The Impact of COVID-19 Isolation on Strength and Power Profiles in Professional Rugby Union Players

Morgan Hutchings

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School of Sport and Recreation
Primary Supervisor: Dr Adam Storey
Secondary Supervisor: Dr. Casey Watkins

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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 that which appears in the citations and acknowledgements. Nor does it contain material which to a substantial extent I have submitted for the qualification for any other degree of another university or other institution of higher learning.

Signature:

Date: 11/08/23

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Ethical Approval

The Auckland University of Technology Ethics Committee (AUTEC) approved this research on 02/05/2023. Ethics Application: 22/212.

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List of Common Abbreviations

CMJ	Countermovement Jump	RFD	Rate of Force Development
DJ	Drop Jump	GRF	Ground Reaction Force
Hip ADD	Hip Adduction	SSC	Stretch-Shortening Cycle
Hip ABD	Hip Abduction	COVID-19	Coronavirus Disease
RSI	Reactive Strength Index (m/s)	COM	Centre of Mass
$RSI_{modified}$	Reactive Strength Index Modified (m/s)	COD	Change of Direction
cm	Centimetre	m	Metre
N	Newton	s	Second
m/s	Meters per second		

Abstract

The aim of this study was to identify the impact of a 10-16 day COVID-19 isolation on lower-body strength and power variables in 32 professional rugby union players. **Methods**: The presentation of COVID-19 naturally split the cohort into four groups including negative cases (Alpha n= 14) and positive cases of differing isolation lengths based upon the presence of positive COVID-19 PCR test results (Bravo n= 8, Charlie n=8, Delta n=2). All players underwent a room-based exercise program during this isolation period, which differed in length (days) according to group. Countermovement jump height (cm), drop jump reactive strength index (m/s), hip adduction (Hip ADD) and hip abduction (Hip ABD) isometric strength (N) was collected at four time points (Pre1, Pre2, Post, RTP) using ForceDecks Dual Force Plate System and ForceFrame Strength Testing System by Vald Performance Human Measurement Technologies (BNE, QLD, AUS). A linear mixed model was used for statistical analyses. **Results**: No significant interactions between timepoint and group were found in any variables. Hip ADD (p= 0.00) and Hip ABD (p= 0.00) significantly improved over time. Drop jump reactive strength index significantly (p= 0.01) differed across group, through which Charlie had a larger RSI than all other groups, whilst being significantly weaker in Hip ABD (p= 0.02). Countermovement jump height did not change across time or group and experienced the greatest variability in results (conditional R^2= 0.18, marginal R^2= 0.70). **Conclusion**: The room-based exercise program was effective at maintaining lower-body power but had a greater influence on lower-body strength-oriented variables. These findings are in contrast to our hypothesis which predicted lower-body power variables to be more susceptible to significant decay effects than lower-body strength variables.

Chapter: 1 Introduction and Rationale

1.1 Background

Rugby union is essentially the construction of collisions, intermittent periods of maximal or high intensity activity, and low activity or rest (Quarrie et al., 2013). Rugby union players must be strong and powerful to effectively meet the demands of the game, fulfill their positional roles, and optimise their overall performance (Posthumus et al., 2020). Forwards must contest for and retain possession in various scenarios such as scrums, mauls, rucks, and lineouts and therefore, require high levels of muscular strength in order to produce maximal force (Posthumus et al., 2020). Conversely, backs predominately capitalise on possession through offensive plays, requiring greater power to accelerate, decelerate and change direction at high speeds (Posthumus et al., 2020). Thus, the optimal periodization of strength and power variables is required to allow a rugby union players to perform at their full potential (Kirby et al., 2010). Players must obtain established physical qualities for the purpose of performance enhancement as well as injury prevention. This is due to the essential role that musculoskeletal strength, inter-limb symmetry, and intra-limb balance play in an individual's predisposition to acute muscle injuries (de la Motte et al., 2017; Lehance et al., 2009; Stokes et al., 2020). Moreover, a player's strength and power capabilities impact both their sports performance and susceptibility to injury (Young, 2006).

Training cessation refers to the temporary or permanent discontinuation of a training program, whereas reduced training involves the nonprogressive reduction in training quantity to optimise physiological and performance adaptations (Mujika & Padilla, 2000a). The unprecedented nature of a COVID-19 isolation, lockdown, or quarantine ensures that training restrictions in this context do not coincide with either of the above two definitions (Cohen et al., 2021). While isolations restrict the movement of those who have tested positive for COVID-19, quarantines restrict the movement of those who have been exposed to COVID-19 (but may not have tested positive) or have travelled to another country (Mahase, 2021). In turn, lockdowns restrict the movement of everyone within a designated area and involves the partial or complete shutdown of private, public, and education facilities (Mahase, 2021). The training stimuli elicited within a COVID-19 imposed training restriction is dependent on the constraints within that specific environment, causing the subsequent detraining effects to vary across cohort, exercise intervention, and training restriction length (Mujika & Padilla, 2000a). COVID-19 symptoms, availability of space, and access to equipment are all examples of the constraints that an athlete may have to navigate during a COVID-imposed training restriction. Aligned with the reversibility principle of training, detraining occurs when the adaptive response to a training stimulus is diminished due to the training stimulus' insufficiency (Mujika & Padilla, 2000a, 2000b). In turn, this maladaptive response can lead to a decrease in sport performance or an increase in risk of injury. One example of a detraining effect is the deterioration of strength or power capabilities during a COVID-19 isolation (Stokes et al., 2020).

The majority of studies investigating COVID-19 influences on lower-body strength and power have been conducted on youth or elite footballers (Alvurdu et al., 2022; Asimakidis et al., 2022; Cohen et al., 2021; Dauty et al., 2022; Demir et al., 2021; Grazioli et al., 2020; Moreno-Pérez et al., 2020; My et al., 2022; Paravlic et al., 2022; Parpa & Michaelides, 2021; Pedersen et al., 2021; Pucsok et al., 2021; Rampinini et al., 2021; Villaseca-Vicuña et al., 2022; Wagemans et al., 2021). The very few other studies investing the impact of COVID-19 on strength and power qualities have involved non-contact sports such as basketball, handball, futsal and badminton. Thus, given the proposed significance of strength and power variables to rugby performance and injury prevention, it would be beneficial for practitioners to understand how these qualities are impacted by a COVID-19 isolation in contact sport athletes. Such research would enable practitioners to implement exercise interventions that minimize decrements or better maintain lower-body strength and power during a COVID-19 isolation and/or quarantine and/or lockdown.

1.2 Purpose Statement

The primary purpose of this dissertation was to better understand what impact a COVID-19 isolation period has on lower-body strength and power capabilities in professional rugby union players. This research was conducted for the following reasons:

1) To date, there is a limited number of previous studies that have conducted an investigation such as this on athletes involved in a collision sport like rugby union.
2) To date, there are a very limited number of studies which effectively analyse the changes in performance metrics between positive and negative COVID-19 cases in professional athletes who are placed under the same isolation constraints.
3) To give insight into the range of expected physiological decay in athlete profiles and provide recommended strategies to better maintain performance measures.

1.3 Research Aims and Hypothesis

The primary aims of this investigation were to; 1) identify the impact of a COVID-19 isolation period on lower-body strength and power variables in professional rugby union players and, 2) determine whether inter-individual differences in physical response varied across groups with differing contraction status (COVID-19 positive versus COVID-19 negative) and isolation length. Due to the heightened sensitivity of power qualities to decay, we hypothesised that lower-body power would be more susceptible to decay than lower-body strength. We also hypothesised that players who spent less time in the COVID-19 isolation, would have a better chance of maintaining strength and power levels than those who did contract COVID-19 (COVID-19 positive).

1.4 Structure of the Dissertation

Chapter two of this dissertation is a review of the current literature which focuses on the impact of COVID-19 imposed training restrictions on strength and power performance. This review highlights the common test metrics and modalities used for lower-body strength and power testing.

Chapter three is a retrospective study where professional rugby union players completed jump performance and isometric hip strength testing before and after a COVID-19 isolation which naturally split the team into four groups, each with varying isolation lengths dependent on positive contraction, or lack of.

Chapter four is the final summary and conclusion for this dissertation. Limitations, practical applications, and areas for future research will be put forth in this chapter.

Chapter: 2 Literature Review of the Impact of COVID-19 on Strength and Power Performance and Common Test Metrics and Modalities

2.1 Prelude

The emphasis of this chapter was to highlight the impact of various COVID-19 imposed training restrictions (isolation, lockdown, quarantine) on athletic performance. The key focus of this chapter was to synthesize, compare, and contrast findings from current research within the field and identify potential gaps in the literature. The purpose of this chapter was to identify expected decay, maintenance, and improvements in strength and power variables across COVID-19 imposed training restrictions that vary in time length and type. The second purpose of this chapter was to determine common testing methodology and equipment used to collect lower-body strength and power data. The results of this investigation help to reiterate the importance for practitioners to understand the influence of a COVID-19 imposed training restriction on athletic performance and strategies in which to mitigate these.

2.2 Introduction

Around the world, preventative social distancing strategies such as isolations, quarantines, and lockdowns, have been implemented to reduce the spread of the infectious respiratory disease, COVID-19. Isolations require individuals who have tested positive for COVID-19 to remain secluded from others in a hospital or at their homes for seven to fourteen days (Alvurdu et al., 2022; Ganesan et al., 2021). Critical workers who become household contacts are able to work if they return daily negative rapid antigen tests (RATs) (NZ Doctor, n.d.). Quarantines require individuals who have been exposed to COVID-19 (but may not have tested positive) or travelled to another country, to remain at home or in a hotel for a period of time ranging from one to two weeks (Mahase, 2021). Lockdowns restrict the movement of people and involve the complete or partial shutdown of private, public and education facilities (Mahase, 2021). The length of each isolation, quarantine, and lockdown period differs depending on the countries' rules and regulations. For example, the current isolation period is 7 days in New Zealand and 5 days in the United Kingdom (NHS, 2022, August 31; Unite against COVID-19, 2022, November 10). Moreover, the impact of contracting the COVID-19 virus on an individual's health and wellbeing can vary, with common symptoms including a fever, cough, dyspnoea, altered taste or smell, headache, sore throat, rhinorrhoea, sneezing and fatigue (BMJBestPractice, 2022). As of the 2nd of August 2023, there have been 6,953,743 COVID-19 deaths worldwide as reported to the World Health Organization (World Health Organisation, 2023, August 2).

Great measures have been taken within the sporting realm to prevent the exposure of COVID-19, such as the stagnation, postponement and cancellation of sporting events and activities (Andreato et al.,

2020). During isolation periods, elite athletes were forced into prolonged training restrictions, through which their everyday access to training regimes, facilities, resources, and practitioners was substituted with exercise and nutrition programs that could be completed within the constraints of their own homes. Following these prolonged training restrictions, athletes were required to return to sport rapidly due to the immediate resumption of competition. Consequentially, in some cases, this has led to an impaired athletic performance and an increased risk of injury (Cohen et al., 2021; Sarto et al., 2020). As a result, the return to play period following COVID-19 has become an expanding area of research within high-performance sport.

Detraining has been seen to have detrimental effects on both the physical state of an athlete as well as their neuromuscular function. Previous literature demonstrates reductions in muscle strength (~15%), power (~10%), rate of force development (~42%), and tendon mechanical properties (~10%) following two weeks of detraining under bed rest and unilateral lower limb suspension conditions (Mujika & Padilla, 2000b). As noted above, in extreme cases of detraining muscle strength and force generating capacity has shown decrements of ~1.5-2% each day (Stokes et al., 2020). Factoring in more severe lifestyle changes, nutritional habits and energy expenditure patterns, these maladaptive responses can be quite significant. COVID-19 imposed training restrictions have brought about detraining effects such as rapid declines in maximal oxygen uptake, muscle size and architecture, tendon mechanical properties, as well as a functional deterioration in muscle strength, power, and rate of force development (Sarto et al., 2020). In relation to injury risk, Seshadri et al. (2021) found a 3-fold increase in acute injury rates within Bundesliga football athletes (n= 537) of which muscular injuries were the most common, following a COVID-19 lockdown period of >4 weeks. Similarly, the five-month lock out in the National Football League in 2011 brought about a 4-fold increase in Achilles tendon ruptures compared to the previous year (Myer et al., 2011). In light of these previous investigations, it is evident that a COVID-19 imposed training restriction such as an isolation, quarantine, or lockdown could result in the detraining of neuromuscular qualities as well as a higher prevalence of injury once athletes return to play. These findings reiterate the need for practitioners to understand the unprecedented nature of a COVID-19 isolation, and its impact on athletic performance variables such as strength and power. Such research would enable practitioners to implement exercise interventions that maintain or minimize decrements in lower-body strength and power during isolation, quarantine, and lockdown periods. Thus, the purpose of this literature review was to identify the impact of a COVID-19 isolation on strength and power performance, and to see whether this effect varies across isolation lengths, cohorts, and exercise interventions. Within this literature review, the common test metrics and modalities used in current research will also be highlighted.

2.3 Search Methods

The CINAHL Complete, MEDLINE, SPORTDiscus and Google Scholar databases were electronically searched by an individual researcher. Varying combinations of the following Boolean phrases were used as search terms: COVID-19, coronavirus, training restriction, home confinement, isolation, strength, power, explosive, force, elite, athlete, and performance. Using 'OR' and 'AND' with truncation '*', these terms were searched for within the article title, abstract, and key words. Studies were included in the review based on the following criteria: 1) original, peer-reviewed articles, 2) publication years of 2019-2022, 3) full text available in English. Studies were excluded if they; 1) did not use commonly used assessment tools and tests for lower-body strength and power.

2.4 Overview of Findings

Various studies have investigated the differing detraining effects on strength and power performance following COVID-19 imposed training restrictions ranging from 13-224 days in duration (Alvurdu et al., 2022; Asimakidis et al., 2022; Cohen et al., 2021; Dauty et al., 2022; Demir et al., 2021; Font et al., 2021; Grazioli et al., 2020; Moreno-Pérez et al., 2021; Moreno-Pérez et al., 2020; My et al., 2022; Paravlic et al., 2022; Parpa & Michaelides, 2021; Pedersen et al., 2021; Pucsok et al., 2021; Rampinini et al., 2021; Salazar et al., 2020; Spyrou et al., 2021; Valenzuela et al., 2021; Villaseca-Vicuña et al., 2022; Wagemans et al., 2021). In particular, five studies compared pre to post data collected during a COVID-19 imposed training restriction with pre to post data collected during an off-season, competition, or transition period. In all studies the COVID-19 isolation was longer than the; off-season by 39 days and 82 days (Cohen et al., 2021; Grazioli et al., 2020), competition by 14, 35 and, 238 days (My et al., 2022; Rampinini et al., 2021), and a transition period by 14 days (Parpa & Michaelides, 2021). For a summary of the studies, refer to Table 1 and Table 2.

Table 1. Summary of previous studies investigating the detraining effects following COVID-19 imposed training restrictions in youth and semi-elite athletes.

Authors	Cohort	COVID-19 Imposed Training Restriction	Assessments	Test Modality	Results
Alvurdu et al. (2022)	68 Youth Football	109 days	CMJ x 3	Optojump Optical Measurement System (Microgate)	↓ CMJ performance.
Asimakidis et al. (2022)	29 Youth Football	~224 days	CMJ x 3	OptoJump Optical Measurement System (Microgate)	Jump performance improved from pre-iso to post-iso (Maturation-related adaptations).
Dauty et al. (2022)	31 Youth Football	~ 30 days	SJ, CMJ, CMJs, Stiffness x 5	OptoJump Optical Measurement System (Microgate)	Jump performance not affected by iso or retraining period.
Moreno-Perez et al. (2020)	30 Semi-Elite Football	~49 days	Nordic hamstring test Bilateral & Unilateral x 2	Video-based method (Smartphone)	Hamstring ecc strength ↓ by 8% after 28 days & ↓ by 14.1% after 49 days
Pucsok et al. (2021)	11 Youth Football	~91 day home-based training program	CMJ x 3	SpeedCourt® 550 Q12 (Global Speed GmbH)	7 x ↑ CMJ, 3 x unchanged CMJ, 1 x ↓ CMJ
Salazar et al. (2020)	9 Youth Basketball	~42 days	SJ & CMJa	Fails to report	SJ ↓ by 8.5% & CMJa ↓ by 8.3%

CMJ= Counter movement jump; **CMJa**= Counter movement jump with arm swing; **1RM Squat=** 1 Repetition Maximum for squat; **ADD=** Adduction; **ABD=** Abduction; **Ecc=** Eccentric; **SJ=** Squat jump; **SSC=** Stretch Shortening Cycle; **NHE=** Nordic hamstring exercise; **MPV20=** Mean propulsive velocity against 20 KG; **MPV30=** Mean propulsive velocity against 30 KG; **MPV40=** Mean propulsive velocity against 40 kg; ↓= Decrease; ↑= Increase.

Table 2. Summary of previous studies investigating the detraining effects following COVID-19 imposed training restrictions in elite athletes.

Authors	Cohort	COVID-19 Imposed Training Restriction	Assessments	Test Modality	Results
Cohen et al. (2016)	16 Elite Football	105 days	CMJ x 3	ForceDecks Dual Force Plate System (Vald Performance)	No change in CMJ performance. Maintenance of slow SSC jump performance, ↓in fast SSC jump performance.
Demir et al. (2021)	30 Elite Football	~60 days	Hip ADD & ABD strength (2 x 5 sec), Hamstring ecc strength x 2	ForceFrame Strength Testing System & Nordbord Hamstring Strength Testing System (Vald Performance)	↓ Hamstring ecc strength for dominant & non-dominant limbs. No change in hip ADD or ABD strength.
Font et al. (2021)	11 Elite Handball	~63 day home-based training program	CMJ bilateral & Unilateral x 2	Chronojump Contact Platform (Boscosystem)	No change in CMJ performance.
Grazioli et al. (2020)	23 Elite Football	63 days	SJ x 3, CMJ x 3, NHE x 3	Elite Jump System Contact Mat (S2 Sports), Custom-made Hamstring Strength Testing Device	No change in SJ performance, ↓ CMJ performance. No change in Hamstring ecc strength.
Moreno-Perez et al. (2021)	21 Elite Referees	~56 days	Nordic hamstring test Bilateral & Unilateral x 2	Video-based method (Smartphone)	Hamstring ecc strength ↓ in Bi & Uni measures during iso.
My et al. (2022)	17 Elite Football	~112 days	CMJ	OptoJump Optical Measurement System (Microgate)	No change in CMJ. Pre-iso to Post-Iso changes sig worse than Pre-comp to Post-comp changes.
Paravlic et al. (2022)	32 Elite Football	~56 days	2-3 x warmup SJ & CMJ, 3 x SJ & CMJ	Quattro Jump Force Plate System (Kistler)	No change in CMJ & SJ performance.
Parpa et al. (2021)	19 Elite Football	~49 days	Isokinetic knee strength, SJ & CMJ x 3	OptoJump Optical Measurement System (Microgate)	↑ jump performance post-iso compared to post-transition period.

Table 3. Continued.

Pederson et al. (2021)	8 Elite Football	~ 84 days	Partial squat 1RM, CMJ x 2	Force Platform FP8 (HUR Labs)	No change in CMJ jump performance and variables.
Rampinini et al. (2021)	11-19 Elite Football (Different # according to measure)	~91 days	CMJ x 6	Quattro Jump Force Plate System (Kistler)	No within-period changes. Sig between-period changes; Post-iso worse than Post-comp for absolute & relative peak power output but not jump height.
Spyrou et al. (2021)	10 Elite Futsal	70 days	Broad jump x 3, CMJ x 3	Quattro Jump Force Plate System (Kistler)	No change in jump performance. Maintenance of slow SSC jump performance, ↓in fast SSC jump performance.
Valenzuela et al. (2021)	7 Elite Badminton	~49-70 days	1RM squat, CMJ x 5	OptoJump Optical Measurement System (Microgate)	↓ CMJ performance.
Villaseca-Vicuna et al. (2022)	19 Elite Football	~152 days	1RM squat x 3, CMJ x 3	Chronojump Contact Platform & Chronojump Linear Position Transducer (Boscosystem)	No change in CMJ performance. ↓ MPV40. No change in MPV20 & MPV30.
Wagemans et al. (2021)	33 Elite Football	~13 days	Nordics x 3, Hip add/abd x 3, CMJ x 3	ForceDecks Dual Force Plate System, ForceFrame Strength Testing System & Nordboard Hamstring Strength Testing Systems (Vald Performance)	No change in CMJ, Add/Abd. Difference in Right & Left ecc ham strength.

CMJ= Counter movement jump; **CMJa**= Counter movement jump with arm swing; **1RM Squat=** 1 Repetition Maximum for squat; **ADD=** Adduction; **ABD=** Abduction; **Ecc=** Eccentric; **SJ=** Squat jump; **SSC=** Stretch Shortening Cycle; **NHE=** Nordic hamstring exercise; **MPV20=** Mean propulsive velocity against 20 KG; **MPV30=** Mean propulsive velocity against 30 KG; **MPV40=** Mean propulsive velocity against 40 kg; ↓= Decrease; ↑= Increase.

2.5 Power Based Assessment

The counter movement jump (CMJ) is a widely used assessment to test lower body power (Krzyszkowski et al., 2022). Extending beyond jump height, additional performance variables have been included into the CMJ analyses to allow researchers a more thorough understanding of an athlete's lower-body power producing capabilities (Krzyszkowski et al., 2022). These variables include the Modified Reactive-Strength Index ($RSI_{modified}$), Rate of Force Development (RFD) and Ground Reaction Forces (GRF) across the unloading, eccentric yielding, eccentric breaking, and concentric phases of the CMJ (Krzyszkowski et al., 2022). $RSI_{modified}$ is the ratio between jump height and time to take-off and is derived from a CMJ rather than a DJ, while RFD is the ratio between the change in force production and the change in time (Cohen et al., 2021; Krzyszkowski et al., 2022). McMahon et al. (2018) found that athletes with a high $RSI_{modified}$ achieved greater jump heights, a shorter time to take off, and higher force, velocity, and power outputs across both eccentric and concentric phases of the CMJ, than athletes with a low $RSI_{modified}$ (Krzyszkowski et al., 2022).

GRF can be horizontal or vertical dependent on the direction of force application, and is described using peak (maximal) or average values (Benjanuvatra et al., 2013). The countermovement portion of the jump involves the unloading and eccentric phases, the eccentric phase of which is further broken down in to the eccentric yielding and eccentric braking subphases (Krzyszkowski et al., 2022). The unloading and eccentric "downward" phases are later followed by the concentric "upward" phase (Krzyszkowski et al., 2022). Vertical GRF helps to indicate the athlete's center of mass (COM) velocity (Krzyszkowski et al., 2022). Within the unloading phase, body mass is reduced to the point where minimum GRF magnitude is achieved (Krzyszkowski et al., 2022). Transitioning to the eccentric yielding subphase, GRF increases as downward COM velocity increases, however these forces continue to remain below or equal to body mass (Krzyszkowski et al., 2022). It is during the eccentric braking subphase that downward COM velocity decreases causing a rapid spike in GRF that greatly exceeds body mass (Krzyszkowski et al., 2022). In the transition between the eccentric yielding subphase and the concentric phase, maximum GRF magnitude is achieved (Krzyszkowski et al., 2022). In order to optimize CMJ performance, the average eccentric RFD must be greater than the average vertical GRF during the concentric phase (Krzyszkowski et al., 2022).

2.6 Impact of COVID-19 Imposed Training Restrictions on Lower-Body Power

Plyometric jumps are categorised dependent on the nature of the task, where fast stretch shortening cycle (SSC) movements are completed in under 250 milliseconds and slow SSC movements are completed in over 250 milliseconds (Schmidtbleicher et al., 1988, as cited in Turner & Jeffreys, 2010). Previous studies

have only investigated the detraining effects from a COVID-19 imposed training restriction on slow SSC jumps such as the CMJ and SJ, and not fast SSC jumps such as the DJ. Despite this, due to access to technology such as force platforms, jump kinetics as well as jump performance data can be derived from any plyometric jump.

Multiple studies exhibited a maintenance of overall jump performance, and significant decays as large as 17.3% ($p = 0.01$) in jump kinetics, following a COVID-19 imposed training restriction (Cohen et al., 2021; Spyrou et al., 2021). In their study on elite footballers following a 105-day isolation period, Cohen et al. (2021) concluded that the RFD in the eccentric yielding phase of the CMJ decreased by 17.3% ($p = 0.01$), while the duration (15.7%, $p = 0.01$) in the eccentric yielding phase, and the displacement (16%, $p = 0.01$) at peak landing force increased. In turn, CMJ height (cm) was not affected following the isolation period. These findings suggest that while less reliance was placed on time-regulated jump kinetics such as RFD, CMJ height was maintained via slow SSC actions such as a longer time period to develop force during the eccentric phase (Flanagan & Comyns, 2008). The reactive strength index modified ($RSI_{modified}$) was also maintained, indicating that the performance of plyometric exercises can be maintained via changes in jump strategy or technique, compensating for potential shifts in time-regulated jump kinetics. Similarly, Spyrou et al. (2021) found a significant reduction in the jump kinetics of elite futsal athletes who endured a 70-day quarantine. Within the eccentric yielding phase of the CMJ, these decrements occurred in deceleration impulse, RFD, peak velocity, and peak power (Spyrou et al., 2021). Furthermore, within the landing phase of the CMJ, the peak force of the athletes was also shown to be reduced (Spyrou et al., 2021). However, there was no significant change in CMJ height or horizontal broad jump distance following the decay of eccentric variables (Spyrou et al., 2021). These findings were similar to Font et al. (2021) who found no change in both bilateral and unilateral CMJ jump height and to Pedersen et al. (2021) who found no change in CMJ height or force production variables such as peak force. These findings are contradictory to those of Valenzuela et al. (2021) and Salazar et al. (2020) who reported marked decreases in CMJ (-8.3%) and SJ (-8.5%) jump height (cm) following a ~49-70 day isolation and a ~42 day isolation, respectively. Furthermore, Dauty et al. (2022), Pucsok et al. (2021), and Asimakidis et al. (2022) found that the maturation-related adaptations of youth football athletes lead to an improved or maintained CMJ jump height following a COVID-19 isolation. Collectively these findings suggest that time-regulated jump kinetic variables such as vertical GRF, deceleration impulse, RFD, peak velocity, and peak power during the eccentric yielding phase, as well as peak force during the landing phase, are specifically stimulated by on field sport-specific training or competition. In combination with a lack of sport-specific training, the vast majority of athletes could not complete high-intensity strength and power training due to no access to gym facilities, lack of equipment, and confinement to small spaces.

2.7 Impact of COVID-19 Imposed Training Restriction on Lower-Body Strength

Mixed findings were reported from the limited number of studies that assessed strength following a COVID-19 imposed training restriction. In one study involving 19 elite football athletes following a five-month confinement period, no change was found in one repetition maximum squat or relative strength (Villaseca-Vicuña et al., 2022). In addition, Demir et al. (2021) conducted a study on 30 elite football athletes who endured a 60-day quarantine which involved a home-based exercise program consisting of aerobic training, core and lower-body strengthening exercises, and stretching (Demir et al., 2021). As was the case in Wagemans et al. (2021) study, the results showed that isometric hip adduction (ADD) and isometric hip abduction (ABD) strength exhibited no change (Demir et al., 2021). Conversely, following 4 weeks of detraining, hamstring eccentric muscle strength for both dominant limbs (-9.5%) and non-dominant limbs (-8.4%) has been shown to significantly diminish (Demir et al., 2021). The sensitivity of eccentric strength qualities explains the pronounced decay of eccentric hamstring strength, when compared to the maintenance of isometric hip ADD and hip ABD strength. Grazioli et al. (2020) reported similar reductions in absolute (1-11%) and relative (2-27%) eccentric hamstring strength in individual athletes following quarantine, however these results were not significant. In their study on 30 semi-elite football athletes, Moreno-Pérez et al. (2020) found significant reductions in eccentric hamstring strength, with decay rates as large as 8% after 28 days of isolation and 14% after 49 days of isolation. In their home-based training programs, Moreno-Pérez et al. (2020) incorporated strength, proprioception, and high intensity interval training. Conversely, Villaseca-Vicuña et al. (2022) incorporated strength and functional activities into their home-based training program and were successful in maintaining lower-body strength which was tested via maximal lifting velocity of the concentric phase within a squat which was then entered into an equation to determine one repetition maximum squat and relative strength (strength relative to body mass) values.

2.8 COVID-19 Imposed Training Restriction Benefits and Limitations

Parpa and Michaelides (2021) reported a significantly higher ($t = -7.43$, $p < 0.01$, $d = 1.11$) CMJ jump height following a 7-week COVID-19 lockdown when compared to a 5-week transition period in professional soccer players. A transition period/off-season is the phase between the end of in-season/competitive season and the beginning of pre-season/preparation phase. The home-based training program in Parpa and Michaelides (2021) study consisted of strength/power and cardiovascular sessions. Parpa and Michaelides (2021) state that the improvements in CMJ performance can be attributed to the variations in strength levels prior to a period of inactivity, through which weaker athletes may be less

susceptible to reductions in jump height when compared to stronger athletes. Parpa and Michaelides (2021) also ascribe the decay in CMJ performance during the transition period to the sensitivity of fast-twitch fibres to detraining. In turn, Cohen et al. (2021) reported that $RSI_{modified}$, eccentric and concentric peak power, eccentric peak velocity and eccentric deceleration impulse decreased during the 23-day off-season but were stable during the 105-day quarantine. The greater likelihood for jump performance to decrease during an off-season compared to a COVID-19 imposed training restriction can also be explained by the expression of MHC isoforms, whereby high muscle activity such as heavy-load resistance training decreases the occurrence of MHC IIX fibres and low muscle activity (muscle inactivity) increases the occurrence of MHC IIX fibres (Andersen & Aagaard, 2000). Despite practitioner's efforts, during COVID-19 imposed training restrictions, the vast majority of athletes were unable to access equipment to undergo heavy-load resistance training. Thus, the COVID-19 imposed training restrictions are in contrast to a traditional off-season or transition period where athletes would have full access to equipment and facilities. Moreover, the increased expression of MHC IIX fibres caused by a period of detraining, such as a COVID-19 imposed training restriction, can result in improved power production capabilities which positively influences jump performance (Andersen & Aagaard, 2000).

In contrast to the findings of Parpa and Michaelides (2021), My et al. (2022), Grazioli et al. (2020), and Rampinini et al. (2021) concluded that the difference in lower-body power between pre-COVID-19 lockdown and post-COVID-19 lockdown was significantly worse than the difference between pre-competition/off-season and post-competition/off-season. During the 13-week COVID-19 lockdown period, aerobic and strength sessions were prescribed as part of the home-based training (Rampinini et al. (2021). Rampinini et al. (2021) stated that greater decrements were found in both relative (moderate effect size) and absolute (moderate effect size) peak power following a 13-week (~91 day) COVID-19 lockdown compared to 8-week (~56 day) and 11-week (~77 day) competitive periods, while CMJ height was not affected. Grazioli et al. (2020) conducted a similar study on elite football athletes who endured a 24-day off-season and a 63-day quarantine that incorporated body mass resistance exercises. When compared with off-season measures, significant impairments were seen in CMJ height, an eccentric-concentric coupled movement, whereas SJ height, a concentric only movement, was maintained (Grazioli et al., 2020). These findings highlight the sensitivity and the difficulty in maintaining eccentric qualities, during prolonged periods of training restriction (Spyrou et al., 2021). The 39-day difference in length is a confounding variable for the results in this study (Grazioli et al., 2020). My et al. (2022) also found significant ($p=0.02$) differences in CMJ performance change between measures taken prior to and following a COVID-19 lockdown (that included aerobic and strength sessions), and prior to and following the 2018/2019 football season. Through a between-period comparison it became clear that the difference in CMJ performance was

significantly worse following the COVID-19 lockdown than following the 2018/2019 season (My et al., 2022). In summary, it appears that home-based training interventions struggle to elicit the required training stimulus to maintain strength and power performance over COVID-19 imposed training interventions.

2.8.1 Lack of Sport-Specific Training

Sport-specific training essentially reflects the contextual demands of a game and in football encompasses pressured decision-making, high-speed running, reactive eccentric actions, directional changes, as well as high-demanding accelerations and decelerations (Cohen et al., 2021). Additionally, a study completed on athletes who had undergone an anterior cruciate ligament reconstruction concluded that the return of an athlete to one year of regular competition brings about the greatest improvements in yielding phase metrics (Taberner et al., 2020, as cited in Cohen et al., 2021). These findings emphasize the efficacy of in-game scenarios in stimulating an athlete's eccentric yielding phase in a specific manner. Negative changes in yielding phase metrics can be detrimental to reactive performance (Cohen et al., 2021). In the study conducted by Alvurdu et al. (2022), body mass resistance exercises were prescribed to subjects during a COVID-19 imposed training restriction. However, based on data derived from the arrowhead agility test, Alvurdu et al. (2022) concluded that change of direction (COD) and CMJ abilities were still negatively affected by the COVID-19 imposed training restrictions. The home-based program by Alvurdu et al. (2022) was therefore unsuccessful in maintaining or improving lower-body strength and power. Changes in eccentric yielding abilities could be a direct cause of decrements to COD performance. These changes include alterations to deceleration and impact attenuation actions which largely contribute to COD performance (Cohen et al., 2021). Finally, alterations to the yielding phase were prevalent following a 105-day quarantine but not the 23-day off-season which indicates a slower decay rate (Cohen et al., 2021). In light of these findings, it is apparent that a lack of sport-specific training during isolation periods can have a significant negative impact on an athlete’s neuromuscular performance. Further research is warranted to investigate ways to mitigate these detrimental effects when access to training equipment and resources is limited and/or restricted.

To date, Dauty et al. (2022) were the only researchers to differentiate exercise prescription dependent on COVID-19 transmission whereby negative cases completed strength, aerobic, and speed training, while positive cases were prescribed 10-days of bed rest. COVID-19 infection did not have any effect on the results of this study as the jump performance and stiffness parameters of the COVID-19 positive cases increased in conjunction with the negative cases (Dauty et al., 2022). The majority of researchers have prescribed a mixture of strength and endurance sessions (Cohen et al., 2021; Font et al., 2021; Salazar et al., 2020), while others incorporated multidirectional movements, plyometrics and jumps

(Pedersen et al., 2021; Pucsok et al., 2021; Spyrou et al., 2021). Thus, in order to maintain both strength and power variables in the absence of sport-specific loading and within the constraints of a COVID-19 imposed training restriction, it is critical that both strength (e.g., isometric holds) and jumps, including fast (e.g. DJ) and slow (e.g. CMJ) SSC exercises, are incorporated throughout the training program.

2.8.2 Muscle-Tendon Properties

In line with the studies conducted by Cohen et al. (2021) and Spyrou et al. (2021), Paravlic et al. (2022) concluded that 32 elite football players were able to maintain jump performance, although contractile properties of the musculoskeletal system such as; delay time of biceps femoris (BF) (ES=1.58), vastus lateralis (VL) (ES=1.42), vastus medialis (VM) (ES=1.09); contraction time of BF (ES=1.59), VL (ES=0.50), VM (ES=0.39); sustain time of VL (ES=0.42); half-relaxation time of VM (ES=0.72); and amplitude of BF (ES=0.45), VL (ES=0.62), were altered following a ~56 day isolation period. Notably, these altered muscle-tendon properties could be similarly responsible for the decrements seen in time-regulated jump mechanics following a COVID-19 isolation (Spyrou et al., 2021). Specifically, contraction dynamics influence tensile strain and resulting jump kinetics by regulating the electromechanical delay in muscle activation, the sequencing of force absorption, the magnitude of energy reciprocation, and concomitant rate of force development (Schmid et al., 2019). These muscle-tendon properties are what allows an individual to quickly decelerate and change direction with great efficacy (Spyrou et al., 2021). The alterations to fast SSC actions in comparison to slow SSC actions can be explained from a tissue perspective, through which tendons lose their elasticity and stiffness quicker than muscles lose their strength (De Boer et al., 2007). Following 90 days of bed rest, tendon stiffness can decrease by 58% compared to muscle size which only decreases by 30% (De Boer et al., 2007). Although not specific to force production capabilities, muscle size is seen to largely contribute to muscle activation and thus overall strength (De Boer et al., 2007). The tendon's adaptability is also applicable with loading, through which tendon stiffness can increase by 65%, muscle volume by 6%, and muscle force by 11% after two weeks of training stimulus exposure (De Boer et al., 2007). Through the series elastic component, tendon stiffness plays a key role in muscle function (De Boer et al., 2007). It is for this reason, alongside injury prevention purposes, that practitioners should strive to maintain tendon loads throughout a COVID-19 imposed training restriction. If not possible, tendons should be progressively reloaded upon return to play.

2.8.3 Bilateral and Unilateral Strength Differences

There were a limited number of studies that presented bilateral and unilateral lower-body strength results following a COVID-19 imposed training restriction. The findings from Wagemans et al. (2021) and Moreno-Pérez et al. (2021) illustrate a decay in eccentric hamstring strength and a maintenance of isometric hip adductor and abductor muscle strength. Moreno-Pérez et al. (2021) compared eccentric hamstring muscle strength during a COVID-19 lockdown to "post-confinement" (one-week following lockdown), "pre-competition" (4-weeks following lockdown), and "post-competition" (~10-weeks following lockdown) data. Participants were required to complete a personalized, home-based training program which involved strength, endurance, and proprioceptive exercises six times per week. They concluded that bilateral and unilateral eccentric hamstring strength was the lowest at 13-days into the 8-week COVID-19 lockdown (Moreno-Pérez et al., 2021). However, the total realized decrements may have been much larger at the end of the 8-week (56-day) lockdown. Similar to Moreno-Pérez et al. (2021), Wagemans et al. (2021) compared results from one-week before COVID-19 detection to two, four, six, and eight weeks after COVID-19 detection. These researchers failed to report the type of training completed during their COVID-19 isolation. While there was no statistically significant difference in isometric hip ADD or ABD muscle strength, eccentric hamstring strength in the right but not left limb improved by +41.8N and +34.8N at two weeks and four weeks respectively, following COVID-19 detection (Wagemans et al., 2021). Moreno-Pérez et al. (2021) reported similar findings in bilateral (+13.2N) and unilateral eccentric hamstring strength of the left limb (+10.6N) and the right limb (+14.3N) at "post-confinement" testing. To which bilateral strength and unilateral strength of the right limb remained stable whilst unilateral strength of the left limb continued to increase (+9.1N) in the following measurement of "pre-competition" testing (Moreno-Pérez et al., 2021). Interestingly, the authors in the previous investigations did not specify the dominance and non-dominance of limbs so no further conclusions can be drawn (Moreno-Pérez et al., 2021; Wagemans et al., 2021). Despite the 4-week retraining period prior to the "pre-competition" testing, bilateral and unilateral (right) eccentric hamstring strength did not continue to improve following "post-confinement" measurement, while unilateral (left) eccentric hamstring strength did. These findings indicate that one-week is a suitable time period to regain bilateral eccentric hamstring strength. Moreover, both studies present differences in left and right unilateral eccentric hamstring strength whereby one limb's strength continues to improve over time while the other essentially stagnates. These findings are particularly meaningful because a reduction in eccentric hamstring strength can limit an athlete's explosive acceleration characteristics, resulting in a decline in jump performance and kinetic expression (Krommes et al., 2017). The resulting decrements in performance may arise due to the role that the hamstring plays in force production and absorption during sprinting and jumping movements. Decrements in eccentric hamstring

strength following training cessation can also predispose athletes to a higher risk of acute hamstring injury once normal training and competition resumes (Demir et al., 2021).

2.9 Conclusion

To conclude, the rate of decay and the maintenance of strength and power following a COVID-19 imposed quarantine period varied across individual studies and adaptive properties. Following a period of detraining, Cohen et al. (2021) and Spyrou et al. (2021) found significant decrements in time-regulated jump mechanics but not jump performance. Conversely, studies conducted by Grazioli et al. (2020) and Alvurdu et al. (2022) found decreases in overall jump performance which they attributed to the pliability of eccentric adaptation. In addition, the majority of studies found decrements in eccentric hamstring strength, predisposing athletes to hamstring-related injuries (Demir et al., 2021; Grazioli et al., 2020). In summary, significant levels of decay can be expected in time-regulated jump mechanics and in jumps involving a dominant eccentric phase. In addition, decreases were found in eccentric hamstring strength, but not in isometric hip adduction and abduction strength following a COVID-19 imposed isolation period. The home-based training program by Villaseca-Vicuña et al. (2022) was the most effective in maintaining lower-body strength and power through the incorporation of strength and SSC-targeted exercises. These findings are of interest to practitioners in high-performance sport who must understand the impact of a COVID-19 imposed training restriction on lower-body power and strength in order to safely return athletes to competitive sport.

2.10 Practical Applications

The access to resources, equipment and facilities, the athlete's commitment to the home-based training intervention, and the effectiveness of the prescribed training intervention will essentially determine the decay rates and maintenance capabilities of strength and power qualities during COVID-19 imposed training restrictions. According to Villaseca-Vicuña et al. (2022), the maintenance of CMJ performance was dependent on the incorporation of plyometric and ballistic exercises, such as loaded and unloaded jumps. SSC-targeted exercises may improve an athlete's coordination and efficiency within power-specific movements while also increasing the muscles' and tendons' capability to produce force quickly through improved stores of elastic energy (Turner & Jeffreys, 2010). The explosive force producing capabilities of the tissues could then translate to improved jump performance such as increased CMJ height, $RSI_{modified}$ or drop jump (DJ) RSI. The incorporation of sport-specific movements in a home-based training intervention has also been deemed to be pivotal, examples of which could include reactive drop jumps, change of direction, accelerations, and decelerations. Practitioners are encouraged to get as creative as possible with

the space and equipment available. To help mitigate decrements in lower-body strength, a combination of eccentric-concentric and isometric body mass exercises should be used within a program. Due to the unavailability of equipment during home-based training periods, key focuses could be speed-strength and strength endurance. While exercise intensity will naturally decrease during a COVID-19 imposed training restriction, the volume can be manipulated to mimic the loading seen within a normal training week.

Chapter: 3 The Impact of COVID-19 Isolation on Strength and Power Profiles in Professional Rugby Union Players

3.1 Prelude

The emphasis of this chapter was to add to the existing literature regarding the efficacy of COVID-19 isolation training periods in team sport athletes. Thus, the primary purpose of this chapter was to understand the impact of a 10-16 day isolation period on strength and power variables in professional rugby union players. The results of this investigation will help to educate practitioners on the best training interventions to implement during a COVID-19 isolation in order to maintain, if not improve, athletic performance variables such as lower-body strength and power.

3.2 Introduction

Athletic performance variables of strength and power are critical to the performance enhancement and injury prevention qualities of professional rugby union players. Many studies have examined the influence of COVID-19 imposed training restrictions on strength and power performance within the scope of sports such as football, but not in full-contact sports such as rugby union (Alvurdu et al., 2022; Asimakidis et al., 2022; Cohen et al., 2021; Dauty et al., 2022; Demir et al., 2021; Grazioli et al., 2020; Moreno-Pérez et al., 2020; My et al., 2022; Paravlic et al., 2022; Parpa & Michaelides, 2021; Pedersen et al., 2021; Pucsok et al., 2021; Rampinini et al., 2021; Villaseca-Vicuña et al., 2022; Wagemans et al., 2021). The impact on strength and power variables has been seen to vary dependent on cohort, training intervention, restriction length and constraints (Mujika & Padilla, 2000a). This study highlights the maintenance of lower-body power and the improvement of lower-body strength that can be experienced by both COVID-19 positive groups (Bravo, Charlie, Delta) and COVID-19 negative groups (Alpha) when an effective room-based exercise program is prescribed to professional rugby union players over a 10-16 day COVID-19 isolation.

3.3 Methods

3.3.1 Experimental Design

The current research was a retrospective, observational study where data was collected longitudinally at four time points across the course of the 2022 Super Rugby Pacific season; 1) 16-23 days prior to COVID-19 isolation (Pre1), 2) 7-15 days prior to COVID-19 isolation (Pre2), 3) Within 3 days post COVID-19 isolation (Post) and 4) 2 days prior to a return to play game following COVID-19 isolation (RTP). Due to the ecological nature of this study, lower-body strength and power tests were conducted on different days for the following timepoints; Pre1 (power: 16 days, strength: 23 days prior to COVID-19 isolation), and Pre2 (power: 7 days, strength: 15 days prior to COVID-19 isolation) (Table 3). As a result of this, two pre COVID-19 isolation timepoints (Pre1 & Pre2) were used in order to portray a general

"baseline" trend for each individual variable leading into the COVID-19 isolation. For RTP and Post time points, all lower-body strength and power testing was conducted on the same days relative to each participants' isolation group. The presentation of COVID-19 within the team's environment naturally split the squad into two groups; Group 1: tested negative for COVID-19 (n = 14) but were still required to isolate, mimicking a COVID-19 pandemic-imposed training restriction, Group 2: tested positive for COVID-19 (n = 18) and were required to isolate. Group 2 was then further split into three sub-groups (Bravo, Charlie, Delta) due to the variance in COVID-19 contraction time and thus the resulting isolation length (Table 4). Due to the retrospective nature of this investigation, all participants were given an information sheet and subsequently signed an informed consent form following the 2022 Super Rugby season. All testing conditions were examined and approved by the Auckland University of Technology Ethics Committee (22/212).

Table 4. Testing timepoints.

		Pre1 Power	Pre1 Strength	Pre2 Power	Pre2 Strength	Post Strength & Power	RTP Strength & Power
Group 1 (Negative)	Alpha	24th Jan	17th Jan	2nd Feb	25th Jan	19th-22nd Feb	2nd March
Group 2 (Positive)	Bravo	24th Jan	17th Jan	2nd Feb	25th Jan	19th-22nd Feb	2nd March
	Charlie	24th Jan	17th Jan	2nd Feb	25th Jan	22nd-25th Feb	2nd March
	Delta	24th Jan	17th Jan	2nd Feb	25th Jan	25th-28th Feb	2nd March

Table 5. Sub-groups and isolation information.

		Isolation Length	Isolation Dates	Forwards	Backs	Age
Group 1 (Negative)	Alpha	10	9th-19th Feb	6	8	26.8 ± 4.1
Group 2 (Positive)	Bravo	10	9th-19th Feb	8	-	25.5 ± 1.8
	Charlie	13	9th-22nd Feb	3	5	23.6 ± 4.3
	Delta	16	9th-25th Feb	2	-	28 ± 2.8

3.3.2 Participants

For this investigation, 32 trained professional male rugby union players between the ages of 20 – 36 were included in this retrospective analysis. The inclusion criteria were as follows; 1) contracted members of the same professional rugby union franchise who travelled to Queenstown for the start of the 2022 Super Rugby Pacific season, 2) individuals who underwent regular COVID-19 polymerase chain reaction (PCR) tests during isolation, 3) no current acute or chronic injuries or medical conditions, 4) had

fully participated in regular team trainings for ≥ 6 months. Three participants were excluded from this study due to incomplete data as a result of non-compliance.

3.3.3 Testing Procedures

Close contact with an external positive COVID-19 case led to the suspicion of COVID-19 contraction within the team. As a result, all players were sent into isolation and required to take COVID-19 PCR tests on the 9th of February, 2022 (day 0). The PCR tests were completed within the quarantine facilities and were conducted by Queenstown District Council health practitioners. The results from these tests confirmed the presence of positive COVID-19 cases, which sent the whole team into a minimum 10-day isolation, including players who tested negative but were still required to isolate. The testing protocol was repeated on the 12th of February (day 3) and the 19th of February (day 6). The 10-day isolation period restarted on the day that the player tested positive. The 10-day isolation ended if the player had tested negative at all four testing points, or if the player had tested negative 10 days after testing positive. As a result, the isolation periods ranged from a minimum of 10 days to a maximum of 16 days. Players that tested negative on day 0 (Alpha group, n=14) underwent a 10-day isolation ranging from the 9th – 19th of February. Players that tested positive on day 0, but negative on subsequent testing days, (Bravo group, n=8) also underwent a 10-day isolation ranging from the 9th – 19th of February. Players that tested positive on day 3 (Charlie group, n=8) underwent a 13-day isolation ranging from the 9th – 22nd of February. Lastly, players that tested positive on day 6 (Delta group, n=2) underwent a 16-day isolation ranging from the 9th-25th of February.

Isolation took place in single rooms in the Queenstown quarantine facilities. During isolation, players partook in room-based exercise programs designed and implemented by the team's Athletic Performance staff (Table 5). Key focuses included joint stability robustness through long-duration time under tension isometrics, whole body range of motion movement patterns, low-intensity force absorption through ankle, knee and hip (e.g., drop landings from 20-30 cm), and unilateral exercises completed at medium-high reps (i.e., 2-4 sets of 6-10 reps) and controlled tempos (3s-1s-1s). Two rep schemes were used for key upper body push and pull movements as well as squats; 1) Reps for time - A set number of reps completed as quickly as possible and, 2) Time for a target number of reps - A set amount of time (i.e., minute (min) or seconds (s)) was given to complete as many reps as possible, aiming for a target number prescribed by practitioners. All of the above exercises were conducted using only body mass loads. In addition to upper/lower/whole body programs, the players also completed bike conditioning sessions, along with yoga and Pilates classes conducted over zoom. Exercise examples included body mass press ups, front

and lateral raises with a chair, chair dips, squat variations (parallel, split, box, single-leg, and isometric parallel squats on a wall), lunges, good mornings, isometric bicep curls, shoulder press and shoulder shrugs with a towel, and core exercises. Superset structures informed the players to complete two exercises in accordance with each other, for the prescribed number of sets x reps, prior to moving on to the next superset. For example, players were to complete 10 reps of body weight (BW) squats followed by five reps each side for BW lunges, repeated three times in total (Table 5). A rest period of 1-2 minutes was prescribed between each set. Both Group 1 (negative COVID-19 cases) and Group 2 (positive COVID-19 cases) followed the same room-based exercise program. However, players in Group 2 (positive COVID-19 cases) were asked to cease taking part in the training session if their heart rate was perceptually too high, which was indicated by a self-determined rate of perceived exertion (RPE) of above 7/10.

Table 6. Whole body program exemplar.

Order	Exercise	Sets x Reps	Tempo
1A.	BM squats	3 x 10	3-1-1 (Eccentric focus)
1B.	BM forward lunges	3 x 5 ea.	3-1-1 (Eccentric focus)
2A.	Tempo BM press ups	Total of 50	3-1-1 (Eccentric focus)
2B.	Towel iso bicep curl	8 x 10 s to Maximum Tension	0-0-10 (Isometric focus)
3A.	BM good mornings	5 x 10	3-1-1 (Eccentric focus)
3B.	BM single leg squats	5 x 6 ea.	3-1-1 (Eccentric focus)
4A.	Chair front raise	5 x 10	3-1-1 (Eccentric focus)
4B.	Chair lateral raise	5 x 6 ea.	3-1-1 (Eccentric focus)
4C.	3 min BM dynamic plank	30 s dead stop, high plank, rolling plank x 2 rounds	N/A

BM= Body mass; **iso** = Isometric, **s**= Seconds, **min**= Minutes, **ea.**= Each.

Lower-body strength and power tests were conducted using Vald Performance Human Measurement Technologies (BNE, QLD, AUS) including the ForceDecks Dual Force Plate System and the ForceFrame Strength Testing System. Four timepoints were included for analysis; Pre1, Pre2, Post and RTP. Prior to each testing trial the equipment was calibrated using the Vald Performance analytic software, Vald Hub (BNE, QLD, AUS). The team's athletic performance director, who did not contract COVID-19,

was able to conduct all the post-isolation strength and power testing. COVID-19 safety regulations included the use of N-95 masks and gloves, the sterilisation of paddles and load cells using alcohol wipes, as well as social distancing strategies of 1.5m were executed during each testing session. For the Post timepoint, data was captured within three days of leaving isolation for each group. For the RTP time point, data was captured on the 2nd of March, two days prior to the team's first competitive game following the COVID-19 isolation (RTP game). This fourth testing time point was conducted in a hired gym where the public were restricted access, social distancing took place, group numbers were limited to 10, and equipment was sanitised between usage.

3.3.4 Jump Performance

The CMJ (Figure 1) and DJ (Figure 2) were performed on the ForceDecks Dual Force Plate System by Vald Performance (BNE, QLD, AUS). The ForceDecks Dual Force Plate System has shown high to very high reliability (ICC= 0.84-0.93) when measuring CMJ and DJ performance . The warm-up for CMJ and DJ involved 1-2 sets of 5-10 repetitions of pogo hops and 3-5 repetitions of single-leg jumps. Prior to each trial, the force plates were zeroed to ensure accurate measurement of subsequent increased force application. Placing one foot on each platform and positioning hands on hips, the player was asked to stand as still as possible for ~one second in order to record their body mass (kg). The player was then instructed to complete two non-consecutive maximal CMJ trials with ~30 seconds rest between trials. The test was inconclusive if the player, 1) removed their hands from their hips at any timepoint, or 2) landed off the force plates. In these cases, the player was asked to repeat the test again. Cues such as "jump as high as you can" and "soft landing" were used by the instructor. Following the CMJ, all players completed one or two DJ trials from a 30-cm box. Players were encouraged to do "one rep well" which was standard testing practice for the team. However, each player was allowed a second opportunity to perform the DJ if they believed that they could complete a better rep. Leading with their preferred foot, players stepped off the box, landing with two feet on the force plates before rebounding into a maximum vertical jump, landing with two feet back on the force plates. The test was ruled inconclusive under the same protocol for the CMJ. Cues such as "stiff ankles" and "rebound quickly" were used by the instructor. The resulting highest jump height trial from the CMJ and the highest RSI trial from the DJ were used for the final analysis. Dependent variables included jump height (cm) for CMJ and RSI (m/s) for DJ. RSI was calculated by dividing jump height (cm) by ground contact time (s). In any instance where force plates are used, jump height is calculated via flight time (s).

Figure 1. Example countermovement jump collection.

Figure 2. Example drop jump collection.

3.3.5 Hip Strength

Maximal isometric hip adduction (ADD) (Figure 3) and hip abduction (ABD) (Figure 4) tests were completed using the ForceFrame Strength Testing System by Vald Performance (BNE, QLD, AUS). The ForceFrame Strength Testing System has shown very high reliability (ICC= 0.94) when measuring hip ADD strength (Ryan et al., 2019). The warm-up for this test incorporated 1-2 sets of 10-20 seconds of Copenhagen isometric holds, 5-10 repetitions of side lying leg lifts with a 10 second isometric hold at the top, and 10-20 seconds of medicine ball groin squeeze variations. The player lay in a supine position with their knees at approximately 90˚, situated within the ForceFrame's paddles. The bar height and paddle position were then adjusted according to the player's femur length and quadricep girth. The player was first asked to complete submaximal holds to activate the muscle groups and practice the movement pattern. Once comfortable, they were then required to complete three sets of ~three second maximal isometric holds

for hip ADD and hip ABD. Instructors used cues such as “squeeze” for hip ADD and “push” for hip ABD, alongside countdowns such as “3, 2, 1”. The test was inconclusive if the player, 1) lifted their hips off the ground which is indicative of glute and/or hamstring activation, or 2) felt pain or discomfort after which, the medical team informed, and the test was terminated. In either of these instances, the player did not complete additional repetitions. Instead, that individual repetition was flagged and excluded from analysis, where the average peak force from the remaining reps was used. The peak force (N) from the three repetitions for hip adduction and hip abduction were averaged for the final analysis.

Figure 3. Example hip adduction collection.

Figure 4. Example hip abduction collection.

3.4 Statistical Analyses

The analytic software, IBM SPSS Statistics (IL, USA) was utilised to calculate means and standard errors for all variables including RSI (m/s), jump height (cm), and peak force (N). A linear mixed model strategy was implemented to compare the changes in dependent variables across both group (Alpha, Bravo, Charlie, Delta) and timepoint (Pre1, Pre2, Post, RTP). Data was checked for normality using histograms. Linear Mixed Model fit was examined using conditional R^2 which describes the amount of variation in the outcome attributed to fixed effects (time point and group), and marginal R^2 which describes the amount of variation in the outcome attributed to fixed and random effects (time point, group, and participant). The effect size was calculated using F values and confidence intervals. Alpha was set to 95% and a p-value of $p \leq 0.05$ will be used to determine statistical significance for all the tests.

3.5 Results

3.6 Lower-Body Power

3.6.1 Countermovement Jump

Linear Mixed Model fit results are presented in Table 6. There was no interaction between group and time. Similarly, there were no significant main effects of group (F= 2.20, p= 0.11) or time (F= 1.49, p= 0.23) on CMJ height (Figure 5). The Linear Mixed Model results are presented in Table 7.

Table 7. Lower-body power model fit & group ICC.

	Mean ± Standard Error	Conditional R^2	Marginal R^2	Group ICC
Countermovement Jump	41.96 ± 1.73	0.18	0.70	0.63
Drop Jump	2.09 ± 0.14	0.27	0.77	0.68

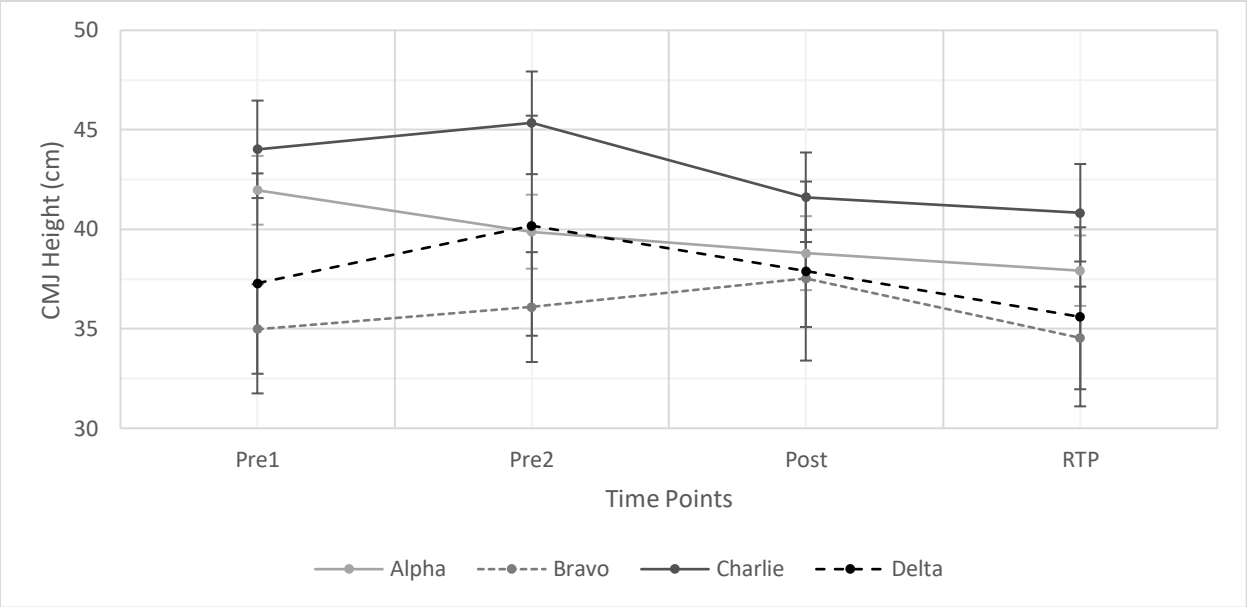

Figure 5. Countermovement jump performance over time for Alpha, Bravo, Charlie and Delta groups. Data is presented as predicted means and 95% standard errors.

3.6.2 Drop Jump

Linear Mixed Model fit results are presented in Table 6. There was no interaction between group and time. However, there was a significant main effect of group (F= 4.42, p= 0.01) on DJ RSI but not time (F= 0.36, p= 0.78) (Figure 6). According to the predicted means, Charlie had a significantly higher RSI across all four time-points when compared to Alpha, Bravo, and Delta (Table 7).

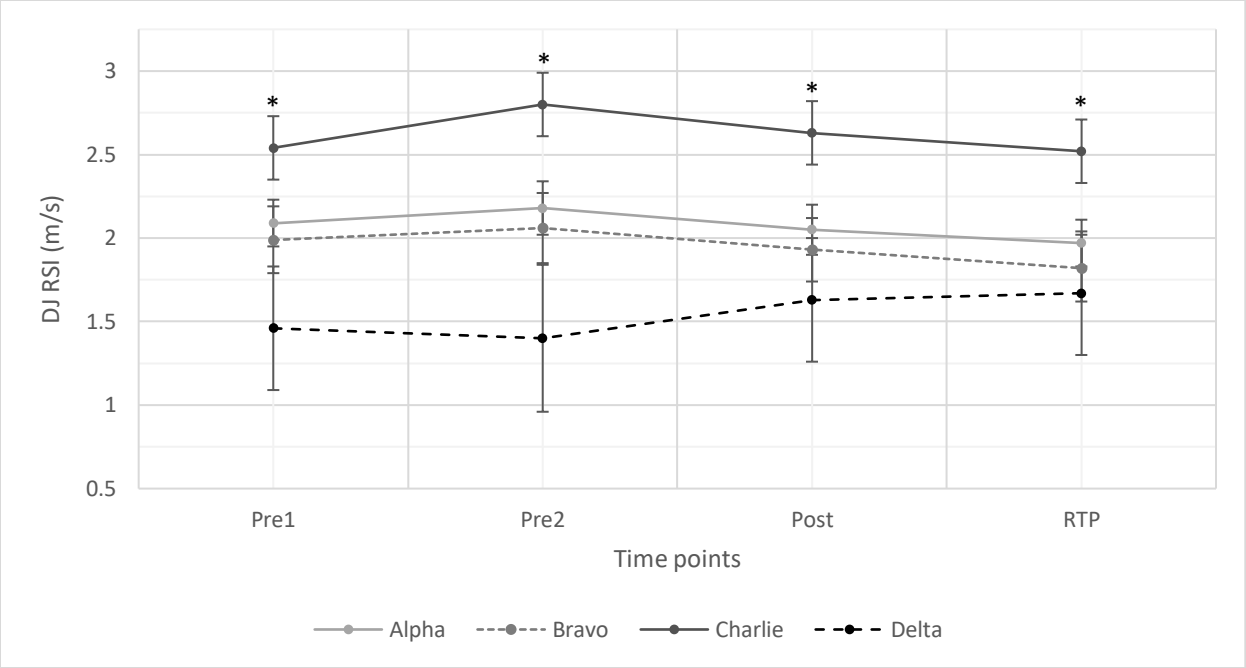

Figure 6. Drop jump reactive strength index performance over time for Alpha, Bravo, Charlie and Delta groups.
Data is presented as predicted means and 95% standard errors. * = group is significantly different to all other groups at given timepoint ($p \leq 0.05$).

Table 8. Countermovement jump height and drop jump reactive strength index results over time for Alpha, Bravo, Charlie and Delta groups. Data is presented as predicted means and 95% standard errors. * = group is significantly different to all other groups at given timepoint ($p \leq 0.05$).

		Countermovement Jump Height (cm)				Drop Jump Reactive Strength Index (m/s)			
Group	Time point	Predicted Mean	Std. Error	Conf. Low	Conf. High	Predicted Mean	Std. Error	Conf. Low	Conf. High
Alpha	Pre1	41.96	1.73	38.51	45.41	2.09	0.14	1.81	2.37
	Pre2	39.88	1.86	36.18	43.57	2.18	0.16	1.87	2.49
	Post	38.80	1.86	35.09	42.50	2.05	0.15	1.76	2.34
	RTP	37.92	1.77	34.40	41.44	1.97	0.14	1.69	2.25
Bravo	Pre1	34.99	2.25	30.51	39.47	1.99	0.20	1.59	2.39
	Pre2	36.09	2.76	30.60	41.58	2.06	0.21	1.64	2.48
	Post	37.53	2.44	32.68	42.39	1.93	0.19	1.55	2.30
	RTP	34.54	2.58	29.41	39.66	1.82	0.20	1.42	2.22
Charlie	Pre1	44.02	2.45	39.15	48.89	2.54*	0.19	2.15	2.93
	Pre2	45.35	2.58	40.21	50.48	2.80*	0.19	2.41	3.19
	Post	41.61	2.25	37.13	46.09	2.63*	0.19	2.26	3.01
	RTP	40.83	2.45	35.96	45.70	2.52*	0.19	2.13	2.90
Delta	Pre1	37.28	5.53	26.27	48.28	1.46	0.37	0.71	2.20
	Pre2	40.18	5.53	29.17	51.18	1.40	0.44	0.51	2.28
	Post	37.90	4.50	28.94	46.86	1.63	0.37	0.88	2.37
	RTP	35.60	4.50	26.64	44.56	1.67	0.37	0.92	2.41

N= Newtons, **Std. error**= Standard error, **Conf. Low**= Low confidence level, **Conf. High**= High Confidence level, ***** = $p < 0.05$.

3.7 Lower-Body Strength

3.7.1 Hip Adduction

Linear Mixed Model fit results are presented in Table 8. There was no significant interaction between group and time. However, there was a significant main effect of time (F=6.06, p= 0.00) on hip ADD but not group (F= 1.85, p= 0.16) (Figure 7). According to predicted means, RTP (M= 989.92, CI [877.85, 1101.99]) values were significantly greater than Pre1 (M= 785.43, CI [675.46, 895.40]) and Pre2 (M= 819.99, CI [696.49, 943.48]) values (Table 9). Alpha (RTP greater than Pre1 and Pre2) and Charlie (RTP greater than Pre1) significantly improved over time while Bravo and Delta did not change.

Table 9. Lower-body strength model fit & group ICC results.

	Mean ± Standard Error	Conditional R^2	Marginal R^2	Group ICC
Hip Adduction	785.43 ± 55.36	0.20	0.71	0.64
Hip Abduction	856.66 ± 41.75	0.29	0.84	0.77

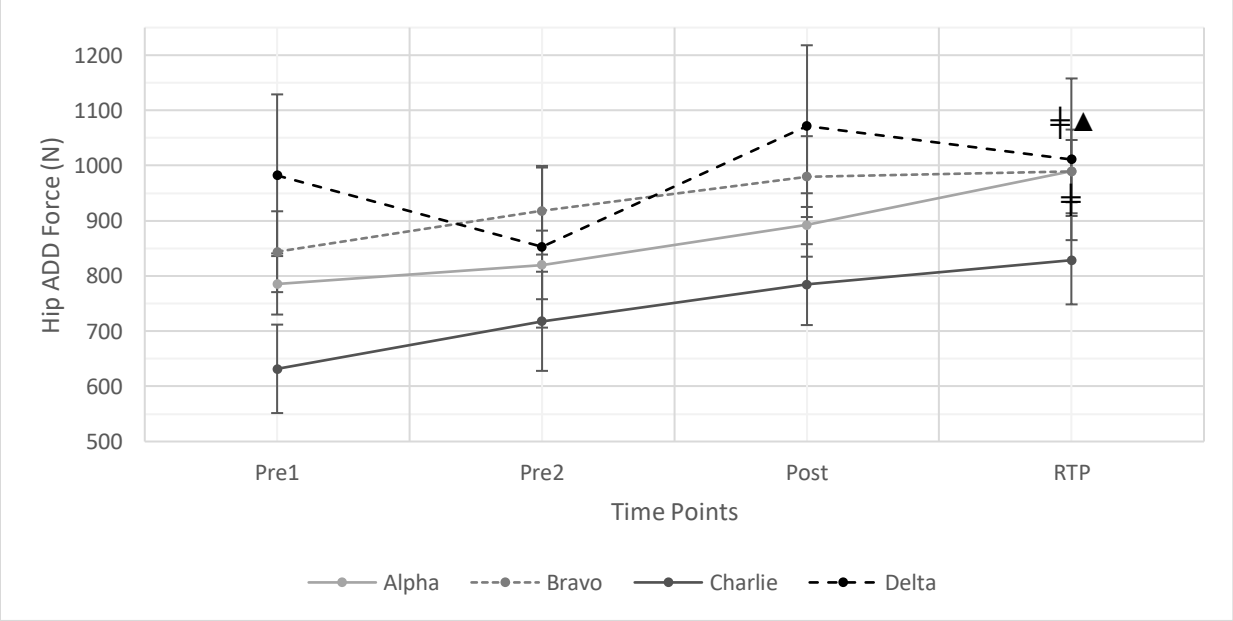

Figure 7. Hip adduction peak force results over time for Alpha, Bravo, Charlie and Delta groups. Data is presented as predicted means and 95% standard errors. ╪ = timepoint is significantly greater than Pre1 for given group ($p \leq 0.05$), ▲ = timepoint is significantly greater than Pre 2 for given group ($p \leq 0.05$).

Table 10. Hip adduction and hip abduction results over time for Alpha, Bravo, Charlie and Delta groups.
Data is presented as predicted means and 95% standard errors.

		Hip Adduction Force (N)				Hip Abduction Force (N)			
Group	Time point	Predicted Mean	Std. error	Conf. Low	Conf. High	Predicted Mean	Std. error	Conf. Low	Conf. High
Alpha	Pre1	785.43	55.36	675.46	895.40	856.66	41.75	773.66	939.66
	Pre2	819.99	62.17	696.49	943.48	891.76	44.23	803.84	979.68
	Post	892.37	57.47	778.22	1006.53	953.34 ╪	42.78	868.29	1038.38
	RTP	989.92 ╪▲	56.42	877.85	1101.99	1023.31 ╪▲	43.47	936.90	1109.71
Bravo	Pre1	843.94	73.24	698.46	989.42	1022.91	55.23	913.11	1132.71
	Pre2	917.64	78.85	761.01	1074.26	973.64	58.01	858.31	1088.96
	Post	980.00	73.24	834.52	1125.48	1010.22	55.23	900.42	1120.02
	RTP	989.37	75.81	838.78	1139.95	1075.91	58.01	960.58	1191.23
Charlie	Pre1	631. 71	80.12	472.57	790.85	785.22 ⧢□	58.82	668.29	902.16
	Pre2	717.83	89.81	539.44	896.22	717.87 ◊⧢	64.22	590.21	845.52
	Post	784.28	73.24	638.80	929.76	822.66*	55.23	712.86	932.46
	RTP	828.58 ╪	80.12	669.44	987.72	864.87 ▲*	64.22	737.21	992.52
Delta	Pre1	982.50	146.48	691.54	1273.46	1043.12	110.47	823.53	1262.72
	Pre2	852.87	146.48	561.92	1143.83	885.00	110.47	665.40	1104.60
	Post	1071.50	146.48	780.54	1362.46	1131.88 ▲	110.47	912.28	1351.47
	RTP	1011.37	146.48	720.42	1302.33	1161.47 ▲	125.76	911.46	1411.48

N= Newtons, **Std. error**= Standard error, **Conf. Low**= Low confidence level, **Conf. High**= High Confidence level, ***** = $p < 0.05$, ╪ = timepoint is significantly greater than Pre1 for given group ($p \leq 0.05$), ▲ = timepoint is significantly greater than Pre 2 for given group ($p \leq 0.05$), * = group is significantly different to all other groups at given timepoint ($p \leq 0.05$), ◊ = group is significantly different to Alpha at given time point ($p \leq 0.05$), ⧢= group is significantly different to Bravo at given time point ($p \leq 0.05$), □= group is significantly different to Delta at given timepoint ($p \leq 0.05$).

3.7.2 Hip Abduction

The model fit results are presented in Table 8. There was no significant interaction between group and time. However, there were significant main effects of both group (F= 3.67, p= 0.02) and time (F= 11.59, p= 0.00) on Hip ABD (Figure 8). According to predicted means, RTP (M= 1023.31, CI [936.90, 1109.71]) values were significantly greater than Pre1 (M= 856.55, CI [773.66, 939.66]) and Pre2 (M= 891.76, CI [803.84, 979.68]) values, whilst Post (M= 953.34, CI [868.29, 1038.38]) values were significantly greater than Pre1 values (Table 9). Alpha (RTP greater than Pre1 and Pre2; Post > Pre1), Charlie (RTP greater than Pre2), and Delta (Post and RTP > Pre2) significantly changed over time while Bravo did not change. Charlie was significantly weaker (F= 3.67, p= 0.02) than Alpha, Bravo, and Delta groups at varying time points.

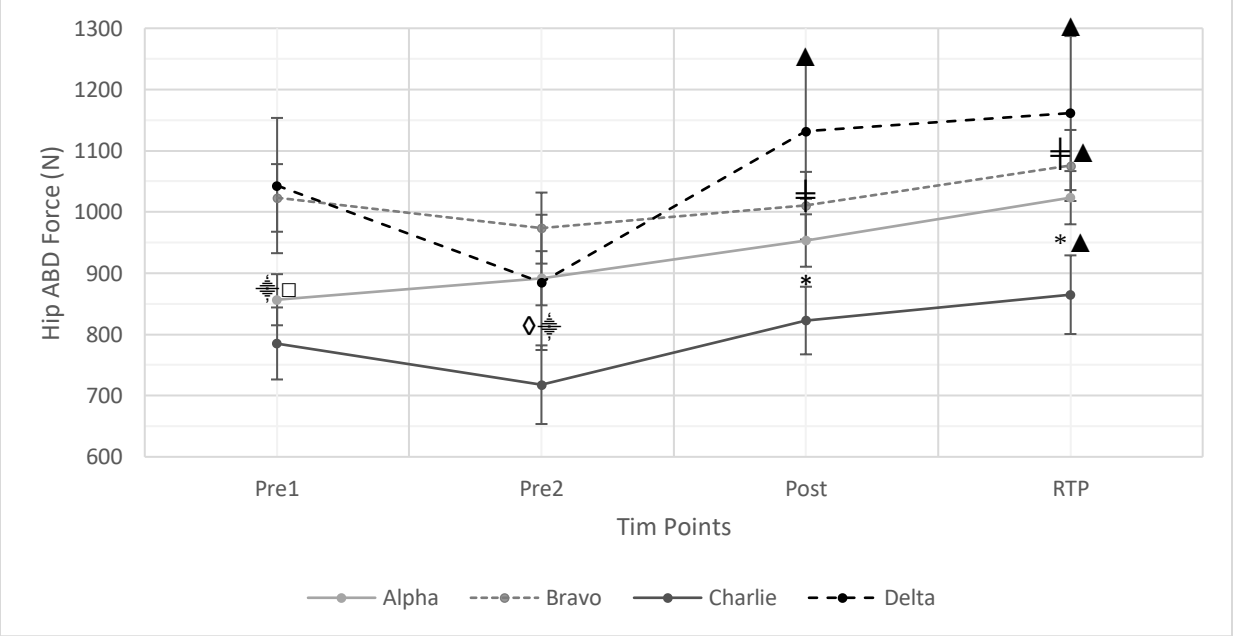

Figure 8. Hip abduction peak force results over time for Alpha, Bravo, Charlie and Delta groups. Data is presented as predicted means and 95% standard errors. * = group is significantly different to all other groups at given timepoint ($p \leq 0.05$), ╪ = timepoint is significantly greater than Pre1 for given group ($p \leq 0.05$), ▲ = timepoint is significantly greater than Pre 2 for given group ($p \leq 0.05$), ◊ = group is significantly different to Alpha at given time point ($p \leq 0.05$), ⧺= group is significantly different to Bravo at given time point ($p \leq 0.05$), □= group is significantly different to Delta at given timepoint ($p \leq 0.05$).

3.8 Discussion

The purpose of this study was to identify the impact of a COVID-19 isolation period on lower-body strength and power variables, and to determine whether inter-individual differences in physical response

occurred across players who tested positive versus negative for COVID-19. The authors hypothesized that lower-body power variables would be more susceptible to decay than lower-body strength variables. We also hypothesized that players who spent a shorter duration in the COVID-19 isolation would better maintain strength and power ability than players who spent a longer duration in the COVID-19 isolation The main findings of the study were; 1) There was no change across group or time points in CMJ height which experienced the greatest amount of variation, 2) Isometric hip force was maintained if not improved over time and, 3) RSI showed group differences in which Charlie had a significantly higher RSI across all time points, but congruently was significantly weaker in hip ABD. Thus, the results of our investigation suggest that the room-based exercise program was effective at maintaining lower-body power and had a greater influence on lower-body strength-oriented variables. These findings are in contrast to our hypothesis which predicted lower-body power variables to be more susceptible to significant decay than lower-body strength variables.

3.8.1 Lower-Body Strength

In relation to rugby union, lower body strength is a crucial aspect of any force-time characteristic, in particular, RFD and external mechanical power (Suchomel et al., 2016). Similar to lower-body power, the enhancement of lower-body strength should transfer to jumping, sprinting, and change of direction abilities (Suchomel et al., 2016). The room-based training programs in the current investigation primarily focused on joint stability robustness through long-duration time under tension isometrics. Furthermore, whole body dynamic bilateral and unilateral exercises which incorporated low-intensity force absorption through the ankles, knees and hips were prescribed. The results of the current investigation revealed that this training approach provided an adequate and specific training stimulus to maintain, if not improve, isometric hip strength (Figure 7, Figure 8, Table 9). These finding are supported by previous investigations which have also reported the maintenance of hip ADD and hip ABD isometric strength following COVID-19 imposed training restrictions lasting ~60 and ~13 days, respectively (Demir et al., 2021; Wagemans et al., 2021). In contrast to the current study, Demir et al. (2021) reported a non-significant negative shift in the hip ABD strength for dominant (-2.9%) and non-dominant (-3.7%) limbs, as well as hip ADD strength for dominant limb (-6.9%). This study however is quite limited due to their inability to test hip strength directly before the COVID-19 lockdown where they also failed to report on the nature of home-based training programs (Demir et al., 2021). Wagemans et al. (2021), who's COVID-19 imposed training restriction lasted for a similar time period (13 days) to ours (10-16 days), also experienced non-significant reductions as large as -21.31N, 2 weeks post and -33.40N, 4 weeks post. Our testing methodology of 3 x 3 s max isometric holds did differ to Demir et al. (2021) who conducted 2 x 5 s max isometric holds and to Wagemans et al. (2021) who despite conducting the same amount of reps, placed athletes in a supine

position with knees extended and sensor paddles at the ankles. Moreover, the lack of specific training may have reduced accumulated fatigue and muscle damage leading to a maintenance of MHC IIX muscle fibres within this current investigation. The isolation training programs were therefore sufficient in maintaining, if not improving isometric hip strength, which is expected when considering the prescribed contraction type (i.e., isometric holds).

The results which showed a general pattern of improvement in strength over time, are in accordance with other research which prevails the maintenance of concentric and isometric strength variables and the decay of eccentric strength variables following a COVID-19 imposed training restriction (Demir et al., 2021). Through which, eccentric hamstring strength showed adverse effects despite the prescription of specific exercises such as Nordics which are primarily eccentric in nature, following a two month COVID-19 confinement period (Demir et al., 2021). Following return to play, hip ADD and ABD strength returned to pre COVID-19 lockdown baselines, whilst eccentric hamstring strength was unable to do so, indicating that a three week retraining period is not sufficient for hamstring strength recovery (Demir et al., 2021) . These previous investigations are contradictory to the negative impact that we would expect a cardiorespiratory infection, such as COVID-19, to have on muscle strength and endurance (Becker & Smith, 2014). However, the results do emphasise the impact that a modified training stimulus (i.e., room/home-based training programs) has on muscular function.

Charlie (RTP greater than Pre1) and Alpha (RTP greater than Pre1 and Pre2) experienced a significant improvement in Hip ADD isometric strength whilst Bravo and Delta experienced no change (Figure 7). Interestingly, Charlie was significantly weaker and Alpha considerably lower in Hip ABD strength than the remaining two groups and so therefore had a greater bandwidth for improvement (Figure 8). Alongside this, all of the backs within this study were distributed across Alpha and Charlie groups as defined by the COVID-19 PCR testing procedures. These divergent strength results act in accordance with previous findings which have shown that forwards are significantly stronger in lower body metrics when compared to backs (Posthumus et al., 2020). An athlete's force producing capabilities i.e. strength, largely contributes to their ability to produce high force output in as short of a time as possible i.e. power (Young, 2006). In accordance with this, previous research has indicated that weaker athletes may be less susceptible to reductions in jump performance when compared to stronger athletes. This is supported by Parpa and Michaelides (2021) who attribute the improvements in CMJ performance to the variations in strength levels prior to a period of inactivity.

3.8.2 Lower-Body Power

Lower body power and reactive strength are essential traits in rugby union for completing athletic tasks that require a large amount of power output such as speed, acceleration, and agility, as well as during sport-specific tasks such as contact events, set piece, and offensive plays against opposing players (Cronin & Sleivert, 2005; Stokes et al., 2020). Plyometric exercises enhance the SSC via the improvement of inter group muscle coordination, eccentric muscular force tolerance, and the pursuing potential for greater concentric work (Komi, 1986, as cited in Król & Mynarski, 2012). Drop jump RSI was significantly different across group, but not time. Despite the contraction of COVID-19 and spending the second longest amount of time in isolation (13 days), Charlie were able to better maintain their DJ RSI which was considerably higher across all four time-points than the remaining three groups; Pre1 by 22-74%, Pre2 by 28-100%, Post by 28-61%, and RTP by 28-51% (Figure 6). Notably, Charlie had the largest percentage of backs (63%) compared to Alpha (57%), Bravo (0%) and Delta (0%), and therefore were comprised of players whose position-specific demands are more suited to the rapid and reactive nature of the DJ. This is supported by previous literature which states that backs produce greater jump heights in CMJ and greater RSI in DJ than forwards in professional rugby league players (Jones et al., 2016). In turn, forwards are generally slower and more force dominant athletes (Posthumus et al., 2020).

With reference to DJ RSI performance, eccentric muscle contractions play a crucial role in the rapid switch between the eccentric loading phase and the concentric power production phase during a SSC movement (Król & Mynarski, 2012). Fast SSC actions such as the DJ, involve short contraction times and transition periods between concentric and eccentric phases and contribute to mechanisms such as the muscle spindle reflex, elastic energy contribution, and potentiation (Flanagan & Comyns, 2008). Decrements in fast SSC actions following a COVID-19 isolation would pose severe implications when the athletes are required to perform time-regulated field events, which in rugby union involves tackling, evading defenders, and executing offensive plays (Flanagan & Comyns, 2008). Despite eccentric loading being prescribed and performed during the isolation training period within this investigation, the absence of sport specific training meant that athletes were not exposed to rapid decelerations or eccentric contractions that they would normally experience during an on-field training. Moreover, it is unlikely that the isometric training focus would have contributed to the maintenance and/or improvement of the SSC in DJ RSI performance. This is supported by Kubo et al. (2006), whom suggest that the nature in which isometric training affects tendon stiffness, may result in a negative impact on the SSC. Isometric training for a period of time has resulted in then delay of contractile properties (Kubo et al., 2006). Despite the advantages of increased tendon stiffness in force transmission, the delay of contractile properties may cause a longer time period between eccentric and concentric contractions, resulting in limited utilisation of the stored elastic energy

within the SSC (Kubo et al., 2006). Despite this, isometric training has been found to improve tendon stiffness, muscle strength and size (Kubo et al., 2001).

There were no significant changes in DJ RSI across timepoints in the current study. The DJ is very rapid and reactive in nature as a result of the "drop" and is therefore classified as a fast SSC action (<250 milliseconds) (Hennessy & Kilty, 2001). DJ performance is heavily influenced by muscle-tendon properties such as eccentric strength, tendon elasticity, and tendon stiffness, all of which play a pivotal role in the tissues ability to tolerate, absorb and redirect the downwards force via rebound qualities. Tendons lose their elasticity and stiffness quicker than muscles lose their strength (De Boer et al., 2007). Tendon stiffness has been seen to decrease by 58% following 90 days of bed rest, and change relatively by ~30% following two months of detraining (De Boer et al., 2007; Kubo et al., 2010). A reduction in tendon stiffness could lead to increased ground contact time due to the delay in force transmission between the muscle and tendon, thus reducing rebound velocity (Cohen et al., 2021). However, the same DJ RSI value can be achieved via two different strategies; 1) greater jump height combined with slower ground contact time, or 2) smaller jump height combined with quicker ground contact time. Therefore, neuromuscular function may have been altered across the course of the four timepoints, but this would not have been reflected in the DJ RSI values that has been used for analyses. Reductions in tendon stiffness in combination with the sensitivity of eccentric strength qualities, suggests that it is unlikely that the isometric strength-oriented training program that was prescribed within this study would be effective in maintaining DJ RSI if the COVID-19 isolation was longer (Spyrou et al., 2021). Moreover, substantial eccentric qualities are required to overcome the high amount of force that must be absorbed and redirected in as short of time as possible, during the landing and pursuing rebounding phases of the DJ. This is in contrast to the CMJ which involves a longer eccentric (pre-stretch) phase, and thus a greater concentric force production focus (Voigt et al., 1995). Therefore, the significant effect of group on DJ but not CMJ can be explained according to the differing attributes such as reactivity and eccentric-concentric strength that constitute performance across the two jump tests.

As expected, the lack of specific plyometric and power training within the isolation training programs resulted in a general decrease (-9.63%) in CMJ height across the board, however these changes were not significant which is likely due to our limited sample size. Evidence of this is the shift across the four time points; Pre1 (41.96cm), Pre2 (39.88cm), Post (38.80cm), and RTP (37.92cm). Previous studies have found significant reductions in CMJ height following a COVID-19 imposed training restriction, with changes including -3.46%, -8.3%, and -6.5% (Grazioli et al., 2020; Salazar et al., 2020; Valenzuela et al., 2021). Although Alvurdu et al. (2022) did not report specific decay values, they also found significant decreases in CMJ height across all four within group analyses for pre COVID-19 lockdown and post

COVID-19 lockdown values. It is important to note when comparing results that the participants within these studies experienced much longer lockdowns or quarantines; 109 days, 63 days, 42 days, and 49-70 days respectively, compared to the 10-16 day isolation in the current study (Alvurdu et al., 2022; Grazioli et al., 2020; Salazar et al., 2020; Valenzuela et al., 2021).

The current investigation is among many others which have found COVID-19 imposed training restrictions to have no impact on CMJ height (Cohen et al., 2021; Font et al., 2021; Pedersen et al., 2021; Spyrou et al., 2021). For example, Cohen et al. (2021) found a maintenance in CMJ height during an 105 day quarantine. This maintenance occurred in accordance with a change in neuromuscular function, particularly during the eccentric "yielding" and landing "loading" phases of the CMJ whereby, RFD decreased whilst duration and displacement increased (Cohen et al., 2021). A longer time period to recruit peak force has been seen to compensate for decreases in time-regulated jump mechanics such as RFD in order to maintain jump performance in slow SSC exercises such as the CMJ (Flanagan & Comyns, 2008). Thus, despite no significant difference being found across time points or groups for CMJ jump height, jump kinetics that contribute to fast SSC variables such as RFD, peak velocity, and peak power may have been affected (Spyrou et al., 2021).

In comparison to other variables within this study, CMJ height results experienced the greatest variation in fixed effects of time point and group (conditional R^2= 0.18), and in random effects of time point, group and participant (marginal R^2= 0.70) (Table 6, Table 8). The variability in lower-body power results, may be attributable to the ecological validity of team protocols where players were encouraged to do "one rep well", however a second opportunity was granted if they believed that they could complete a better rep. Jump performance can improve over multiple efforts, so there is a possibility that each player's "best effort" was not in fact their true best effort which may have contributed to the wide spread of results across the time points. Thus, although the retrospective data was captured as per the standard testing practice for the team, it may be advisable for professional teams to revise their data collection protocols in order to enhance the accuracy of the information.

3.9 Conclusions

To conclude, the room-based training program that was implemented during the 10-16 day COVID-19 isolation was effective in maintaining lower-body power variables of CMJ height and DJ RSI, but had a greater effect on lower-body strength variables of Hip ADD and Hip ABD maximum isometric force. This is supported by our three main findings which include; 1) There was no change across group or time

points in CMJ height which experienced the greatest amount of variation, 2) Isometric hip force was maintained if not improved over time, 3) RSI showed group differences in which Charlie had a significantly higher RSI across all time points, but congruently was significantly weaker. These results highlight the ability for performance variables to be maintained given the implementation of an effective exercise program.

Chapter: 4 Summary

4.1 Summary

The aims of this dissertation were to conduct a review of the current literature in the field, identify the impact of a COVID-19 isolation period on lower-body strength and power variables in professional rugby union players, and determine whether inter-individual differences in physical response varied across groups with differing isolation lengths.

To begin, the literature review (Chapter 2) sought to highlight the impact of various COVID-19 imposed training restrictions (isolation, lockdown, quarantine) on athletic performance. In the literature review, the expected decay, maintenance, and improvements in strength and power variables across COVID-19 imposed training restrictions that vary in time length and type have been identified. The key findings of the literature review were the heightened sensitivity of time-regulated jump mechanics and eccentric strength qualities to decay following a COVID-19 imposed training restriction, when compared to isometric strength variables such as hip ADD and ABD which were maintained across the board. These changes can be explained by alterations to jump strategy and technique, muscle-tendon properties, as well as the lack of sport-specific training, and highlight the need for training interventions that are catered to the constraints of the COVID-19 imposed training restriction.

Following the literature review, the primary aim of the Chapter 3 was to identify the impact of a 10-16 day COVID-19 isolation on lower-body strength and power variables in 32 professional rugby union players. In order to achieve this, lower-body strength (Hip ADD, Hip ABD) and power (CMJ height, DJ RSI) data was recorded at four timepoints across four different groups, each of which differed according to COVID-19 contraction (positive versus negative) and isolation length. The primary findings were 1) isometric hip strength was maintained, if not improved, across the four timepoints, 2) Charlie had a higher DJ RSI in accordance with being the weakest in Hip ABD and similarly in Hip ADD and, 3) CMJ did not change over groups or timepoints but did experience the greatest variability as a result of the team's testing protocol.

In conclusion, the room-based exercise program elicited a sufficient training stimulus that led to positive adaptations in isometric hip strength as well as the maintenance of CMJ and DJ measures. In contrast to our hypothesis, the training intervention was effective in maintaining both lower-body strength and power variable in professional rugby union players following a 10-16 day COVID-19 isolation.

4.2 Limitations

It is important to note there were several limiting factors in the current investigation. First, the limited sample size and the distribution of players (i.e., forwards vs. backs) across the isolation groups was a result of the unprecedented nature in which COVID-19 arose within this specific professional rugby union environment. The positional demands of rugby union means that forwards are generally more force-dominant athletes, whilst back are more power-dominant (Jones et al., 2016; Posthumus et al., 2020). The uneven distribution of forwards and backs across isolation groups may have skewed the results due to the variation in strength levels rather than the direct impact of a COVID-19 isolation. Alongside this, the group sizes varied with Delta (n=2) being the smallest and thus presenting the greatest standard error.

Second, the retrospective nature in which this data was obtained from the professional rugby union franchise meant that the primary researcher did not have direct control over the data collection methodology and implementation. Thus, it could be speculated that in some instances, the testing protocols may not have been implemented with the same level of academic rigor that is required of peer-reviewed experimental investigations. However, all the analysed data was obtained as per the team's standard testing protocol that was implemented on a weekly basis throughout the preceding in-season period. Thus, all the players and staff (who were responsible for capturing the data) were highly accustomed with the protocols which maintained the ecological validity of the methods.

Third, the presence and severity of COVID-19 symptoms was not tracked by the team's medical staff during isolation, so it is unclear how the respiratory infection affected each player's overall wellbeing It is entirely possible that some individuals experienced more severe symptoms than others which would have negatively impacted their ability to perform the room-based training. Following on from this point, the constraints of the COVID-19 isolation also meant that the team's staff were unable to supervise room-based training programs to ensure maximum intent and proper execution.

4.3 Practical Recommendations

The present dissertation identified that a room-based program which focuses on joint stability robustness through long-duration time under tension isometrics, whole body range of motion movement patterns, low-intensity force absorption through ankle, knee and hip (e.g., drop landings from 20-30 cm), and unilateral exercises completed at medium-high reps (i.e., 2-4 sets of 6-10 reps) and controlled tempos (3s-1s-1s), can be effective in maintaining lower-body power and maintaining, if not improving, lower-body strength. Alongside this, the implementation of exercises that utilise the SSC such as fast SSC actions

(e.g., DJ) and slow SSC actions (e.g., CMJ) is also recommended to counteract the potential changes to neuromuscular integrity (e.g., tendon stiffness) and function (e.g., contraction speed). Practitioners should also strive to incorporate sport-specific movements such as drop jumps, change of directions, accelerations and decelerations, where possible in order to better maintain reactive, time-regulated movements to allow for an easier transition into on-field trainings.

4.4 Future Research

Based off the results from the current investigation, future research could involve a focus on the following: 1) Does a higher DJ RSI help to facilitate quick recovery in strength? 2) Are acute decreases in strength associated with subsequent positive diagnosis? 3) What impact does symptom severity have the ability to maintain and/or improve neuromuscular function?

Lastly, if a similar situation arises with regards to the presentation of COVID-19 within a team environment, practitioners should look to explore the effects of COVID-19 on upper-body strength and power performance particularly if the cohort is made up of collision sport athletes such as rugby union or rugby league players.

4.5 References

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4.6 Appendices

Appendix A- Consent Form

Consent Form

Project title: ***The Impact of COVID-19 Isolation on Strength and Power Performance in Professional Rugby Union Players: Positive versus Negative Cases.***

Project Supervisor: ***Dr. Adam Storey***

Researcher: ***Morgan Hutchings***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 29 JULY 2022.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- ○ I understand that if I withdraw from the study then I will be offered the choice between having any data or tissue that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- ○ I agree to provide the researchers access to my lower-body power (countermovement jump and drop jump) and strength (hip adduction, hip abduction, nordic hamstring) data, and my COVID-19 polymerase chain reaction (PCR) test results, that were collected during the 2022 Super Rugby Pacific season.
- ○ I agree to take part in this research.
- ○ I wish to receive a summary of my individual results (please tick one): Yes○ No○
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: .....

Participant's name: .....

Participant's Contact Details (if appropriate):

.....

.....

.....

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on ***type the date on which the final approval was granted*** ***AUTEC Reference number*** ***type the AUTEC reference number***

Note: The Participant should retain a copy of this form.

Appendix B- Ethics Approval

Auckland University of Technology Ethics Committee (AUTEC)

2 May 2023

Adam Storey
Faculty of Health and Environmental Sciences

Dear Adam

Re Ethics Application: **22/212 The Impact of COVID-19 Isolation on Strength and Power Profiles in Professional Rugby Union Players**

Thank you for your responses to AUTEC's conditions.

Your ethics application has been approved for three years until 2 May 2026.

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: Morgan66hutch@gmail.com

Appendix C- Study Advertisement/Flyer

REQUEST FOR STUDY PARTICIPANTS

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Project Title:

"The Impact of COVID-19 Isolation on Strength and Power Performance in Professional Rugby Union Players: Positive versus Negative Cases."

Qualifications:

1. A member of the Moana Pasifika rugby union team who travelled to Queenstown for the start of the 2022 Super Rugby Pacific season.
2. Willing to give consent for retrospective data (lower-body strength and power performance, COVID-19 PCR test results, and isolation period lengths) to be used in this research.
3. Free from acute or chronic injury throughout the three retrospective testing time points.
4. Fully participated in regular team trainings throughout the three retrospective testing time points.

Purpose of the study:

The rapid return to competition following a COVID-19 isolation can impair athletic performance and increase an athlete's risk of injury. Recent studies have put these implications down to the rapid declines in muscle strength, power, and rate of force development following a period where athletes are limited with regards to their training capacity. A greater understanding in this area will enable practitioners to implement exercise interventions that maintain or minimize decreases in lower-body strength and power during COVID-19 imposed training restrictions such as isolations. Therefore, the purpose of this research is to determine if athletic performance variables of strength and power are impacted by isolation periods, and if the performance responses to isolation periods differ among athletes who tested positive and athletes who tested negative.

What was involved:

For the purpose of this investigation, we will be analysing the performance data obtained during four timepoints throughout the 2022 Super Rugby Pacific season. The four time points of interest are; 1) Pre-COVID-19 isolation (16 days prior to COVID-19 isolation), 2. Pre-COVID-19 isolation (7 days prior to COVID-19 isolation), 3) Post-COVID-19 isolation (max 3 days post COVID-19 isolation) and 4) return to play following COVID-19 isolation (2 days prior to RTP game). The performance tests for lower body power included 1-3 countermovement jump trials and one drop jump trial on a ForceDecks dual uniaxial force plate system (Vald Performance, AUS) which produced a variety of metrics including reactive strength index, flight time, jump height, concentric peak force, eccentric peak force, and peak vertical force. For lower-body strength, the performance tests included 3 x 3 five-second isometric holds for hip adduction and hip abduction on the ForceFrame strength testing system (Vald Performance, AUS). The appearance of COVID-19 within the team was detected using COVID polymerase chain reaction (PCR) tests. These PCR tests were conducted by external health practitioners within the quarantine facilities. The length of isolation depended on the occurrence and timing of positive COVID-19 cases. With isolation period lengths ranging from 10-days to 16-days.

Benefits of the study:

Participants will receive a summary report of the research findings, as well as an enhanced understanding of the unprecedented nature of a COVID-19 isolation, and its impact on athletic performance. The researchers will benefit by adding to the current body of literature regarding Return to Play protocols following COVID-19.

Whom do I contact for further information about this research?

Researcher **Morgan Hutchings PH:** 021 2149312 **E:** morgan66hutch@gmail.com
Project supervisor **Dr. Adam Storey PH:** 021 2124200 **E:** adam.storey@aut.ac.nz

Appendix D- Participant Information Sheet

Participant Information Sheet

Date Information Sheet Produced:

15 MAY 2023

Project Title

The Impact of COVID-19 Isolation on Strength and Power Performance in Professional Rugby Union Players: Positive versus Negative Cases.

An Invitation

Kia ora, my name is Morgan Hutchings and I am currently a Masters student at the Auckland University of Technology. I am inviting you to participate in the above-named study which is a research-based investigation conducted by Miss. Morgan Hutchings and supervised by Dr. Adam Storey.

What is the purpose of this research?

Due to the COVID-19 pandemic, social distancing strategies such as isolations have resulted in the stagnation, postponement and cancellation of sporting events and activities. The mandatory isolations posed by the COVID-19 pandemic also forces athletes to undergo prolonged training restrictions where performance effects are bound to occur.

Return to play following COVID-19 is an expanding area of research within the high-performance sports realm. The rapid return to competition following a COVID-19 isolation can impair athletic performance and increase an athlete's risk of injury. Recent studies have put these implications down to the rapid declines in muscle strength, power, and rate of force development following a period where athletes are limited with regards to their training capacity. These findings reiterate the importance for practitioners to understand the unprecedented nature of a COVID-19 imposed training restriction such as an isolation, and its impact on athletic performance.

Therefore, the purpose of this research is to determine if athletic performance variables of strength and power are impacted by isolation periods, and if the performance responses to isolation periods differ among athletes who tested positive and athletes who tested negative.

These findings will contribute towards a Masters degree and will be presented in a dissertation format. In addition, the research findings may be used for academic publications and presentations.

How was I identified and why am I being invited to participate in this research?

A flyer requesting study participants was posted to the Moana Pasifika team's online sharing platform. If, you were interested in participating in this study after having read the flyer, you were instructed to approach Miss Morgan Hutchings for an information sheet. You have been identified as a potential participant in this research because you are an athlete within the organisation where Miss. Morgan Hutchings is completing her Master of Sport, Exercise and Health internship and research project. You are invited to participate in this research because you are a member of the Moana Pasifika rugby union franchise, to which your athletic performance data has been frequently collected throughout the 2022 Super Rugby Pacific season using Vald Performance Human Measurement Technologies (BNE, AUS). The test results were automatically uploaded to Vald Hub (Data and administration platform) and stored on a Moana Pasifika database as a standard requirement of the Super Rugby Pacific competition. The retrospective data, collected using Vald Performance Human Measurement Technologies (BNE, AUS), will be the foundation of Miss. Morgan Hutchings' Master's Research Project, if consent is given by each team member to access, analyse, report, and publish the data. This testing battery includes counter-movement jump (cm), drop jump (RSI), hip adduction (N) and hip abduction (N) measures, and was implemented by Head of Athletic Performance and Pathways at Moana Pasifika, Paul Downes. Due to his influence on this scope of research and his position at Moana Pasifika, Paul Downes will act as an assistant researcher in a supervisory role, in order to minimise the conflicts of interest and power differences. As per the Moana Pasifika's performance monitoring and injury screening protocols, the collection of strength and power data has occurred during four significant time-points; Pre-COVID-19 isolation (baseline), Pre-COVID-19 isolation, Post-COVID-19 isolation, and Return To Play following COVID-19 isolation. With permission from each individual participant, the team's strength and power data will be used for analysis. You are eligible to participate in this study if you are; 1) a member of the Moana Pasifika 35-man playing squad who travelled to Queenstown for the start of the 2022 Super Rugby Pacific season, 2) took four COVID tests during the

10-16 day isolation, 3) had no acute or chronic injuries or medical conditions between 2nd Feb-4th March 2022, and 4) fully participated in regular team trainings and screening sessions between the 2nd Feb-4th March 2022.

How do I agree to participate in this research?

If you meet the four eligibility criteria, then you are eligible to participate in this study. Please notify Morgan Hutchings if you are; 1) Eligible, and 2) Willing to participate in this study. She will then provide you with a consent form. Your informed and voluntary consent to participate in this research study will be indicated by you signing and dating the consent form and returning it to Morgan Hutchings. Signing the consent form indicates that you have read and understood this information sheet, freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT. If you have questions or queries about the study at any time, please address Morgan Hutchings.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you within the Moana Pasifika environment. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible. Please note that participants' information and data will be coded on all materials used for data collection, analysis, reports and publications. Additionally, only the banded age groups (20-25, 26-30, 31-35, 36+) and positional groups (forwards and backs) will be reported, this is to prevent any participants from being identified in the publications related to this study.

What will happen in this research?

This research requires participants to give consent for the analysis of retrospective data and the presentation of the research findings within a dissertation and subsequent journal articles. The data, which includes lower-body strength and power performance, COVID PCR test results, and isolation period lengths, has already been collected throughout the 2022 Super Rugby Pacific season as per Moana Pasifika's performance monitoring and injury prevention protocols. Thus, if willing, the participant is giving consent for the researcher Miss. Morgan Hutchings and her supervisor Dr. Adam Storey to use the data for a purpose other than what that it was originally collected for.

The frequency of performance testing throughout the 2022 Super Rugby Pacific season has allowed the researcher to focus on four significant time-points; 1) Pre-COVID-19 isolation (baseline), 2) Pre-COVID-19 isolation, 3) Post-COVID-19 isolation and 3) Return to play following COVID-19 isolation. At these four timepoints, two countermovement jump trials and one drop jump trial (ForceDecks dual uniaxial force plate system, Vald Performance, AUS) were used to measure lower body power. While, 3 x three-second isometric holds for hip adduction and hip abduction (ForceFrame strength testing system, Vald Performance, AUS), were used to measure lower body strength. The appearance of COVID-19 within the team was detected using COVID polymerase chain reaction (PCR) tests. These PCR tests were conducted by external health practitioners within the quarantine facilities. The length of isolation depended on the occurrence and timing of positive COVID-19 cases. With isolation period lengths ranging from 10-days to 16-days.

What are the benefits?

Participants will receive summary reports of both their individual results and overall research findings, as well as an enhanced understanding of the unprecedented nature of a COVID-19 isolation, and its impact on athletic performance. The researchers will benefit by adding to the current body of literature regarding Return to Play protocols following COVID-19.

The results of this research are intended for publication and will contribute to part of Morgan Hutching's Masters dissertation and will also be submitted to peer-reviewed journals for publication.

How will my privacy be protected?

Your privacy will be protected at all times by the data being de-identified (i.e., coded numbers I.D 432 will be assigned to your data instead of your name), and the researcher will not disclose any participants involvement in this study. During the research study, only the applicant and named researchers will have access to the data collected. The results of the study may be used for further analysis and submitted to peer-viewed journals or submitted to conferences. However, only the banded age groups (20-25, 26-30, 31-35, 36+) and positional groups (forwards and backs) will be reported, this is to prevent any participants from being identified in the publications related to this study. Your privacy and anonymity will be upheld as the primary concern when handling the data collected.

All data collected will be stored on password protected computers or in securely locked files. Following completion of the data analysis process your data will be stored by the AUT SPRINZ research officer in the AUT SPRINZ secure Ethics and Data facility at the AUT Millennium campus and at Moana Pasifika Headquarters (Gate A at Mt. Smart)

for ten years. Following the ten-year storage period all hard copies of data will be destroyed (shredded) and electronic data will be deleted.

What are the costs of participating in this research?

To participate in this research, you are required to give your retrospective consent for your testing results to be used within this study, at no cost associated with money, time, or effort.

What opportunity do I have to consider this invitation?

It will be appreciated if you could let us know within one month whether you would like to or be available to take part in the study or not. After consideration you may withdraw your participation at any time.

Will I receive feedback on the results of this research?

Yes, participants will receive a one page summary of the key findings from the study.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr. Adam Storey, adam.storey@aut.ac.nz, 021 2124200.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Erin Moloney, *ethics@aut.ac.nz* , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Morgan Hutchings

AUT-Millennium, 17 Antares Place, Mairangi Bay

0212149312

morgan66hutch@gmail.com

Project Supervisor Contact Details:

Dr. Adam Storey

AUT-Millennium, 17 Antares Place, Mairangi Bay

0212124200

adam.storey@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.