 1 repetition @80% 1RM, *Group B*: R40 – 4 sets, 2 repetitions @40%1RM, *Group C*: ROW – Light rowing, *Group D*: CON – control group

Figure 5-3 Effect of period for squat and bench press repetitions



Data represented as mean± standard deviation. *Periods* 1-4 represent the 4 weeks of intervention (i.e., period 1 = week 1) and the associated recovery modality based on randomisation.

Plyometric Performance

The main effect of condition was statistically significant (p=.02) and medium (n_p^2 =.08) for CMJ. The main effect for time was statistically significant for CMJ (p=0, large n_p^2 =.26) and PPU (p=0, large n_p^2 =.17). The main effect of period was statistically significant for CMJ (p=0, medium n_p^2 =.12) and PPU (p=0, large n_p^2 =.28). Data are presented in Figure 5-4 and Tables 5-1 and 5-2 in detail.

Table 5-2 Estimated marginal means and contrasts for time by group in performance outcomes

	Variable	Estimated means			Contrasts								
		Pre	*24hr*	*48hr*	*Pre vs 24hr*			*Pre vs 48hr*			*24hr vs 48hr*		
		Mean (CI)	*Mean (CI)*	*Mean (CI)*	*p-value*	*Estimate*	*SE*	*p-value*	*Estimate*	*SE*	*p-value*	*Estimate*	*SE*
R80 condition	Squat repetitions	13.78(12.25; 15.31)	-	13.47(11.94; 15)	-	-	-	.61	0.31	0.61	-	-	-
	CMJ (cm)	37(31.6; 42.5)	33.9(28.4; 39.4)	35(29.5; 40.5)	0	0.03	0.01	.02	0.02	0.01	.29	-0.01	0.01
	Squat v1 (m/s)	1.01(0.99; 1.04)	0.92(0.9; 0.94)	0.94(0.92; 0.97)	0	0.09	0.01	0	0.07	0.01	.26	-0.02	0.01
	Squat v75 (m/s)	0.59(0.53; 0.64)	0.5(0.44; 0.56)	0.55(0.49; 0.61)	0	0.08	0.02	.18	0.04	0.02	.11	-0.04	0.02
	Bench repetitions	15.43(13.74; 17.11)	-	14.2(12.51; 15.88)	-	-	-	.02	1.23	0.51	-	-	-
	PPU (cm)	15(13; 16.9)	13.5(11.6; 15.5)	14.7(12.8; 16.7)	.1	0.02	0.01	.91	0	0.01	.22	-0.01	0.01
	Bench v1 (m/s)	0.99(0.96; 1.02)	0.91(0.88; 0.94)	0.92(0.89; 0.95)	0	0.08	0.02	0	0.07	0.02	.76	-0.01	0.02
	Bench v75 (m/s)	0.47(0.41; 0.53)	0.4(0.34; 0.46)	0.44 (0.38; 0.5)	0	0.07	0.02	.24	0.03	0.02	.07	-0.04	0.02
R40 condition	Squat repetitions	13.75(12.2; 15.3)	-	13.5(11.95; 15.05)	-	-	-	.69	0.25	0.63	-	-	-
	CMJ (cm)	37.1(31.6; 42.6)	35.5(30; 41)	36.7(31.2; 42.2)	.1	0.02	0.01	.86	0	0.01	.26	-0.01	0.01
	Squat v1 (m/s)	0.98(0.96; 1)	0.93(0.91; 0.96)	0.97(0.95; 0.99)	0	0.05	0.01	.62	0.01	0.01	.03	-0.04	0.01
	Squat v75 (m/s)	0.58(0.53; 0.64)	0.51(0.45; 0.57)	0.57(0.51; 0.63)	0	0.08	0.02	.75	0.02	0.02	.02	-0.06	0.02
	Bench repetitions	15.15(13.45; 16.85)	-	15.32(13.62; 17.01)	-	-	-	.75	-0.17	0.53	-	-	-
	PPU (cm)	16.1(14.2; 18.1)	13.8(11.8; 15.8)	15(13; 16.9)	.01	0.02	0.01	.24	0.01	0.01	.26	-0.01	0.01
	Bench v1 (m/s)	0.99(0.96; 1.02)	0.9(0.92; 0.98)	0.97(0.94; 1)	.06	0.04	0.02	.51	0.02	0.02	.46	-0.02	0.02
	Bench v75 (m/s)	0.46(0.4; 0.52)	0.41(0.35; 0.47)	0.43(0.37; 0.49)	.01	0.05	0.02	.26	0.03	0.02	.39	-0.02	0.02

ROW condition	Squat repetitions	13.83(12.28; 15.38)	-	12.3(11.45; 15.55)	-	-	-	.19	0.83	0.63	-	-	-
	CMJ (cm)	37.6(32.1; 43.1)	35.3(29.8; 40.8)	36.9(31.4; 42.4)	.01	0.02	0.01	.62	0.01	0.01	.1	-0.02	0.01
	Squat v1 (m/s)	0.99(0.97; 1.02)	0.94(0.92; 0.97)	0.95(0.92; 0.97)	0	0.05	0.01	0	0.05	0.01	.99	0.00	0.01
	Squat v75 (m/s)	0.58(0.53; 0.64)	0.56(0.5; 0.61)	0.55(0.49; 0.61)	.39	0.03	0.02	.28	0.04	0.02	.97	0.01	0.02
	Bench repetitions	16.07(14.37; 17.76)	-	15.23(13.54; 16.93)	-	-	-	.12	0.83	0.53	-	-	-
	PPU (cm)	15.4(13.4; 17.4)	14.2 (12.2; 16.2)	14.6(12.7; 16.6)	.24	0.01	0.01	.56	0.01	0.01	.82	0.00	0.01
	Bench v1 (m/s)	0.99(0.96; 1.02)	0.93(0.9; 0.97)	0.94(0.91; 0.97)	.01	0.06	0.02	.02	0.05	0.02	.93	-0.01	0.02
	Bench v75 (m/s)	0.45(0.39; 0.51)	0.41(0.35; 0.47)	0.44(0.38; 0.5)	.06	0.04	0.02	.72	0.01	0.02	.27	-0.03	0.02
CTRL condition	Squat repetitions	13.08(11.53; 14.63)	-	13.16(11.61; 14.71)	-	-	-	.9	-0.08	0.63	-	-	-
	CMJ (cm)	37.6(32.2; 43.1)	34.9(29.5; 40.4)	36.5(31; 41.9)	0	0.03	0.01	.27	0.01	0.01	.12	-0.02	0.01
	Squat v1 (m/s)	0.99(0.97; 1.01)	0.93(0.91; 0.96)	0.94(0.92; 0.97)	0	0.06	0.01	0	0.05	0.01	.57	-0.01	0.01
	Squat v75 (m/s)	0.57(0.47; 0.59)	0.53(0.47; 0.59)	0.57(0.51; 0.63)	.14	0.04	0.02	1	0	0.02	.12	-0.05	0.02
	Bench repetitions	15.32(13.62; 17.01)	-	14.07(12.37; 15.76)	-	-	-	.02	1.25	0.53	-	-	-
	PPU (cm)	15.2(13.3; 17.2)	13.1(11.2; 15.1)	13.4(11.4; 15.4)	.01	0.02	0.01	.03	0.02	0.01	.93	0	0.01
	Bench v1 (m/s)	1(0.97; 1.03)	0.94(0.91; 0.97)	0.92(0.89; 0.95)	0	0.06	0.02	0	0.08	0.02	.49	0.02	0.02
	Bench v75 (m/s)	0.45(0.39; 0.51)	0.42 (0.36; 0.48)	0.43(0.37; 0.49)	.22	0.03	0.02	.57	0.02	0.02	.78	-0.01	0.02

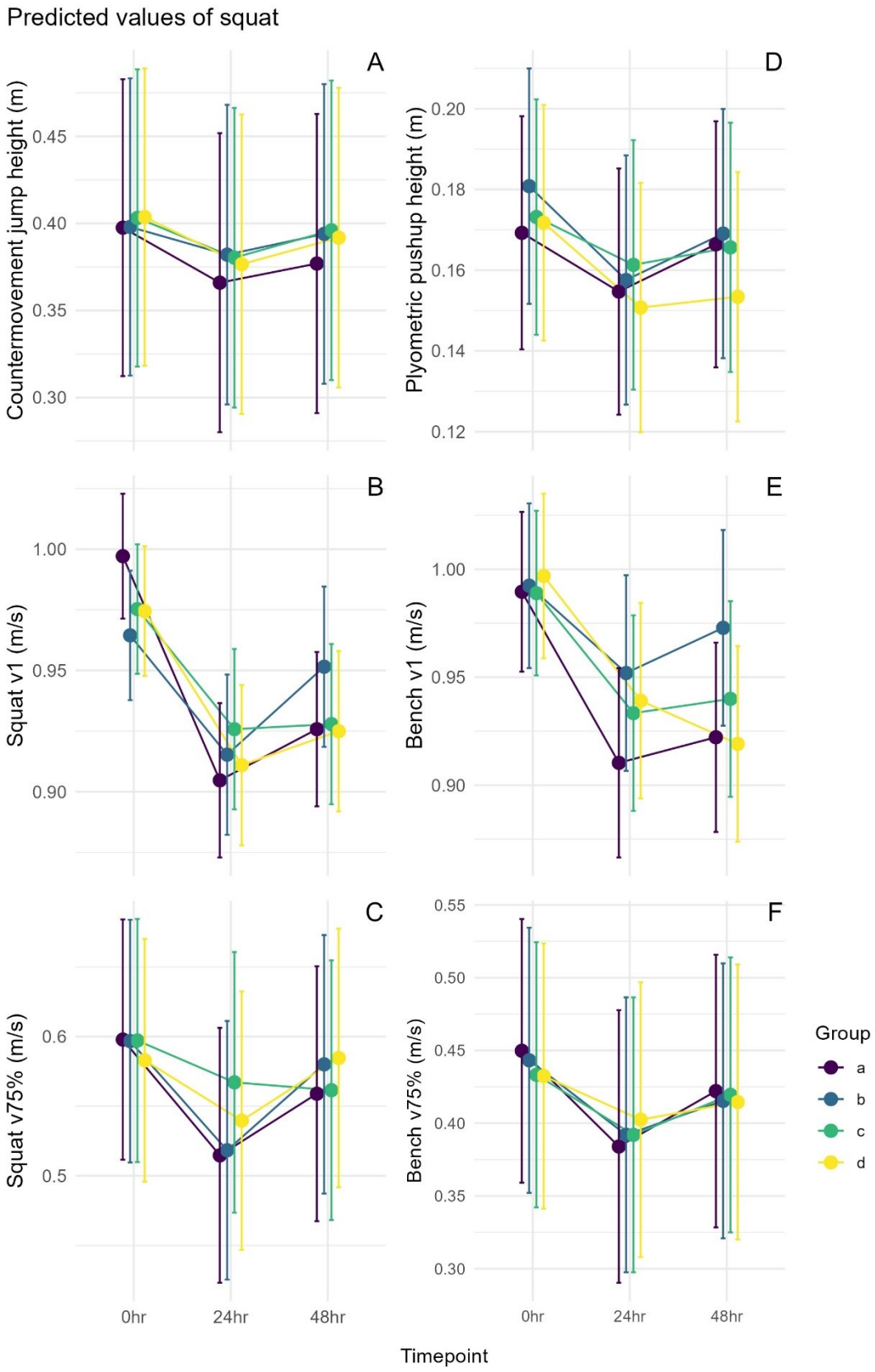
R80 4 sets x 1 repetition x 80% one repetition maximum (1RM), *R40* 4x2x40% 1RM, *ROW* 20 minutes light rowing, *CTRL* passive recovery control, *CMJ* countermovement jump,

PPU plyometric push up, *V1* movement velocity against the load that elicits 1 m/s, v75 movement velocity against 75% of 1RM

Velocity Performance

The main effect of condition was statistically significant (p=.02) and medium (n_p^2 =.08) for bench v1. The main effect for time was statistically significant for squat v1 (p=0, large n_p^2 =.43), squat v75 (p=0, large n_p^2 =.19), bench v1 (p=0, large n_p^2 =.32), and bench v75 (p=0, large n_p^2 =.19). The main effect of condition x time was statistically significant for squat v1 (p=.05, medium n_p^2= .01). significantly different in the 24 vs 48hr contrasts in the R40 condition (p=.03, SE=.01).). Additionally, the main effect of condition x time was statistically significant for bench v75 (p=.02, small n_p^2= .02), most notably in the 24 vs 48hr comparison (p=.07, SE=.02). Data are presented in Figure 5-4 and Tables 1 and 2 in detail.

Figure 5-4 Predicted values of squat



V1 movement velocity against the load that elicits 1 m/s, v75 movement velocity against 75% of 1RM

Section 4: Discussion

This is one of the few existing studies to assess the effects of AR methods following a damaging bout of RT for the lower and upper body in a resistance-trained population. Our aim was to determine if performance could be enhanced across various indices of RT repetition, strength and power performance following AR in the form of a low-load or high-load power-type session, an easy rowing session, or PR. Our hypotheses were partially supported by our findings. Specifically, in support of our hypotheses, R40 promoted significant post-RT recovery of v1 of the squat ($p=.03$). However, repetition, plyometric, and v75 performance favoured the null, with no significant changes in recovery detected between conditions.

Regarding velocity performance, there was significant improvement of squat v1 in the 24 vs 48hr comparison. Given the principle of specificity, it is perhaps unsurprising that R40 - a low-load power-type session - improved recovery of v1. Specifically, v1 load was typically between 35-45% of 1RM for the squat and bench press and the low-load power-type session consisted of four sets of two repetitions at 40%1RM. Indeed, previous research which reported improved recovery used an AR protocol of five sets of 10 repetitions with only 10% of 1RM in the bench press after a damaging bout of bench press (Bartolomei et al., 2019). These results were accredited to increased blood flow from AR without additional fatigue, thus, leading to reductions in muscle swelling and the inflammatory response which may have also occurred in the present study. Further, a PAP priming effect from R40 can't be ruled out, possibly resulting in a short-term supercompensation of explosive strength performance (Bishop et al., 2008; Mujika, 2009; Raastad & Hallen, 2000; Wyland et al., 2015). Previously, Tsoukos and colleagues (Tsoukos et al., 2018) reported improved explosive strength performance in the 24-48 hours after a priming session (greatest at 24 hours), which the authors attributed at least partially to the absence of fatigue, allowing for this enhanced performance to be expressed. Their protocol of five sets of four repetitions with 40% of 1RM using the jump squat exercise, which was most similar to R40 in the present study but of higher volume, suggests that slightly

greater loads (as their participants likely produced higher forces given they left the ground each repetition) and volumes than R40 used possibly can be completed without additional fatigue accumulation, impairment to recovery, and even a potential enhancement of subsequent performance. For example, in the present study, significance was found in the condition by time interaction in bench v75, most notable in the R80 condition; however, this was non-significant ($p = 0.07$). Thus, this may agree with the idea that heavier loads than 40% of 1RM may be favourable, though single repetitions with 80% of 1RM possibly too heavy for some individuals, thereby interfering with the recovery process (Tillin & Bishop, 2009; Zarrouk et al., 2011).

Another consideration is that the present study's protocol, unlike prior research by Tsoukos and colleagues (Tsoukos et al., 2018), may be more favourable for barbell-based strength athletes – at least from a specificity of training standpoint - as jump squats are not typically programmed for those with the principal goal of increasing hypertrophy and maximal strength. Nonetheless, it seems that eliciting a potential priming effect is contingent on the overall volume and load prescription, as there may be a point of diminishing returns. For example, Raastad and colleagues (Raastad & Hallen, 2000) examined neuromuscular fatigue and recovery after RT with high (3 sets 3RM back and front squats and 3 sets of 3-repetition 6RM knee extensions) and moderate (70% of high protocol) loads. Squat jump height decreased by 12% 15 minutes after the high-load protocol and remained reduced 22 hours after as well, while jump height did not significantly change 15 minutes following moderate load, but then increased 5% higher than baseline 22-33 hours post-moderate protocol. Therefore, with significant improvements in v1 in the R40 condition and notable improvements in v75 in the R80 condition, this perhaps demonstrates the specificity of power-based AR prescriptions for subsequent performance outcomes.

We speculated that R80 would improve repetition performance on the subsequent day; however, no significant improvements in repetition performance were detected and some individuals performed slightly fewer repetitions than at baseline. Thus, it may be that regardless of total volume, the absolute load of 80% of 1RM 24 hours after a damaging protocol and

before a session is too taxing to act as AR. For example, 80% of 1RM may be heavy enough on the barbell back squat and bench press that individuals must approach the exercise with a certain degree of focus due to coordination demands (i.e., bracing, balance) (Haff, 2000; Saeterbakken & Fimland, 2013). Similar to the results from Mujika and colleagues (Mujika, 2009), if excess fatigue is present, it may compound during an attempt at AR and thus, delay recovery. Interestingly, Zourdos and colleagues (Zourdos et al., 2016) reported greater training volumes when a power session of single repetitions with 80-90% 1RM was spaced 48 hours between two sessions (i.e., on the Wednesday, between a Monday and Friday session) during a six-week mesocycle. Thus, it is possible that AR with this load may be tolerable if at least 48 hours is given between sessions to allow for sufficient recovery, compared to the present study where the damaging bout, AR, and the testing session were all on subsequent days. The protocol used by Zourdos and colleagues (Zourdos et al., 2016) may provide utility for those wishing to enhance muscular strength and hypertrophy (Baz-Valle et al., 2022; Currier et al., 2023; Ralston et al., 2017). However, to our knowledge, Zourdos et al's work (Zourdos et al., 2016) and the present study are the only to investigate this research question, warranting further research.

It was anticipated that plyometric recovery and performance would be improved by R40; however, no significant changes were observed. Performance in both the CMJ and PPU typically recovered back to or just below baseline in all conditions and importantly, no significant negative effects were detected. This finding contradicts previous research where training to failure led to greater recovery times for CMJ, with it not returning to baseline at 48 and even 72 hours post failure training (Morán-Navarro et al., 2017). However, Moran Novarro and colleagues prescribed a damaging bout of three sets of 10 repetitions, specifically to muscular failure, with 75% of 1RM on the Smith machine squat and bench press. Therefore, while speculative, it is possible that the Smith machine may have decreased the stability, coordination, and technical demands allowing for the participants to induce greater local muscular fatigue, possibly increasing recovery demands (Dourado et al., 2023; Soares et al., 2015). We defined failure as volitional failure and used the free weight barbell back squat and

bench press, so it is possible these variables influenced performance and true muscular failure was not achieved, potentially leading to these unanticipated results.

Previously, AR prescribed as low intensity cycling resulted in similar outcomes as CWI for minimizing the inflammatory and stress responses after RT (Peake, Roberts, et al., 2017). Based on these findings, we included the ROW condition, although we didn't anticipate ROW would outperform the power-type conditions. Part of our rationale for not anticipating a superior recovery effect from ROW, is due to the prescription of RT in the study by Peake and colleagues not being clearly defined in terms of proximity to failure. Since no specific performance outcomes were measured, uncertainty remained regarding the practical efficacy of low intensity cardio as a RT AR modality. In the current study, ROW was prescribed as 20 minutes at 50-60W in an attempt to provide a low intensity aerobic stimulus targeting the lower and upper body. However, it is possible that this modality and prescription was insufficient to significantly improve blood flow or other potential mechanisms of recovery. On average, Borg RPE scores (Borg, 1998) were "8" - between extremely light and very light. This level of exertion may not have been high enough to promote AR, suggesting that greater difficult of aerobic exercise may be tolerated and potentially beneficial; however, specific prescription to enhance recovery is uncertain.

Contrary to previous literature, AR was not significantly better for recovery compared to PR outside of v1. Specifically, AR of very low loads in the bench press resulted in greater recovery of both maximal strength and power in AR vs PR (Bartolomei et al., 2019) with PR consisting of sitting in a room for 15 minutes. However, in the present study, while there was no additional recovery method completed for the CTRL session, the participants still reported to the lab for plyometric and movement velocity measures. Therefore, even in the CTRL condition, the participants still engaged in some form of activity (the testing itself) which may have acted as AR, and possibly influenced our results. Indeed, it is possible that complete training cessation may be viable for recovery as some research indicates strength and power are at least preserved and potentially improved following ~3 days of training cessation (Pritchard et al., 2018; Travis et al., 2022). This time away from training may allow for decreases in fatigue

and improved recovery by allowing the body to adequately rest. However, these training cessation lengths are greater than what may be feasibly prescribed during typical training. Thus, future research is needed to determine whether one or two days of training cessation would be sufficient for fatigue dissipation.

The current study is not without limitations. First, this study only included resistance-trained males and only used the barbell back squat and bench press exercises; thus, the results presented may not extrapolate to other populations or exercises. Importantly, other exercises will likely be included in a training program which may increase recovery demands. Future research should further examine the effects of AR in different exercises and RT protocols that may more accurately reflect traditional RT sessions to improve ecological validity. Further, future research should investigate the effects of true PR with zero additional activity (i.e., no mid-testing session) for different lengths (24-72 hours) to clearly distinguish any potential differences between AR and PR. Further, four sets to volitional failure with 80% of 1RM were completed to induce muscle damage, which while based on prior research, is relatively arbitrary. Thus, it is unknown how more or less damaging protocols would affect the results, which may be a valuable direction for future study. Due to the effect of period demonstrated in the current study, it is possible that a training/learning effect occurred where individuals became more familiar with performing repetitions to failure; thus, this may have influenced performance which should be accounted for via a washout period in future research. Finally, due to the multifaceted nature of recovery, it is possible that other factors may have influenced recovery. For example, sleep (Bird, 2013), nutrition (Beck et al., 2015) and stress (Bartholomew et al., 2008) can influence recovery and performance; while participants were asked to keep these variables as consistent as possible, these are often difficult to accurately control and monitor.

In summary, the present study demonstrates that after a damaging bout of RT in the lower and upper body, AR in the form of a lower-load power-type session significantly improved recovery in v1 of the squat and bench press. Further, no additional improvements in recovery were experienced in the other AR modalities. Importantly, however, the AR methods used in this study did not significantly impair performance recovery and arguably even the

CTRL group performed some AR via day two testing; therefore, practically, any of the studied AR methods may be more favourable than other purported recovery methods such as CWI, which can negatively impact hypertrophy if used chronically (Fyfe et al., 2019; Roberts et al., 2015).

Section 5: Practical Applications

If low-load movement velocity performance is a desired outcome, implementing AR in the form of low-load power-type sessions may promote recovery and induce a potential PAP priming effect the following day. For example, if there are two intense bouts of exercise programmed within a micro cycle, placing a low-load power-type session between them may enhance recovery and improve performance on the subsequent session. Additionally, coaches and athletes may utilize AR sessions as an autoregulation tool. Specifically, if a difficult session is prescribed and the individual determines they do not feel adequately recovered, a lighter session such as the one utilized in this study can be performed instead, and then harder session delayed until recovery occurs (if scheduling allows it). Thus, rather than a potentially impaired performance on a high priority day, an easier session can be completed to still practice a power-based skill and allow for improved recovery.

Chapter 6 Discussion, future research directions, and practical applications

Section 1: Discussion

This thesis aimed to determine the importance of recovery for RT microcycle construction as established in the literature and in the eyes of RT coaches. In addition to surveying the literature and practitioners, quantitative relationships between RT recovery and performance were explored. Finally, an empirical investigation of the impact of incorporating a low-volume power-type RT session following a damaging bout of RT on subsequent day recovery and performance in RT men was conducted. The literature review in Chapter 2 revealed that multiple RT variables may impact total recovery time and if insufficient recovery is experienced, performance may be impaired. Furthermore, evidence suggests that AR may be beneficial; however, limited evidence exists for improving recovery between RT sessions.

The first investigation (Chapter 3) was an anonymous survey that investigated current recovery-related practices of coaches who create RT programs. Notably, 97% of coaches collectively attributed “a lot”, “a great deal”, or “a moderate amount” of importance to program design for recovery, highlighting the significance of appropriately designed training programs for fatigue management. These findings agree with research on training periodisation, which emphasises the need to balance the necessary stress for promoting adaptation while managing the accumulation of fatigue (Mujika et al., 2018; Turner, 2011). The majority of coaches (61%) primarily monitor athlete recovery using methods such as muscle soreness (84%) and sleep (80%), acknowledging the well documented negative impacts of elevated muscle soreness (Peake, Neubauer, et al., 2017) and insufficient sleep (Craven et al., 2022) on performance. Additionally, sRPE (70%) and RIR-based RPE (63%) are commonly employed for monitoring recovery, with sRPE valued for its simplicity in representing workload and intensity, while RIR/RPE offers specific insights into changes in force production during individual sets, providing information regarding intra-session recovery in a practical and reliable manner (Helms et al., 2020). Seventy three percent of coaches assessed session difficulty by considering overall session intensity (94%) rather than individual exercises. Thus, considering session

difficulty to determine their placement within a microcycle to ensure difficult sessions are not too close together, so as to not potentially impair recovery or performance, may have merit. About half of coaches deliberately incorporate sessions with lower volume (51%), load (51%), and proximity to failure (50%), primarily to ensure adequate recovery between sessions (89%, 75%, and 67% respectively). The most common application of this practice was to include one session per week with reduced volume and load (60%), while incorporating one (44%) or two (41%) sessions with lower proximity to failure was also common. Interestingly, coaches' decisions regarding incorporating sessions with lower proximity to failure parallels the ongoing, varied interpretations regarding the impact of training to failure on muscular adaptation, highlighted in recent studies (Refalo et al., 2023; Robinson et al., 2023).

Since recovery was deemed important for RT program design both in the literature and practice of current coaches, a randomised crossover study was conducted to explore the ability of different monitoring metrics to assess recovery and predict RT-relevant performance in 13 RT men. PRS scores prior to exercise significantly predicted squat and bench press performance, where higher scores (indicating better recovery) were associated with improved squat and bench press repetition performance (0.42 and 0.51 repetitions for a one-unit increase respectively). Originally designed to gauge subjective recovery and sprinting ability, the PRS scale showed promise in identifying inadequate recovery and decreased performance (Laurent et al., 2011) and was supported further by our study, but more specifically to RT. Furthermore, higher perceived muscle soreness scores were associated with decreased bench press repetition performance with a one unit increase in soreness corresponding to about a half-repetition decrease in bench repetitions. The average velocity of two repetitions at 75% of 1RM strongly predicted repetition performance with a 0.1m/s increase in squat v75 corresponding to about a one repetition increase in squat repetitions (1.08); however, large confidence intervals suggest these associations are variable (CI=0.15-2.00). This finding aligns with previous research indicating that velocity loss persists 24 hours after training to failure, with recovery occurring by the 48-hour time point in the squat and bench press (Morán-Navarro et al., 2017). Additionally, consistent with our findings, a case series demonstrated significant relationships between RIR-based RPE scores and 1RM performance at 85% 1RM (Zourdos et al., 2015),

demonstrating the potential utility of using low-repetition, moderate- to high-load performance as an acute performance predictor for maximal strength. Bench press v75 strongly predicted PPU performance with a one-unit increase in bench press v75 (0.1m/s) corresponding to a 0.84cm increase in PPU height. In the lower body, squat v1 was an indicator of performance against medium loads and significantly predicted CMJ performance. Therefore, v1 and v75 may be used as tools to measure neuromuscular fatigue and can be incorporated during a barbell specific warmup which also serves to assess levels of fatigue and recovery. HRV significantly predicted PPU performance, providing insight for its potential use where data on the use of HRV as a RT monitoring metric are scarce (Flatt et al., 2019; Schneider et al., 2019). However, due to individual differences, the rather small difference in PPU height (one-unit increase in HRV = 0.02cm PPU height) and the large variation in HRV (~61.99± 22.71), the use of this metric as a monitoring tool for RT should be viewed cautiously. Additional research is needed with larger samples, and if a practitioner was to use HRV as a RT monitoring tool, it should be in conjunction with other metrics to provide a more comprehensive assessment of recovery. In practice, these objective and subjective metrics offer non-invasive, straightforward tools that are easy to apply and provide a comprehensive assessment of recovery and subsequent performance.

After establishing the importance of recovery in microcycle design (Chapters 2-3) and demonstrating the utility and practicality of different metrics to measure recovery and predict RT-relevant performance (Chapter 4), Chapter 5 was needed to empirically compare different recovery strategies to hopefully provide novel, performance enhancing strategies to coaches and athletes. This study consisted of a randomised crossover study in 13 RT men, comparing the effect of three different AR methods and PR on RT relevant performance following a damaging session of RT. Of note, squat v1 was significantly improved following the R40 condition in the 24 vs 48-hour comparison ($p=.03$), perhaps due to the specificity of 40% 1RM with typical v1 loads, which typically fell between 35-45% of 1RM. Further, the low absolute load and volume of this prescription likely produced minimal to no additional fatigue, providing minimal interference with the recovery process and potentially invoking a priming effect similar to previous low-load priming research (Bartolomei et al., 2019; Tsoukos et al., 2018).

Additionally, a condition by time effect was significant for bench v75 comparing the 24 vs 48-hour time points, although the condition-specific post-hoc comparison did not meet the a priori alpha cutoff for the R80 condition (p=.07). Assuming this low, but non-significant effect is practically meaningful, this finding may also be attributed to the similarities of load and the principle of specificity, given v75 and 80% of 1RM are reasonably similar. This notion is partially supported by prior work from Zourdos and colleagues (Zourdos et al., 2016), where a power session with single repetitions at 80-90% of 1RM completed 48 hours before a strength session allowed for greater training volumes to be performed. Therefore, in aggregate, a low-volume power-type session with either light, or more moderate to heavy loads placed 24-48 hours prior to an important session may allow for greater subsequent performance for light, or moderate to heavy loads, respectively.

Section 2: Limitations

This thesis has several limitations, primarily due to COVID-19 lockdowns in New Zealand, which greatly affected study designs and data collection. When data collection for the randomised control trial was about to commence, New Zealand was placed in the first lockdown, bringing collection to a halt. Once the lab reopened following this lockdown, only one participant completed the trial before Auckland was placed into another lockdown. Once these lockdowns concluded, recruiting participants was still challenging due to the high prevalence of COVID-19 in the community, frequent occurrence of illness, and the understandable reticence of potential participants. Scheduling and adherence remained an issue as participants and researchers continued to contract COVID-19 throughout data collection, with each COVID-19 contraction leading to a mandatory one-week quarantine and the subsequent time needed for any quarantined participant to return to their normal training schedule and undo any effects of de-training. Despite these difficulties, extended timelines, and adjustments to the original plan, a sufficient amount of data was eventually collected. Outside of COVID-19 related constraints, the principal limitations of the research are related to the multi-faceted nature of recovery, a relatively small sample size, and the balance between laboratory control and ecological validity. Specifically, recovery and performance are multi-dimensional,

and not all aspects of them could be represented by the metrics in the present research. Further, while participants acted as their own controls in the crossover, and were asked to keep their normal routines as consistent as possible and variables of interest accounted for (i.e., sleep, nutrition, training program outside of the study, etc.), we cannot guarantee that these potentially confounding factors were held constant in both arms of the crossover, or that any differences were perfectly controlled for with randomisation considering the small sample size. Further, while three forms of AR were compared to PR, the PR condition did not consist of complete rest, as testing itself caused some unavoidable degree of stimulus and fatigue. Finally, the trial included only RT men, and the exercises and proxies measured were largely specific to the barbell back squat and bench press. Therefore, the inferences should be viewed conceptually rather than absolutely, and in the context of which they were studied, rather than applied in all contexts and to all populations.

Section 3: Practical applications

Based on the findings in this thesis, the following recommendations are suggested:

- Training to failure can lengthen recovery, but if included strategically with sufficient rest between sessions targeting the same muscle groups, or in consideration of within-session exercise order, may still be beneficial. Machine-based or isolation exercises may be more suitable for failure training than complex, multi-joint barbell movements. Volume allocation is crucial when considering training to failure, with optimal ranges per recent meta-analyses typically falling between 10-20 sets per muscle group for hypertrophy and 5+ sets per movement for strength. If high volume training is implemented, especially combined with failure, it should be strategically implemented, perhaps in specialisation phases such that only a single lift or muscle group is assigned high volumes, while others are not, to prevent excessive fatigue accumulation. Frequency manipulation can help to manage fatigue by spreading volume across multiple sessions. Ensuring no single session produces an excessive demand on recovery may improve the effectiveness of entire microcycles. Consideration should be

given to exercise characteristics such as those that target the lower body, involve multiple joints, recruit greater musculature, emphasise the lengthened muscle position, and/or eccentric portion of the movement, as each may extend recovery time frames. When sessions combine these factors, especially with higher volumes and closer proximities to failure, a DUP format whereby an easier session providing AR can precede or follow to allow for gradual recovery. Further, training opposing muscle groups or choosing low-fatigue exercises consecutively on such AR sessions can aid recovery, possibly through improving blood flow during the recovery period. Finally, such sessions, if they are power-based and low volume in nature, can serve as tapering and priming sessions before testing, possibly improving performance.

- Coaches involved with RT program design consider sleep, program design, and nutrition as primary variables that influence recovery and are typically tracked via self-reported data. Importantly, given the frequent use of self-reported data, communication and education regarding recovery may be valuable for improving the coach/athlete relationship.
- Further, given the findings in this thesis, coaches can potentially augment the use of self-reported data with metrics that may be predictive of performance. Specifically, PRS scores taken before squat and bench press exercises may accurately assess recovery and predict certain types of performance, offering further options for autoregulating training sessions. Lower scores may prompt adjustments in load, volume, or proximity to failure, while higher scores may allow for increased stimulus. Further research is needed to confirm the specific relationship between scores and RT variable changes, but coaches are encouraged to monitor these variables in individual athletes to find predictive relationships that can be used in practice. Based on the present data, squat repetition performance may be prioritised on days with high PRS scores, while easier sessions may be chosen on days with poorer recovery to avoid excessive fatigue. Additionally, velocity measurements, particularly squat v1 for CMJ prediction and v75 for recovery assessment against high loads, may provide valuable insights. Velocity, along with RIR-based RPE offers comprehensive feedback on recovery; however, if

velocity devices are not available, RIR-based RPE alone may suffice. While HRV offers a non-invasive means of assessing recovery and upper body power performance, more research is needed on its efficacy for RT. Therefore, a multi-dimensional approach using various monitoring tools tailored to desired outcomes is recommended for accurate assessment of post-RT recovery and subsequent performance prediction.

- If the goal is to improve low-load, high movement velocity performance, low-load power sessions may facilitate recovery and potentially elicit a PAP priming effect on the following day. For example, placing a low-load power session between two intense exercise sessions in a microcycle could aid in recovery and boost performance in subsequent sessions. Coaches and athletes may also use AR sessions as a tool for autoregulation. If an individual feels insufficiently recovered for a challenging session, they could opt for a lighter session similar to the one described in Chapter 5 to both practice a power-based skill, preventing detraining and stagnation, while also allowing for improved recovery. Thus, the more demanding session can be postponed (if scheduling allows) until adequate recovery is achieved, thereby avoiding potentially diminished performance on a high-priority day.
- As previously discussed, the literature extensively documents variation in individual responses to training, thus, implementing strategies from this discussion should be approached with consideration for individualised needs. It is recommended that practitioners closely observe both objective and subjective individual data to evaluate fatigue and recovery demands when determining if such monitoring should dictate when training be adjusted.

Section 4: Recommendations for future research

- Chapter 2 elucidated that limited research exists examining the long-term effects of AR within a microcycle. Specifically, no studies measured the longitudinal effect of RT programs with integrated AR sessions– which have been shown to acutely improve performance – on longitudinal adaptations, such as strength and hypertrophy.

- Chapter 3 demonstrated that coaches who currently provide RT programs give importance to recovery during the RT programming process; however, this information was collected via an anonymous survey. To add to this literature, conducting qualitative interviews with coaches to get more detailed information regarding their perceptions of, motivations for and lived experiences related to such decisions is suggested.
- Chapters 4 and 5 examined exclusively RT men using the barbell squat and bench press. Thus, future research should examine different populations and exercises, exploring other types of RT sessions performed by mixed sex, and female samples, to determine whether these findings apply more broadly.
- While Chapter 2 revealed limited evidence that biochemical analysis of recovery can be incorporated into a comprehensive assessment of recovery, biochemical analysis was not included in Chapters 4 and 5. While the present thesis focused on practical methods of assessment, as technology advances, biochemical analysis may become commercially available. Therefore, future research should investigate recovery and RT performance using biochemical analyses in varying durations of training.
- In Chapter 5, PR did not consist entirely of no activity. Thus, future research should examine the effect of complete training cessation, as well as for different lengths varying from 24-72 hours to provide clearer distinctions between the potentially disparate effects of AR and PR.

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Appendix A Ethics approval (Chapter 3)

Auckland University of Technology Ethics Committee
(AUTEC)

30 March 2023

Eric Helms
Faculty of Health and Environmental Sciences

Dear Eric

Re Ethics Application: **23/82 An Examination of Coaches' Perceptions of Recovery in Designing Resistance Training Mesocycles**

Thank you responding to AUTEC's conditions.

Your ethics application has been approved for three years until 30 March 2026.

Non-Standard Conditions of Approval

1. In the Information Sheet update the date of 21st of April to be 4 weeks out.

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact ethics@aut.ac.nz
(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: csousa2016@fau.edu

Auckland University of Technology, D-88, Private Bag 92006, Auckland 1142, New Zealand.
T: +64 9 921 9999 ext. 8316: E: ethics@aut.ac.nz: www.aut.ac.nz/researchethics

Appendix B Ethics approval (Chapters 4 and 5)

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

23 September 2020

Eric Helms
Faculty of Health and Environmental Sciences

Dear Eric

Re Ethics Application: **20/54 Implementation of a low-volume power-type day to improve resistance training performance and recovery**

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 22 September 2023.

Non-Standard Conditions of Approval

1. Amendment of the Information Sheet as follows:
    a. Complete the sentence in the 'an invitation' section.
    b. Update the name of the Executive Secretary to Dr Carina Meares.

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: csousa2016@fau.edu

Appendix C Survey questions from Chapter 3

This is a URL to access the survey questions that were used for Chapter 3

https://aut.au1.qualtrics.com/jfe/form/SV_bCb1PI7dEzvtqMm