The Effects of Wearable Resistance on Shoulder Strength and Throwing Velocity in Baseball Pitchers

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Abstract

Throwing velocity is a key attribute for baseball pitchers. Accordingly, substantial effort has been dedicated to enhancing throwing velocity and its underlying characteristics. Wearable resistance (WR) for throwing athletes is a relatively new training method where micro-loads are attached to the throwing arm, allowing for load placement variation and deceleration phase overload, with the primary aim of sport specific strengthening of the throwing arm musculature. However, currently there is no research investigating WR utilisation to improve pitching performance. The overarching question of this thesis was what are the effects of throwing arm WR loading and training on shoulder strength and throwing velocity in pitchers?

This thesis encompassed a series of acute studies and a training study to address the research question. Two studies quantified peak force (Fmax) and rate of force development (RFD) reliability during shoulder internal (IR) and external rotation (ER) with strain gauge technology. First, swimmers (n = 18) were evaluated in three testing positions, with acceptable Fmax reliability observed in all positions (coefficient of variation, CV = 5.2-8.8%, intraclass correlation coefficient 95% confidence intervals, ICC 95% CI = .69-.98), however, RFD reliability was questionable (CV = 11.5-18.1%, ICC 95% CI = .34-.96). Subsequently, college and high school (HS) pitchers (n=15) were assessed in the supine 90^{o} position, which provided the least variability. IR Fmax reliability was found acceptable (CV = 5.8%, ICC 95% CI = .56-.95), ER Fmax reliability was mixed (CV = 4.3%, ICC 95% CI = .39-.93) and RFD reliability unacceptable (CV = 16-29%, ICC 95% CI = .41-.97).

Relationships between shoulder rotator strength (Fmax and RFD during shoulder IR and ER) and throwing velocity was then explored. College and HS pitchers (n = 26) were assessed, the highest shared variance (adjusted R^2 = .12-.13, $p < .05$) was between Fmax and throwing velocity. An acute WR throwing analysis with college and HS pitchers (n = 10) was used to quantify the effects of above and below elbow placement of WR (100-g, 150-g and 200-g) on throwing velocity, arm speed and temporal phase mechanics compared to unloaded trials. The effect of load on throwing velocity differed by placement with small to moderate reductions in throwing velocity

(-1.8 to -2.7%, $p < .01$) detected with below elbow loads. Large decreases in arm speed (-5.1 to -6.5%, $p < .05$) with 150-g and 200-g below elbow were observed and the effects on temporal phase timing not clearly affected.

College pitchers ($n = 17$) were randomly assigned to a control or upper-arm WR group using a matched-volume design, implemented two times per week over six weeks of training. Pre- and post-test training of shoulder rotator strength, range of motion (ROM) and throwing performance unveiled no clear changes ($p > .05$) in throwing performance or shoulder rotator strength in either group. ER ROM increased over time ($p < .05$), predominantly attributed to changes in the control group (+15.8%). There is not sufficient evidence to support the use of WR for improving shoulder strength or throwing velocity in pitchers, within the protocols employed in this research. Despite unclear results, practical findings regarding shoulder strength assessment and suggestions for training pitchers were included in an opinion piece, which provides direction for practitioners and future researchers.

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List of Common Abbreviations

%: percentage

CI: confidence interval

cm: centimetres

CV: coefficient of variation

d: Cohen's d effect size

deg/s: degrees per second

e.g.: example

ER: external rotation

ER:IR: external rotation to internal rotation ratio

ES: effect size

Fmax: peak force

I: inertia

ICC: intraclass correlation coefficient

i.e.: that is

IR: internal rotation

Hz: Hertz

kg: kilogram

m: metres

m/s: metres per second

ms: milliseconds

N: Newtons

RFD: rate of force development

RKE: rotational kinetic energy

ROM: range of motion

RTD: rate of torque development

s: seconds

SD: standard deviation

Tmax: peak torque

TV: throwing velocity

UCL: ulnar collateral ligament

WR: wearable resistance

Attestation of Authorship

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

Chapters 2 through 8 of this thesis represent separate papers that have either been published or have been submitted to peer-reviewed journals for consideration for publication. The contributions of myself and the various co-authors of these papers are outlined at the beginning of each chapter. All co-authors have approved the inclusion of the joint work in this doctoral thesis.

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Trey Job

Co-Authorship Contributions within this Thesis

The publications listed below are a result of the research performed in fulfilment of the degree of Doctor of Philosophy:

STUDENT AND SUPERVISOR APPROVALS				
By signing you are confirming that the co-author contributions stated in the table(s) below are accurate.				
Student Name	Trey Job	**Signature**	**Date**	June 6. 2025
Supervisor Name	Matt Cross	**Signature**	**Date**	June 6, 2025

Chapter Number:	2
Manuscript Title:	Training methods to increase throwing velocity in baseball athletes: a brief review
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AUTHOR SURNAME:	CONTRIBUTION
Job	Conception and design of the project or output; contribution of knowledge; Critically revising it so as to contribute to its quality and interpretation; contribution of knowledge.
Neville	Critically revising it so as to contribute to its quality and interpretation; contribution of knowledge.
Cahill	Critically revising it so as to contribute to its quality and interpretation; contribution of knowledge.
Bourgeois	Critically revising it so as to contribute to its quality and interpretation; contribution of knowledge.
Crotin	Critically revising it so as to contribute to its quality and interpretation; contribution of knowledge.

Cronin	Critically revising it so as to contribute to its quality and interpretation; contribution of knowledge.

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Job TDW, Cross MR and Cronin JB. The relationship of shoulder internal and external rotation peak force and rate of force development to throwing velocity in high school and collegiate pitchers. *Journal of Biomechanics*.
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Ethics Approval

Ethical approval for this thesis was granted by Auckland University of Technology Ethics Committee (AUTEC) for the following:

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Chapter 1: Introduction

1.1 Background and Rationale

Throwing velocity is critical for success in baseball pitchers and several methods are commonly used to improve performance. Two notable and common categories of training are non-specific (e.g., training with barbells, dumbbells and resistance bands among others) and specific methods (e.g., throwing weighted baseballs) (67, 129). Non-specific training utilises a variety of loads, heavier and lighter, to develop a general basis of strength (13, 18, 41, 42, 75, 83, 90, 99, 102, 116, 126). Conversely, specific training includes biomechanically similar exercises or simply throwing with varied loads (13, 28, 29, 39, 80, 105, 116, 128). Wearable resistance (WR) secured to the throwing arm is an underexplored throwing-specific method that may provide unique advantages compared to other specific methods. This thesis has been conceived to better comprehend the physical qualities (i.e., strength) of the shoulder rotators of pitchers and the associations of these qualities to throwing performance. These learnings, along with understanding the acute effects of throwing with WR will inform practical applications for WR training to improve throwing performance.

Since throwing velocity is valuable to success on the field, it is regularly measured and monitored using tools like radar. Throwing velocity is an important outcome variable, but its assessment lacks granularity in terms of understanding the underlying determinants and provides little actionable data for coaches and athletes on which to effectively train for improvement. For example, two pitchers with similar throwing velocities may possess different physical capabilities. For this purpose, other tests might provide insight, such as internal (IR) and external rotation (ER) strength assessments to focus on the contributions of the rotator cuff. Historically, strength assessments of the upper limb have seen limited uptake due to largely inaccessible and impractical technologies (e.g., isokinetic dynamometry). Technology is continually evolving to become more portable and capable of capturing more granular data, which signals utility for integration into the field – provided the measurements are reliable. Furthermore, the devices

could be used to monitor training and measure the effectiveness of interventions such as WR. It is important to note that pitching occurs on the pitcher's mound and is different from flat ground throwing even though pitching and throwing may be colloquially used interchangeably. Flat ground throwing is commonly used by pitchers in training and will be the primary modality used throughout this thesis.

Every pitcher has a unique throwing motion (or pitching delivery) related to factors including individual anthropometry and biomechanics. Nonetheless, higher velocity pitchers consistently produce more force throughout their delivery (89). Notably, greater elbow varus torque, shoulder IR torque, elbow flexion torque, elbow proximal force and shoulder proximal force, have all been observed in pitchers producing higher throwing velocities (49). The shoulder IR musculature is responsible for accelerating the arm forward. During the arm cocking, acceleration and deceleration phases of throwing, forces at the shoulder and elbow are at their greatest. Therefore, strengthening the arm to contribute to and withstand these forces should likely be considered during training (19, 49). The posterior shoulder musculature, including those responsible for ER, is responsible for eccentrically slowing the arm and is prone to overuse injuries (19), hence shoulder ER strength metrics could provide insight into factors underlying arm health. Since substantial force must be generated quickly during throwing, capturing both the maximum force (Fmax) and the rate at which that force can be maximally developed (RFD) of the shoulder rotators might provide a more holistic view of important strength qualities.

Theoretically, WR could overload the arm accelerators prior to ball release and the arm decelerators after ball release, but at present, this contention remains unsubstantiated. Overall, the utilisation of WR with throwing athletes has received little research attention, the underpinning knowledge in this area rudimentary at best. In understanding both physiological and biomechanical effects, a greater awareness of the arm motion while integrating WR, should result in enhanced athletic performance and injury resilience. In any case, WR training should be nestled within a broader biomechanical analysis of the throwing delivery. The applied understandings derived from this thesis will guide coaches and players on how WR impacts

throwing arm strength and competitive outcomes that can collectively enhance throwing performance and arm health.

1.2 Purpose of the Research

The overarching question of this thesis was, "What are the effects of WR throwing on shoulder strength and throwing velocity in baseball pitchers?" To answer this question, several specific research questions were formulated:

1. Can a strain gauge device reliably measure shoulder rotator Fmax and RFD?
2. What are shoulder rotator strength characteristics of competitive high school and collegiate pitchers?
3. Is there a relationship between internal and external shoulder rotator force production capabilities and throwing velocity?
4. Do throwing performance measures change with different placement and magnitude of WR applied to the throwing arm?
5. Do throwing velocity and rotator cuff strength measures differ following a 6-week block of loaded throwing using increasing WR loads compared to a control group?

1.3 Significance of the Thesis

Overall, this thesis aims to provide a comprehensive view of targeted specific training to improve throwing performance. To this end, it leverages using practical tools to assess qualities which might underscore throwing performance and attempts to build a case for the specific use of WR with practical results from acute and training studies. Given WR has already seen adoption within practice, providing a more rigorous examination of its utility should be valuable for coaches, athletes and researchers in determining appropriate approaches to training.

In the first instance, there is surprisingly little information on strength assessments relative to throwing, and improving and clarifying this area could be beneficial for monitoring training, pending sufficient reliability. Accordingly, this thesis will offer valuable information for coaches and athletes by providing shoulder rotator assessment data via a portable, versatile, high

sampling frequency device. This preliminary testing will additionally allow for the collection of normative data, which can be used to identify weaknesses or imbalances so that training can be individualised based upon needs.

Accordingly, using data from this new tool, understanding the relationship between shoulder rotator strength and throwing velocity will provide context into the utility of WR as a training tool. This should allow for a targeted approach to maintaining or improving shoulder strength to optimise pitching performance. There is little information on how to determine WR loading for throwing. Thus, overloading the throwing action with WR needs to be objectified to give practitioners a better understanding of the magnitude and placement of the micro-loads to optimise pitching performance. Understanding the acute effects of WR applied to the throwing arm during pitching will better guide coaches and athletes in terms of sport/activity specific exercise prescription to improve pitching performance. Of real interest is whether strength and performance gains can occur within a practice setting, which has interesting applications for the training and/or retention of these qualities.

1.4 Structure of the Thesis

The chapters of this thesis have been formatted for publication in peer-reviewed journals (see Publications section). As such, they are written to be understood in isolation from the surrounding thesis content. Because of this thesis by publication approach (i.e., a Pathway 2 thesis), there will be some repetition between chapters and throughout the thesis. To aid in creating a cohesive document, preludes have been added at the opening of each piece which describe where the content fits within the overall thesis. The content from this work is separated into nine chapters over four distinct sections (see Figure 1):

- Section one provides an overview of the thesis and Chapter 2 provides a review of the existing literature investigating training methods to increase throwing velocity in baseball athletes.
- Section two includes acute studies focusing on reliability testing, quantifying the relationships between physical and technical ability, and the acute effects of WR on

throwing performance. Specifically, Chapters 3 and 4 assesses the technology used in the subsequent studies with insights into testing shoulder rotator force expression in multiple positions with a novel strain gauge. In Chapter 5, the association between shoulder rotator strength and throwing velocity are explored. The effects of WR applied above and below the elbow of the throwing arm on the biomechanics of throwing are investigated via radar gun, an inertial sensor, and video analysis.

- Section three includes a longitudinal study, leveraging the findings from the preceding section to allocate WR in training. Chapter 7 aimed to determine the effectiveness of throwing with WR applied above the elbow to increase throwing velocity and influence underlying strength measures in baseball pitchers.
- Section four concludes with practical applications of this thesis. Chapter 8 collects the findings from the thesis and places them in context to the broader field of practice and aims to provide researchers and coaches with guidelines on how to best implement WR with baseball players to increase throwing velocity. Furthermore, a summary of the main findings and future research directions are detailed in Chapter 9.

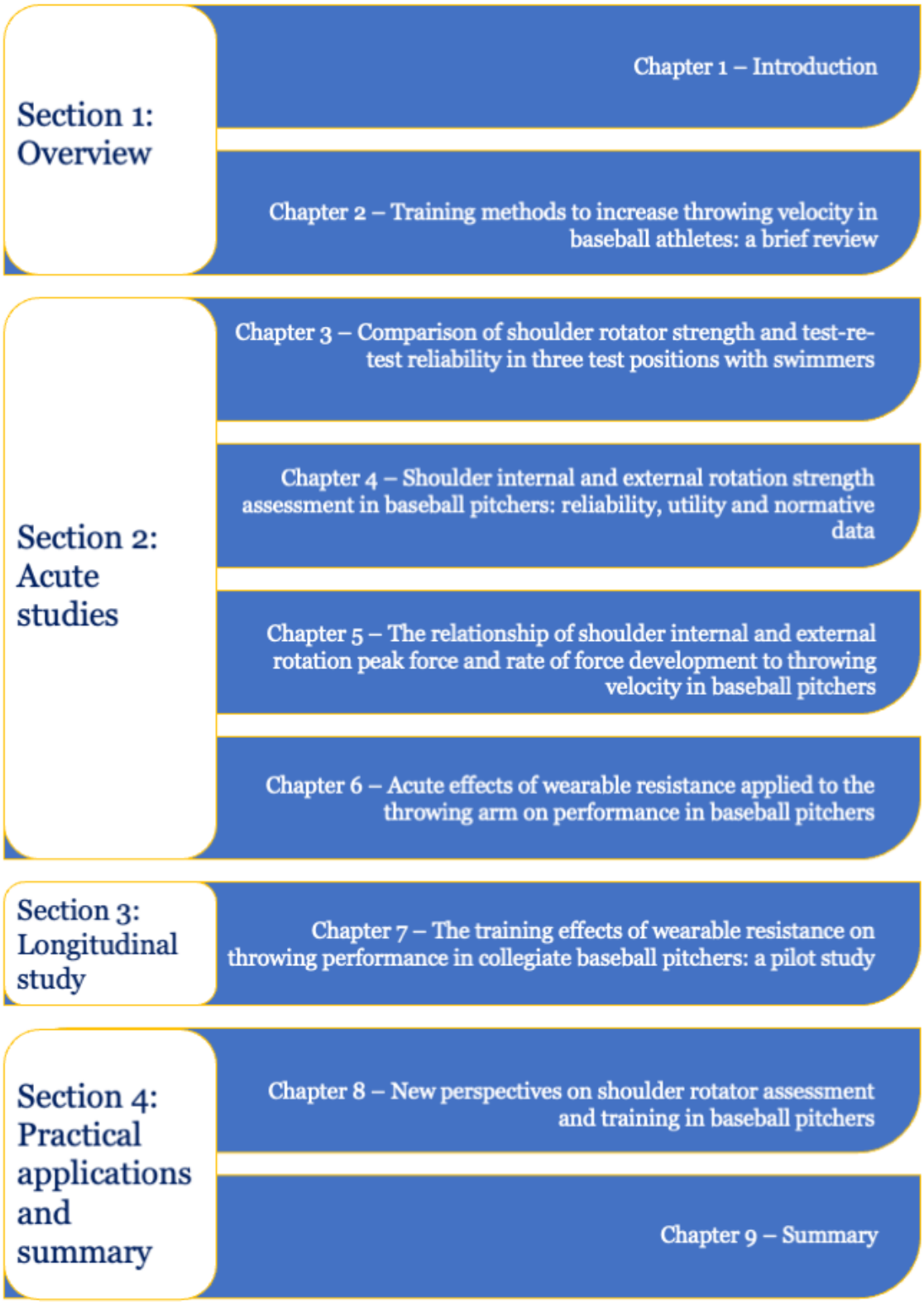

Figure 1. *Thesis chapter outline.*

Chapter 2: Training Methods to Increase Throwing Velocity in Baseball Athletes: A Brief Review

2.0 Prelude

Throwing velocity is a prized defensive attribute in the sport of baseball, particularly for pitchers. It is critical for career advancement and longevity, as well as success for baseball pitchers, and thus, has been the subject of research in sports science. The purpose of this chapter was to deliver a comprehensive review of literature concentrating on various training methods to enhance throwing velocity in baseball pitchers. It sets the foundation for the chapters of this thesis by highlighting benefits of strength development for baseball pitchers and limitations of current training practises. This chapter also identifies gaps in the literature and provides purpose for the research direction of this thesis.

This chapter comprises the following published paper:

Job T. D. W., Neville J., Cahill M. J., Bourgeois F. A., Crotin R. L., & Cronin J.B. Training methods to increase throwing velocity in baseball athletes: a brief review. *Strength & Conditioning Journal* 44: 1-9, 2022. doi: 10.1519/SSC.0000000000000694.

2.1 Introduction

Various training programs are implemented by baseball and strength and conditioning coaches at the youth, high school, collegiate and professional levels (18, 28, 41, 75, 90, 105, 115, 128). Effective training strategies to increase and maintain throwing velocity are vital to gaining a competitive advantage over opponents. While throwing velocity is a prized attribute of pitching performance and defensive talent, it can also be associated with increased risk of arm injury (39). Throwing is a foundational athletic motor skill developed throughout childhood (82). This action predicates the more technical skill of pitching in baseball, which can be improved from youth to professional levels (49). Kinematic similarities have been identified during throwing among youth, high school, collegiate, and professional baseball players, which are consistent throughout development (49). Because distinguishable kinetic differences were observed, it may be concluded that as baseball athletes mature and increase muscular strength, greater throwing velocity is produced along with increased arm stress and likelihood of injury (20, 49). Therefore, increasing strength while maintaining safe and efficient throwing mechanics are essential to increasing throwing velocity. Once efficient throwing mechanics are established, various methods exist to enhance pitching performance. These training modalities may be divided into non-specific and specific training methods. Non-specific methods consist of traditional resistance training, plyometrics (e.g., light-weight bench press) and prehabilitation exercises. Whereas specific training consists of throwing overweight, greater than 5-ounces (oz), and underweight, less than 5-oz, baseballs to increase arm strength and velocity, respectively. Multiple non-specific and specific training modalities have been shown to enhance pitching performance (18, 28, 41, 75, 90, 102, 105, 115, 128).

The purpose of this literature review is to explore different methods used by baseball players and coaches to increase throwing velocity outside the technical demands of pitching. Resistance training, plyometrics, prehabilitation exercises and variably weighted baseballs have been established as effective modalities to successfully increase throwing velocity. However, little consistency exists in regards to volume and intensity prescriptions. This review will focus on

identifying non-specific and specific training methods that have been found to have the greatest pitching performance enhancement.

2.2 Results: Overview of Training Methods

Non-specific and specific training methods have led to positive increases in throwing velocity and are outlined below in two separate tables. It should be noted, not all studies reviewed reported specifically on throwing velocity; however, effort has been made to include all available and relevant statistics. During higher load resistance training, force is high due to increasing mass through external loading in a way that is non-specific to the throwing motion. Although resistance training is non-specific to the throwing motion, throwing velocity can be increased due to higher force outputs from muscle-tendon units and favourable activation strategies of the nervous system (75). Various methods of non-specific strength training have been observed to increase throwing velocity in baseball athletes, including resistance training (42, 75, 99, 102, 116), plyometrics (18, 42, 90, 99) and prehabilitation exercises (41, 42, 53, 126). From Table 1 it can be observed that 11 studies utilizing baseball athletes have investigated the effects of resistance training on throwing velocity. Sample sizes ranged from seven to 17 participants per group with ages ranging from 12 to 24 (17.4 ± 5.9) years, and skill levels ranged from youth to professional athletes. Resistance training was undertaken one to five days per week for four to ten weeks in duration. Despite the range of equipment being used, five out of ten studies specifically mentioned training the shoulder external rotator group during the training intervention in some way which is responsible for arm cocking and the deceleration of the arm after ball release (18, 41, 42, 75, 126). Methods can also be categorized by repetition maximum (RM): loads of 3- to 12-RM and loads greater than 12-RM. Statistics for each study were reported when available and appropriate, and no studies reported any significant injuries during or after training.

Table 1. *Non-specific strength studies.*

Reference	n	Age (yrs)	Level	Duration (weeks)	Training group	Sessions per week	Training protocol	Control group	Increase (%, ES, p-value)
Brose and Hanson, 1967 (13)	7	18-19	College	6	Wall pulley device	3	10 lbs; unspecified rest	75 throws with 5 oz ball	Yes (NS)
Carter et al., 2007 (18)	13	19.7 ± 1.3	College	8	"Ballistic Six" Upper body plyometrics	2	Resistance tubing and medicine balls; 30 seconds rest	Rotator cuff training	2.4, NS, $p < .05$
Escamilla et al., 2010 (41)	17	12.9 ± 1.7	Youth	4	Resistance tubing + interval throwing	3	Resistance tubing; unspecified rest	No extra training	4.0, 0.36, $p = .004$
Escamilla et al., 2012 (42)	14	15.2 ± 1.1	HS	6	Thrower's ten program	3	8-12 RM; 1-2 minutes rest	No extra training	1.9, 0.29, $p = .013$
	15	15.4 ± 1.3	HS	6	Keiser pneumatic resistance	3	8-12 RM; 1-2 minutes rest	No extra training	1.2, 0.19, $p = .048$

	14	15.8 ± 0.8	HS	6	Plyometrics	3	6-10 RM; 1-2 minutes rest	No extra training	2.1, 0.31, p = .001
Lachowetz et al., 1998 (75)	11	18-22	College	8	Upper body resistance training	4	10 RM + 5 assisted repetitions; 2 minutes rest	No extra training	2.5, 0.84, p < .05
Logan et al., 1966 (83)	7	NS	College	6	Isotonic resistance pulley	5	2.5 lbs; unspecified rest	No training	10.7, NS, p < .05
McEvoy and Newton, 1998 (90)	9	24 ± 4	Pro	10	Bench press throws and squat jumps	1.5	6-8 RM; 3 minutes rest	Baseball practice only	1.8, 0.64, p < .05
Newton and	8	18.6 ± 1.9	Pro	8	Medicine ball throws	2	3 kg; 3 minutes rest	Baseball practice only	No increase
McEvoy, 1994 (99)	8	18.6 ± 1.9	Pro	8	Bench press	2	6-10 RM; 3 minutes rest	Baseball practice only	4.1, 0.91, p ≤ .05
Szymanski et al., 2011 (116)	10	16.0 ± 1.1	HS	8	Full body resistance training	3	3-10 RM; unspecified rest	No control group	No increase

Wooden et al., 1992 (126)	9	15.5 ± 1.0	HS	5	Isokinetic training	3	500 deg/s; 1 minute rest	No training	No increase
	9	15.5 ± 1.0	HS	5	Dynamic variable resistance training	3	Varied resistance from dynamometer; 1 minute rest	No training	2.06 mph, NA, p = 0.01

ES = Effect size; NS = not specified; HS = high school; lbs = pounds; kg = kilogram; RM = repetition maximum; deg/s = degrees per second; mph = miles per hour.

With regards to specific training methods, eight studies have investigated baseball athletes utilizing overweight or underweight baseballs as a training stimulus with the intent of increasing throwing velocity (Table 2). Researchers have examined throwing balls that are heavier than the standard 5-oz ball (13, 29, 80, 116) as well as throwing balls that are less mass than standard baseballs (29, 39, 128), and a combination of overweight and underweight balls (28, 105). Typically, overweight balls are used to overload force and increase strength, while underweight balls are utilized to enhance velocity during training (115, 121). Sample sizes in these studies ranged from seven to 44 participants per group; however one study examined 150 high school and collegiate baseball players (28). Participants were between 13 to 19 years of age. While skill level (i.e. youth, high school, college, pro) was commonly reported in the literature it is worth noting that individual experience (i.e. years pitching or playing baseball) was not reported. Athlete experience should be considered by coaches before introducing variably weighted balls into training due to the necessity of proper throwing mechanics. Resistance training experience should also be considered before starting a weighted ball program as an athlete with no resistance training experience may not tolerate the tensile stress of a weighted ball program. All studies used male volunteers since females traditionally play softball, which uses a different ball and throwing motion during pitching. Training studies utilizing overweight and underweight baseballs ranged from six to 15 weeks in duration. Participants completed 75 to 234 (172 ± 44.7) throws each week, while ball mass ranged from 4- to 12-oz (13, 28, 29, 39, 80, 128). There is one exception with a paper reporting a significantly lower number of throws. A six-week study featuring youth and high school baseball athletes required only 15 to 35 throws each week with variably weighted balls ranging from 2- to 32-oz (105). This study had the largest variance in ball mass used during training and was also the only study to report any arm injuries. These studies can be categorized by ball mass: high specificity, or within 20% mass of a standard baseball (e.g. 4- to 6- oz), low specificity, or greater than 20% mass more or less a standard baseball (e.g. heavier than 6-oz or lighter than 4-oz).

Table 2. *Specific strength studies.*

Reference	n	Age (yrs)	Level	Duration (weeks)	Sessions per week	Throws per week	Intervention	Control group	Increase (%, ES, p-value)
Brose and Hanson, 1967 (13)	7	18-19	College	6	NS	75	10-oz	5-oz	Increase (NS)
DeRenne et al., 1990 (29)	10	16-18	HS	10	3	150	5- to 6-oz	5-oz	5.31, 0.69, $p < .05$
	10	16-18	HS	10	3	150	4- to 5-oz	5-oz	6.67, 0.95, $p < .05$
DeRenne et al., 1994 (28)	75 total; 15 HS, 60 college	16.6 ± 0.5 (HS), 19.6 ± 0.5 (College)	HS and College	10	3	162-234	5- to 6-oz (5 weeks), 4-to 5-oz (5 weeks)	5-oz	4.4-6, NA, $p = .0001$
	75 total; 15 HS, 60 college	16.6 ± 0.5 (HS), 19.6 ± 0.5 (College)	HS and College	10	3	162-234	4- to 6-oz	5-oz	4.4-6, NA, $p = .0001$

Erickson et al., 2020 (39)	44	14.7 ± 1.8	Youth and HS	15	2	40+	3- to 5-oz	None	7.34, 0.57, $p < .001$
Litwhiler and Hamm, 1973 (80)	5	NS	College	12	NS	165	7- to 12-oz	None	Increase (5 m/s)
Reinold et al., 2018 (105)	19	15.3 ± 1.2	Youth and HS	6	3	15-35	2- to 32-oz	5-oz	3.34, 0.50, $p < .001$
Szymanski et al., 2011 (116)	11	15.8 ± 1.2	HS	8	3	192-216	5- and 7-oz	5-oz	No increase
Yang et al., 2013 (128)	12	14.1 ± 0.9	Youth	10	3	126-198	4.4-oz	5-oz	3.13, 0.34, $p \leq .05$

ES = Effect size; NS = not specified; NA = not applicable; HS = high school; oz = ounces; m/s = meters per second

2.3 Discussion

2.3.1 Non-Specific Resistance Training

Resistance training is utilized by sports performance practitioners to improve athletic capabilities. The benefits of resistance training include improved movement quality, increased muscle mass, strength, power and speed qualities (19, 75, 90, 102, 126, 127). Traditionally, successful baseball players have lean muscle mass with the ability to execute proper trunk rotation timing (19, 127). Performance may be enhanced in the weight room by developing strength and power alongside these anthropometric advantages such as sport specific increases in muscle mass.

Five groups of researchers (42, 75, 99, 102, 116) have implemented heavier strength training methods (3- to 12-RM) using various multi-joint exercises. High school, college and professional baseball players were examined in which three studies have reported 1.2-4.1% increases in throwing velocity and one study reported no increase. Training interventions took place during preseason (75, 102, 116) and summer season (42), while one study did not specify (99). The greatest four effect sizes among all reviewed studies were observed with college and professional baseball players (75, 99). The bench press exercise was used in four interventions, suggesting the exercise may be beneficial to the musculature utilized to throw a baseball. However, more research is needed regarding heavier resistance training methods due to small sample sizes and similarities in training interventions (i.e. bench press).

Resistance training with lighter loads (greater than a 12-RM) can be utilized with lower repetitions to emphasize speed production, or with higher reps to learn technique, build muscle and injury resistance. It is thought that baseball athletes should train with lighter resistances to facilitate velocity development (18, 42, 90). Furthermore, many single-joint, prehabilitation-type exercises require the use of lighter loads due to smaller musculature. Seven studies featuring eight interventions utilized resistances greater than 12-RM for various exercises (13, 18, 41, 83, 90, 99, 126). Seven out of eight interventions reported increases in throwing velocity ranging from 2.0-10.7% (13, 18, 41, 83, 90, 99, 126). Improvements in throwing velocity may be due to learning proper movement technique, strengthening specific throwing musculature in isolated

exercises and an emphasis on contraction speed (see Figure 2). Lighter load training resulted in improvements across all age groups; however, caution should be taken with younger age groups as there is limited research (41). Greater percentage increases (2.4-10.7%) to throwing velocity can be achieved with lighter loads utilizing a variety of equipment (i.e. resistance tubing, pulley device).

Figure 2. *Overhead toss for height with medicine ball.*

Two studies mimicked the throwing motion with external load attached to a pulley device with collegiate baseball athletes (13, 83). Both studies observed increases in throwing velocity, including the largest increase (10.7%) in the studies reviewed (13). However, a lack of information with regards to the athlete's experience, training methods and data collection tools makes it difficult to conclude why the improvements were the highest. Using a pulley system could be a legitimate method of increasing throwing velocity by allowing the athlete to recreate the throwing motion (i.e. principle of specificity). While most non-specific training studies did not attempt to mimic throwing motion, five studies did include training the shoulder external rotator group which is responsible for decelerating the arm after ball release (18, 41, 42, 75, 126). Training this muscle group (see Figure 3) is important due to high forces experienced in the shoulder during the deceleration phase of the throwing motion (49).

Figure 3. *Prehabilitation exercises focused on shoulder external rotation.*

The reviewed studies utilized baseball players at the youth, high school, collegiate and professional levels. Youth baseball players exceeded the minimum increase in throwing velocity of 4.0% in as little as four weeks of training with light resistance (41). Light resistance can be used with youth athletes to teach proper movement technique while still providing increases in velocity. Lighter loading strategies were more commonly used among the high school studies (42, 126); however, the most impactful intervention (ES = 0.31) used a heavier (6- to 10-RM) loading strategy (42). Perhaps heavy resistance training loading strategies would provide more impactful increases in throwing velocity for high school baseball players (i.e. advanced training status), though more research is needed to support such a contention.

Resistance training is an effective tool for strengthening the arm to throw at higher velocities (18, 41, 42, 75, 90, 99, 102, 115, 126). Heavy resistance training made impactful increases in throwing velocity in college and professional baseball players (75, 90, 99, 102); however, lighter loads did stimulate increases in throwing velocity in these groups as well (13, 18, 83). Youth and high school baseball athletes have shown improvements in throwing velocity following training with lighter loads, while college and professional baseball athletes have seen increases following heavy and light training. For physically mature baseball athletes, there could be an optimal balance of training with heavy and light loads to develop and maintain performance; however, more research is needed. Interventions in all studies varied, thus making it difficult to draw more

specific conclusions. Furthermore, training and testing could be refined by assessing shoulder strength or peak force and rate of force development to provide better diagnostic information as to the effects of various types of strength training. Testing for these metrics could be completed via Biodex, handheld dynamometer or strain gauge. Specifically, more effective guidance to training prescription may be gained by assessing shoulder internal and external rotation strength measures.

2.3.2 Specific Strength Training, Overweight and Underweight Balls

Weighted baseballs closely resemble standard baseballs (5-oz) with stitched seams but vary in mass and are used for velocity-specific training. These variably weighted baseballs can be used while throwing and aim to improve specific arm strength and throwing velocity. Researchers have investigated the use of overweight and underweight baseballs as a training tool with increases in throwing velocity ranging from 3.1-7.3% (28, 29, 39, 105, 116, 128). Training studies were compared by using overweight balls, underweight balls or a combined approach using over- and underweight balls (Table 3). Overweight balls with high specificity include balls that are up to 6-oz, while balls weighing more than 6-oz are considered to be low specificity. Similarly, underweight balls of high specificity include balls that are as light as 4-oz, while balls less than 4-oz are considered to be low specificity.

Table 3. *Variably weighted baseballs.*

	High specificity	Low specificity
Overweight balls	5- to 6-oz	> 6-oz
Underweight balls	4- to 5-oz	< 4-oz

Overweight baseballs used in training have successfully increased (5.31%) throwing velocity in high school and college baseball players. Training with baseballs of high specificity produced a moderate increase (ES=0.69) after 10 weeks of training (29); however, heavier baseballs of low specificity produced conflicting results. Positive increases were observed with college baseball

players after a minimum training intervention of six weeks, but small sample sizes and limited information about training were available (13, 80). Reviewed research regarding training with heavier weighted baseballs of low specificity for high school athletes was limited to one preseason study which did not see a significant increase in throwing velocity (116), nonetheless more research with this training modality is needed. When training with heavier baseballs, high specificity baseballs seem to be favourable compared to heavier, low specificity baseballs which allow the athlete to keep similar throwing mechanics, we assume, to a standard weight baseball as mechanics were not reported in the mentioned study.

Training with underweight baseballs has successfully increased throwing velocity (3.13 – 7.34%) with high and low specificity baseballs with athletes ranging from the youth to high school levels. Improvements were seen after a minimum of 10 weeks of training for youth and high school baseball players (29, 39, 128). Underweight baseballs should allow these athletes to throw at faster velocities and maintain those adaptations after training for a specific duration (e.g. 10 weeks). More research is needed with college and professional baseball players; however, similar methodologies could be applied in an effort to increase throwing velocity.

The combined use of overweight and underweight variably weighted balls has been effective in increasing throwing velocity (28, 105). Multiple combined approaches with overweight and underweight baseballs have successfully increased throwing velocity. In combined approaches with high specificity, training groups used a 2:1 variably weighted to standard baseball ratio while throwing and always finished throwing standard baseballs. Using overweight and underweight variably weighted baseballs of low specificity have demonstrated to increase throwing velocity in as little as six weeks with youth and high school baseball athletes. When combining overweight and underweight variably weighted balls, high and low specificity has been shown to increase throwing velocity; however, more research is needed on overweight, low specificity weighted ball training. Coaches should consider experience, training history and shoulder and elbow strength before introducing overweight, low specificity weighted baseballs into training.

Variably weighted baseballs can be used to enhance throwing velocity in baseball players across multiple levels. Underweight baseballs of high and low specificity have been demonstrated to be successful across most age ranges; however, heavier baseballs of low specificity should be used with caution. Introducing heavier baseballs of low specificity to baseball athletes needs more clarity, perhaps measures of shoulder strength and range of motion could provide more insight regarding progressions and arm health. High specificity variably weighted baseballs should be a safe option for athletes and may be introduced at the high school level while underweight baseballs can be introduced at the youth level.

2.5 Practical Applications

Non-specific strength training can enhance throwing velocity utilizing heavier or lighter loads. Heavy resistance (3- to 12-RM) training methods can be used to enhance force development at the college and professional levels; however, no significant increase has been seen at the high school level (116). Lighter loads (greater than 12-RM) can be used to target smaller contributing musculature, such as the shoulder rotator cuff group, or emphasize velocity development. Training the musculature responsible for decelerating the throwing arm should be considered for non-specific training so that the arm may sustain high forces after ball release.

Specific strength training methods, such as variably weighted baseballs, can be incorporated to develop throwing velocity by using balls of high specificity among youth, high school and college aged baseball players. Underweight baseballs can be utilized by youth, high school and college baseball players, and traditionally provide greater increases in throwing velocity which may be due to velocity overload. Baseball athletes could be introduced to underweight balls, progressed towards overweight, high specificity baseballs (up to 6-oz), and finally towards overweight, low specificity baseballs. These recommendations need to be researched but it is important for coaches to progressively introduce variably weighted baseballs with more mass to ensure throwing mechanics remain consistent through training. However, research is needed on when it may be appropriate to introduce specific strength training methods and heavier weighted

baseballs. Assessing shoulder strength and ROM should be monitored while implementing variably weighted baseball training; however, this is outside the scope of this review.

Weighted balls can overload musculature that accelerates the throwing arm; however, after ball release, load outside of the throwing arm's mass is not available to further overload muscles in deceleration. It would be interesting to investigate methods such as wearable resistance above the elbow (shoulder strength focus) and above the wrist (shoulder and elbow strength focus) while throwing. Such targeted strength training could be much more beneficial than weighted ball training, especially in terms of deceleration mechanics after ball release. These contentions need to be investigated.

Chapter 3: Comparison of Shoulder Rotation Strength and Test-Retest Reliability in Three Test Positions with Swimmers

3.0 Prelude

In the previous chapter, rotator cuff strength was highlighted as an important attribute to measure, monitor and potentially develop in baseball athletes. Strength was, however, commonly measured by a variety of tests ranging from isolated rotator cuff assessments to maximum load at set repetitions with compound exercises; similarly, various testing positions have been adopted, which can complicate interpretations. Many assessments adopt technology that is impractical outside of a laboratory, or otherwise lacks granularity (e.g., low sampling frequency). Developing a simple isometric shoulder rotator strength protocol relevant to pitchers' shoulder was judged necessary for further thesis work, and ultimately of interest to the broader throwing community. Moreover, updated technology should allow more granular assessment of force-time data, allowing both Fmax and RFD to be extracted. With this in mind, this chapter explores the utility of using novel, portable strain gauge technology to assess rotator cuff strength. Swimmers, a shoulder dominant athletic population, were recruited as a convenient sample (notably due to restrictions around COVID-19) to provide initial insight into reliability across varying positions. The focus on establishing protocols with portable technology was seen as important for latter chapters—and more broadly to practitioners—to allow testing to be administered in athletes' regular training environments without having to relocate to a laboratory. Measuring force outputs across the three positions would allow for differences to be measured and if certain positions favoured IR or ER force production.

This chapter comprises the following original publication:

Job T. D. W., Cross M. R., & Cronin J.B. Comparison of shoulder rotation strength and test-retest reliability in three test positions with swimmers. *Journal of Sports Rehabilitation*, *1*(aop), 1-7. doi: 10.1123/jsr.2024-0150.

3.1 Introduction

Swimming performance is influenced by upper-body strength and power (71). Swimming is a bilateral activity, however, unilateral dominance exists and arm-strength asymmetry can be accommodated via swimming technique (107). Previous researchers have investigated shoulder internal rotation (IR) and external rotation (ER) strength in swimmers, which may provide deeper insight into performance and injury risk (8, 9, 33). Logically, IR surpasses ER strength in male and female swimmers of varying competition levels (e.g., ER:IR ratio = 0.6-0.8) (6-9, 23, 24) due to repeated IR during three of the four swim strokes. Therefore, understanding shoulder rotation forces and the magnitude of this ratio can provide insight into dryland training design and rehabilitation.

Testing protocols quantifying shoulder rotation strength differ by methodology (8, 9, 23, 24). Both maximal force production (Fmax) and maximal rate of force development (RFD) are conceptually interesting for understanding components of sports performance (87), although Fmax is more commonly used due to its ease of calculation and associated reliability. Two technologies are prevalent in the swimming literature: isokinetic dynamometry (8, 24) and handheld dynamometry (HHD) (9, 23). Comparisons of the measurement outcomes from these techniques, their reliability, and ultimately their influence on practical utility and whether interchangeable for upper-body strength, is mostly unexplored. Isokinetic dynamometry is relatively common in research and clinical practice, but its use is primarily restricted to laboratory settings due to its cost and complexity. HHD represent a more portable and cost-effective method of assess Fmax and has been shown reliable (ICC estimate = .92-.98) (9, 15, 23, 35, 54, 94, 98). Such portable technologies may also facilitate testing in a range of positions (e.g., supine versus sitting), allow more targeted assessments of sport- or musculature-specific test positions, and can be used in a variety of settings.

Swimmer shoulder rotation strength has been assessed in seated (24), standing (9) and prone (8, 23) testing positions. One convenience of HHD is an ability to vary testing positions during shoulder rotation testing, such as seated with the shoulder abducted to 0° (ICC estimate =.93-

.96) (54, 94), supine with the shoulder abducted to 90° (ICC estimate =.93-.96) (35, 98) or prone with the shoulder abducted to 90° (ICC estimate=.92-.98) (23). Muscle activation during shoulder rotation varies with the elbow at 0° and 90° of shoulder abduction (44) which could influence different force outcomes. Elucidating the impact of position on force production, and accordingly their shared association and reliability, will help practitioners better understand outcomes and ultimately select the most appropriate test for their subjects.

RFD is potentially an interesting variable to assess in the aim of characterizing explosive ability. For example, an increased capacity to develop force quickly in the shoulder might aid in elevating force throughout repetitive strokes and allow quicker repositioning of the limbs. More broadly, as an indicator of neuromuscular function, it likely has further interest in monitoring ongoing arm health. Reliability (ICC estimate = .44-.97, CV = 4.1-23.3%) in lower-body tests range from moderate to excellent (73) with varying technology (14, 36, 37, 62, 118). Nonetheless, there is a relative paucity of data on RFD for shoulder rotator assessment, and in swimmers. Unfortunately, where some portable units show promise for assessing RFD, limitations like low-sampling rates and reliance on physical input from the tester may affect their reliability and practical utility (10). However, rapidly improving technology and signal processing capability is enabling integration of advanced technologies such as portable load-cells with high precision to be incorporated into field-based strength assessment (10, 27, 87). Evaluating the reliability of new technology and its capability to capture force production is important to confidently use these assessments in practice.

This study had two aims: 1) to test differences in IR and ER Fmax and RFD across three positions (seated-0°, supine-0° and supine-90°); and 2) explore the test-retest reliability of these different protocols across multiple testing occasions. Ultimately, the information will provide the practitioner interested in swimming, with normative force (Fmax and RFD) data on the shoulder IR and ER musculature, detail which protocols (movements and variables) are reliable, and whether protocols can be used interchangeably, or is there a preferred protocol for swimmers.

3.2 Materials and Methods

3.2.1 Study Design

A within-subjects repeated measures design was adopted to compare the intersession values and reliability of Fmax and RFD for both shoulder IR and ER across three positions; seated-0°, supine-0° and supine-90°. Dominant and non-dominant maximal isometric contractions were measured; however, the results and discussion sections primarily focus on the dominant arm.

3.2.2 Participants

Male (N = 8; age = 17.0 ± 1.2 years) and female (N = 10; age = 16.7 ± 0.9 years) national-level swimmers (91) volunteered to participate in this study. Athletes were recruited from the top tier of a swim club. Participants were injury free and approval to participate was sought in the form of a signed informed consent from each participant or assent from their caregiver, where appropriate. A sample of 13 participants was estimated as sufficient to detect an expected ICC of .90 and a minimal acceptable ICC of .50, with alpha and power set at .05 and 80%, respectively (12). This study was approved by the appropriate academic ethics committee (AUTEC 19/445).

3.2.3 Procedures

Testing consisted of three sessions, each following identical procedures and seven to 14 days apart, with athletes in the same rested state. Participants completed a standardized warm-up consisting of two sets of 10 repetitions with self-selected submaximal pneumatic resistance for shoulder IR and ER exercises to prepare for testing. Each session required participants to perform three 3-second maximum isometric contractions in three positions (seated-0°, supine-0° and supine-90°) to target shoulder IR and ER strength in both arms (i.e., dominant and non-dominant). Thus 18 total maximal contractions per arm, were performed in a randomized order. Two minutes of rest were given between trials.

Force-time data was measured (1,000 Hz) using a custom, wireless S-beam load-cell (TruStrength Tech, Sports Performance Research Institute New Zealand, Auckland, NZ), which was affixed to two heavy-duty stainless-steel eye bolts, one of which was attached by a chain to an immovable

point via a carabiner, and the other bolt to a handle which was held by the participants (see Figure 4). The load-cell was zeroed between trials, with output raw data transferred to a laptop via Bluetooth.

Multiple testing positions were selected to improve the potential relevance for practice and provide supplemental information regarding testing in the supine orientation. The positions included: 1) seated at 0° of shoulder abduction (Figure 4A); 2) supine at 0° of shoulder abduction (supine-0° position, Figure 4B); and 3) supine at 90° of shoulder abduction (supine-90° position, Figure 4C). Positions one and two differed in the body orientation (seated vs supine), and two and three by the elbow position (0° of shoulder abduction vs 90° of shoulder abduction). The seated position required a rolled towel to be placed between the arm and trunk to help stabilize the arm, as detailed by previous researchers (15, 94). In the supine testing positions a rolled towel was placed between the participants' elbow and the ground to keep the shoulder in the scapular plane. The hand of the non-testing arm was placed on the subjects' hip while seated and on the stomach while supine. For consistency in all three test positions, feet were placed flat on the ground with the knees bent.

For each trial, the subjects were arranged per their position and prompted by the tester to create a pretension that removed slack from the chains to avoid snapping and false force peaks during the trials. Once pretension was steady (~30 N), the participants verbally received a countdown from three followed by "go" and "stop" commands. Prior to the trials, athletes were instructed to rotate "fast and hard" to capture Fmax and RFD characteristics. Subjects were required to keep their hips on the ground in supine positions, and trials were discontinued and deleted if the hips were lifted during testing. In all test positions, participants were required to keep their feet flat on the ground. Three trials for each position were performed, in the case of a mistrial (e.g., premature trial start), an additional trial was allowed. The resulting force-time data was saved in raw form for subsequent analysis.

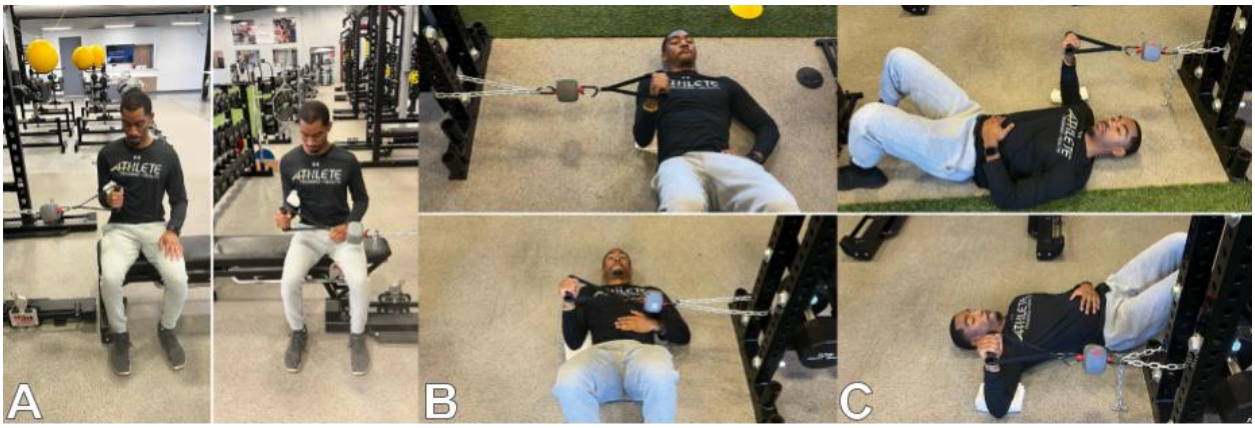

Figure 4. *(A) Seated-0° testing position. Dominant arm internal rotation test (left) and dominant arm external rotation test (right). (B) Supine-0° testing position. Dominant arm internal rotation test (top) and dominant arm external rotation test (bottom). (C) Supine-90° testing position. Dominant arm internal rotation test (top) and dominant arm external rotation test (bottom).*

Raw data were imported into MATLAB (MATLAB 2019B, The MathWorks, Inc., MA USA), and trials were screened and removed if any abnormalities were observed on the force-time graphs. Trials were clipped by manual detection of force onset as the first point of increase from resting force via visual inspection. Subsequently, Fmax and RFD were detected as the instantaneous peak across the whole trial and the average value over the 120-milliseconds following force onset, respectively (87). These variables were calculated for each position for shoulder IR and ER in the dominant and non-dominant arms. Averages for each position, arm and shoulder rotation were calculated for the final analysis. Data were included for subjects that completed three testing sessions seven to 14 days apart. While the first session was primarily used to familiarize participants, data from all three sessions were used to determine reliability and provide a more encompassing view of its utility.

3.2.4 Statistical Analysis

Statistical procedures were performed in JASP (61). Means and standard deviations were calculated for all three sessions and represented measures of centrality and spread of data. At the outset, data were examined to determine if analysing the male and female data artificially

inflated the ICCs due to clustering. For example, disparate measures from males and females could have influenced the results; however, since this did not appear to be the case (i.e., analyses were similar when separated by group), and due to the otherwise underpowered analyses, we opted to analyse both sexes collapsed.

To address our first aim, a variety of paired samples t-tests were used to determine if Fmax and RFD differed between dominant and non-dominant limbs, and IR and ER across movement patterns. Pearson's correlations were used to determine the degree of difference and agreement between force outputs across the three positions (i.e., to determine whether the information provided by each was unique). Where appropriate, percent difference and the ratio between internal and external rotation (ER:IR) was reported. For the paired t-tests, magnitude of effect was determined as Cohen's d, and interpreted as trivial (< 0.1), very small (0.1-0.19), small (0.2-0.49), moderate (0.5-0.79), large (0.8-1.19) or very large (> 1.2) thresholds of effect (22). For Pearson's coefficient, the following association thresholds were defined, *r*: weak as .1-.39, moderate as .40-.69, strong as .70-.89 and very strong as .90-1.0 (110).

To address our second aim and the reliability of the tests, change in the mean (CIM), CV, and ICC (two-way mixed effects, absolute agreement) were used to provide insight into the bias, variability, and agreement between testing sessions 1-2 and 2-3. Particular attention was paid to the lower bound of the ICC 95% confidence intervals (CI), with poor reliability defined as <.50, moderate reliability as .50-.74, good reliability as .75-.89 and excellent as >.90 (73). CVs less than 10% were considered acceptable (5). The alpha value for all tests was set at .05.

3.3 Results

Dominant arm Fmax exceeded the non-dominant arm (small to moderate, $p < .05$) in all but supine-0° for IR and seated-0° for ER ($p > .13$; see Table 4). For RFD, IR and ER seated-0°, and IR supine-90°, were each moderately greater for the dominant limb ($p < .04$).

Table 4. *Effect sizes and p-values for between dominant and non-dominant arm internal and external rotation forces (session three).*

	Fmax		RFD	
Position	Cohen's d	p-value	Cohen's d	p-value
Internal				
Seated-0°	0.64	.02	0.51	.04
Supine-0°	0.37	.13	0.26	.29
Supine-90°	0.80	.00	0.66	.02
External				
Seated-0°	0.27	.31	0.59	.04
Supine-0°	0.92	.00	0.19	.47
Supine-90°	0.63	.02	0.12	.62

Fmax, maximal force production; RFD, rate of force development.

Within the dominant arm, IR Fmax and RFD were greater (12.5-47.0%; moderate to huge magnitude, $p < .027$) than ER across all positions (see Table 5), and ER:IR ratios ranged from 0.62-0.88. Moderate to very strong associations ($r = .561$-$.947$) existed among these test positions (see Table 6), the action performed (IR and ER) and their respective force outputs (Fmax and RFD).

Table 5. *Ratio, percent difference, effect sizes and p-values between internal and external rotation forces, per position, of the dominant arm (session three).*

	Fmax				RFD			
	ER:IR	Δ (%)	Cohen's d	p-value	ER:IR	Δ (%)	Cohen's d	p-value
Seated-0°	0.70	35.3	2.2	< .001	0.62	47.0	2.0	< .001
Supine-0°	0.81	20.9	1.5	< .001	0.69	37.0	1.6	< .001
Supine-90°	0.87	13.9	1.2	< .001	0.88	12.5	0.57	.027

Fmax, maximal force production; RFD, rate of force development; ER:IR, external rotation to internal rotation ratio; Δ, difference. Data reported is extracted solely from Session 3 (representing the measure where they are feasibly the most familiar), and from the dominant arm (to simplify representation).

Table 6. *Correlations (Pearson's r) between testing positions (session 3).*

	Supine-0°	Supine-90°
Dominant arm IR Fmax		
Seated-0°	.903***	.926***
Supine-0°		.887***
Dominant arm ER Fmax		
Seated-0°	.893***	.937***
Supine-0°		.947***
Dominant arm IR RFD		
Seated-0°	.642**	.731***
Supine-0°		.561*
Dominant arm ER RFD		
Seated-0°	.851***	.846***
Supine-0°		.943***

Fmax, maximal force production; RFD, rate of force development; IR, internal rotation; ER, external rotation. ***p < .001, **p < .01, *p < .05. Note: Data reported is extracted solely from Session 3 (representing the measure where they are feasibly the most familiar).

Reliability for Fmax is displayed in Table 7. The CVs ranged from 4.2-8.8% for all positions, the largest variation occurred from session two to three in the seated-0° ER condition. The ICC estimate ranged from good to excellent reliability, and 95% CI ranged from moderate to excellent.

Reliability for RFD can be observed in Table 8. The CVs ranged from 9.7-18.1% for all positions, the largest variation occurred from session two to three in the supine-0° ER condition. The ICC estimate ranged from moderate to excellent, and 95% CIs broadly ranged from poor to excellent reliability.

Table 7. *Mean, standard deviation and reliability measures for shoulder rotation Fmax of dominant arm.*

	Session 1	Session 2	Session 3	CIM%		CV (%)		ICC	
	Mean ± SD (N)	Mean ± SD (N)	Mean ± SD (N)	S1-S2	S2-S3	S1-S2	S2-S3	S1-S2 [95% CI]	S2-S3 [95% CI]
Internal									
Seated-0°	113.2 ± 28.8	115.0 ± 32.2	123.2 ± 38.4	1.6	7.1	6.3	6.9	.90 [.76, .96]	.91 [.78, .97]
Supine-0°	103.2 ± 24.4	102.8 ± 26.6	107.4 ± 29.5	-0.3	4.5	4.2	7.0	.95 [.86, .98]	.92 [.79, .97]
Supine-90°	102.5 ± 25.3	99.7 ± 28.1	104.6 ± 25.8	-2.7	4.9	5.6	5.2	.93 [.82, .98]	.96 [.89, .98]
External									
Seated-0°	78.6 ± 22.7	81.3 ± 19.2	86.2 ± 23.3	3.4	8.6	6.9	8.8	.82 [.52, .94]	.89 [.69, .96]
Supine-0°	80.4 ± 17.7	81.7 ± 20.8	87.1 ± 20.3	1.6	6.6	4.4	6.3	.94 [.86, .98]	.91 [.75, .96]
Supine-90°	87.4 ± 18.8	89.2 ± 22.3	91.0 ± 24.8	2.0	2.0	5.6	6.3	.87 [.65, .95]	.92 [.79, .97]

N, Newtons; SD, standard deviation; CIM, change in mean; CV, coefficient of variation; ICC, intraclass correlation coefficient; CI, confidence interval.

Table 8. *Mean, standard deviation and reliability measures for shoulder rotation RFD of dominant arm.*

	Session 1	Session 2	Session 3	CIM%		CV (%)		ICC [95% CI]	
	Mean ± SD (N/s)	Mean ± SD (N/s)	Mean ± SD (N/s)	S1-S2	S2-S3	S1-S2	S2-S3	S1-S2	S2-S3
Internal									
Seated-0°	615.5 ± 220.5	599.7 ± 214.1	547.5 ± 192.1	-2.6	-8.7	9.7	13.3	.81 [.56, .92]	.80 [.55, .92]
Supine-0°	534.2 ± 172.1	477.9 ± 190.2	473.8 ± 160.7	-1.5	-0.9	13.5	15.2	.80 [.54, .92]	.74 [.44, .90]
Supine-90°	537.4 ± 191.5	462.2 ± 183.4	418.4 ± 143.1	-14.0	-9.5	13.8	11.5	.72 [.36, .89]	.90 [.76, .96]
External									
Seated-0°	360.3 ± 149.3	342.9 ± 114.1	339.1 ± 134.7	-4.8	-1.1	13.8	16.2	.79 [.44, .92]	.74 [.34, .91]
Supine-0°	369.2 ± 105.4	367.2 ± 153.8	325.9 ± 120.9	-0.5	-11.2	14.7	18.1	.80 [.55, .92]	.75 [.43, .90]
Supine-90°	424.4 ± 114.3	423.7 ± 170.3	369.0 ± 156.2	-0.1	-12.9	17.0	15.2	.56 [.08, .82]	.87 [.68, .95]

N/s, Newtons per second; SD, standard deviation; CIM, change in mean; CV, coefficient of variation; ICC, intraclass correlation coefficient; CI, confidence interval.

3.4 Discussion

The main findings of the analysis were: 1) differences were noted in seven out of 12 conditions between the dominant and non-dominant arms characterized by greater values in the dominant arm; 2) IR force outputs were greater than ER, although differences tended to be smaller in supine-90° versus the seated-0° position; 3) IR Fmax and RFD outputs were greatest in the seated-0° position and ER Fmax and RFD outputs were greatest in the supine-90° position; and, 4) Fmax was found to have good to excellent reliability across all positions whereas RFD had moderate to excellent reliability.

Previous researchers investigating shoulder rotator strength with HHD and swimming cohorts reported greater outputs (23) and similar ratios (9, 23) to the present findings. Swimmers (12 females, eight males, 16.2 $\pm$ 1.2 years old) tested in a prone orientation and 90^{o} of shoulder abduction had greater Fmax values (IR = 153 N, ER = 118 N) compared to the present cohort (23). It is unclear whether the difference between cohorts is due to the differing orientations in body position or if one group is simply stronger than the other. The ER:IR ratio in the prone position and 90^{o} of shoulder abduction was 0.82 (23), similar to the ratio tested in the supine-90^{o} position (see Table 5) in this study. With the shoulder at 0^{o} of abduction a similar ER:IR ratio was reported (ER:IR = 0.7) in elite level swimmers (28 females, 40 males, 19.9 $\pm$ 3.2 years old) (9). Rotator strength was normalized to body mass, which was not reported, leaving absolute Fmax values unknown.

The majority (~60%) of the tests exhibited interlimb differences, with the dominant arm generally stronger than the non-dominant arm, albeit not statistically significant across all positions and rotations (see Table 4). While some differences between dominant and non-dominant arms might be expected, on average in swimmers some variability might be attributed to the adoption of unilateral or bilateral breathing techniques (103, 107); unfortunately, technical aspects of our sample's swimming were not recorded, and could be an interesting avenue for future research.

For simplicity, we have focused on the results of the dominant arm to discuss the differences among testing positions.

Greater force production was observed in IR Fmax and RFD as compared to ER across all positions. Similarly, this is expected since three of the four competitive swimming strokes (i.e., front crawl, breaststroke and butterfly) predominantly utilize shoulder IR to propel swimmers through the water. The greatest difference was seen in the seated-0° position (35.3-47.0%, $p < .001$) and the smallest difference was observed in the supine-90° position (12.5-13.9%, $p < .05$), corresponding to huge and moderate-large effects, respectively. The ER:IR ratios (.62-.88) of this study were similar to previous research (.52-.84) (8, 9, 15, 23, 24, 35, 54, 94, 98). Varying ER:IR ratios may be explained by testing positions which may place musculature in more/less favourable positions (44). This is important to consider when selecting, interpreting and comparing data that use ER:IR ratios to guide diagnostics and exercise prescription. Further, this is worth consideration as swimmers may alter their balance of shoulder rotator strength throughout the competitive season and may maintain balance with dryland training (6, 7). Given this information, it may be prudent for practitioners to use the test position with the best consistency.

Testing positions in this study shared commonality in elbow orientation (i.e., seated-0° and supine-0°) or body orientation (i.e., supine positions). In both aspects seated-0° was different to supine-90°. Generally, clear differences were observed in force production across the three positions. Interestingly, seated-0° produced higher IR force outputs compared to the supine positions (13.7-26.7%, $p < .001$), however ER had the highest force values in supine-90° compared to the other two positions (4.4-12.4%). Elbow position may influence shoulder rotation force production by altering muscular line of pull and force vectors within the shoulder joint. Shoulder IR capabilities may be greater at 0° of shoulder abduction by recruiting larger muscles such as the pectoralis major to generate force (44). Shoulder ER force production at 90° of abduction may be greater due to better posterior deltoid recruitment (44). Moderate to very strong associations (r = .561-.947) among the variables exist. Notably, 79-90% of the variance in Fmax was shared across positions. Conversely, shared variance was markedly lower during IR RFD (32-53% vs 72-

89% for IR vs ER, respectively), which may be partially explained by greater variability for IR RFD compared to ER RFD. It would seem from the correlational analysis that subjects score relatively similarly across tests, however, the unexplained variance among positions suggest they should not be used interchangeably. Practitioners and clinicians should utilize a position appropriate to an individual's physical capabilities (i.e., range of motion) and/or activity (i.e., body orientation and elbow position).

Fmax reliability in this study was good to excellent (ICC = .89-.96, CV = 5.2-8.8%), having similar values to previous results (ICC = .82-.96) (15, 35, 54, 94, 98). It was thought that the higher sampling rate device used in this study may have lower consistency compared with low-sampling rate technology (HHD) (15, 23, 35, 54, 94, 98), however this was not the case. Surprisingly, a somewhat systematic increase in CIM across positions and sessions 2-3 was observed in Fmax only. While participants were familiarized with the protocol during session one, it seemed that there was a systematic learning effect between the later sessions, enabling increased force production. Additional testing sessions would have been necessary to determine if the learning effect stabilized over time, however further testing was not possible given the study's time course and subject availability. Nonetheless, irrespective of that systematic increase, the Fmax reliability measures were found acceptable, however, greater familiarization is recommended. Understanding Fmax capabilities can help to identify imbalances or weaknesses in the shoulder rotator muscles. This could be used for exercise prescription in healthy or rehabilitating athletes and guide progress over time.

The ICC values for RFD ranged from moderate to excellent across all conditions and CVs were typically unacceptable (> 10%). To our knowledge, this is the first shoulder rotator strength assessment reporting RFD which gives a greater scope of understanding strength in this muscle group, albeit of potentially limited practical utility without adapting methodological approaches. Upper-extremity RFD assessments with elbow extensors and flexors and handgrip displayed moderate to good estimates of reliability (ICC = .67-.87) and unacceptable variability was noted with the handgrip assessment (CV = 42.8%) (62, 95). Although greater variability was observed in

RFD assessments (87), the results of this study, particularly in the supine-90° test position (CV = 11.5-15.2%) show some promise. It is recommended that future research refines (e.g., averaging over more trials, improved familiarization, instructions, etc.) the testing protocol used in this study to reduce the variability associated with RFD. With improved protocol reliability, RFD could potentially provide diagnostic information for healthy or rehabilitating athletes.

A limitation of this study was the lack of a prone testing position, which is relevant for swimmers as most competitive strokes are performed prone. While some specialist equipment or modification of typical gym-based equipment might be necessary to obtain standardized measurement (e.g., plinth or wide bench to help stabilize the torso and abducted shoulder at 90°, future research might adopt and evaluate the interest in such a protocol. Although the prone position was excluded for practical purposes, the learnings from the three positions used in this study can be applied for shoulder rotator strength assessments.

3.5 Conclusion

Assessing shoulder rotator health and injury status is important for many practitioners. Implementing technology that is affordable, portable and of high utility is preferable for practitioners, and the load-cell satisfies such criteria. This was the first study to compare shoulder rotation using three testing positions. It was determined that certain positions allowed better IR (seated-0°) and ER (supine-90°) force production, and the measures quantified in one position should not be used interchangeably. Finally, the reliability of Fmax across all positions was acceptable, however, the use of RFD warrants caution without protocol refinement. Regular monitoring of Fmax could provide valuable analytics to inform performance enhancement or rehabilitation of the shoulder rotators. The supine-90° position was found to provide the best consistency between sessions.

Chapter 4: Shoulder Internal and External Rotation Strength Assessment in Baseball Pitchers: Reliability, Utility and Normative Data

4.0 Prelude

In the previous chapter shoulder IR and ER Fmax had acceptable consistency (ICCs) and typical error (CVs) in all three testing positions, however, RFD only had acceptable relative consistency. No test position emerged as markedly more reliable, therefore, the supine 90^{o} position was deemed preferable because of the biomechanical similarities to throwing. Since baseball pitchers are the focus of this thesis, this study aimed to use this protocol to capture normative data and assess reliability of a baseball cohort–notably easier following relaxed COVID-19 restrictions—and to observe whether steps could be taken to reduce the error observed with the previous RFD measurements. Additionally, individualising force expression by accounting for forearm length (deemed conceptually interesting for baseball athletes) was investigated. Overall, the normative data assembled from this chapter can be used in future studies to characterise pitchers by strength in addition to commonly measured throwing performance metrics. More specifically, within this thesis it is important to first understand the reliability of the assessments likely to be used in practice, before they are implemented into further studies; particularly, understanding the relationship between strength and performance metrics, and how these measures change with training.

This chapter comprises the following original publication:

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4.1 Introduction

Throwing is an athletic skill used in many sports and activities such as baseball, softball, American football, javelin, among others. It is a total-body action that transmits forces generated from the ground through the legs and trunk via the arm to the implement in hand (19, 49, 111). Shoulder rotator cuff musculature funnels forces from the preceding kinetic chain, dynamically stabilizing the glenohumeral joint and subsequently decelerating the throwing arm (19, 111). Given their crucial role, means of measuring and monitoring the strength characteristics of the shoulder rotator cuff are of interest to researchers and practitioners of throwing sports performance and injury risk reduction.

In baseball, muscles responsible for shoulder internal rotation (IR) contribute to the throwing motion as the arm accelerates forward (19, 40, 98, 111). Overall rotator cuff weakness has been associated with ulnar collateral ligament repair (54). Specifically, preseason external rotation (ER) weakness has been linked to in-season throwing arm injuries (15). Given the elevated acute stress coupled with high throwing volumes, monitoring baseball pitchers' shoulder rotation strength seems important. Accurate, efficient rotator cuff strength assessments may provide valuable information on training status and fatigue. This information could be feasibly used to reduce injury frequency, maintain performance during the competitive season, and inform training during the offseason.

Maximal force production (e.g., Fmax) and the ability to produce force rapidly (e.g., rate of force development, RFD) are two core components of strength. Both are considered important qualities for injury prevention and optimizing pitching/throwing performance (67), and so measured, monitored and developed by strength and conditioning coaches. In terms of the rotator cuff, strength is usually measured with expensive laboratory equipment [i.e., isokinetic dynamometer, (21, 26, 56)] or portable hand-held dynamometry [HHD, (15, 35, 54, 94, 98, 112, 120)]; the latter is practical, given its ease of use, portability and cost. Assessments of IR and ER Fmax using HHD with pitchers have been found reliable (intraclass correlation coefficient, ICC estimate = .89-.98) (15, 35, 54, 59, 94, 98). Coefficients of variation (CV) are also important for

understanding the typical error of a measure, however, this measure seems under-reported in the literature. Reported Fmax values for pitchers from the high school (HS) to professional level range from 137-233 N for IR and 122-180 N for ER, resulting in ER:IR ratios ranging from 0.7-0.9 (35, 54, 59, 94, 98). Also, RFD is interesting to consider due to the extraordinary arm speeds observed while throwing (48). Devices such as HHD rarely provide useable measures of RFD due to low-sampling rates, and despite RFD potential interest for throwing athletes (15, 35, 54, 59, 94, 98) it remains under-measured in the field.

The length of an arm or forearm, or more generally a lever, is known to influence the torque or rotational forces that a limb produces (force multiplied by the perpendicular distance from axis of rotation). Practically, torque can influence throwing velocity as described by the work-energy relationship. Given this relationship, it may be advantageous for strength and conditioning coaches to monitor torque related measures, in favour of force. Shoulder peak torque (Tmax) and rate of torque development (RTD) can be estimated as the product of forearm length and Fmax and RFD, respectively (3, 106), and may provide better diagnostic information and insight into pitching velocity than force expression alone. This approach, utilized with youth baseball players (11.1 $\pm$ 1.2 years old), resulted in excellent reliability with HHD (ICC = .98-.99) and a positive relationship of Tmax (r^2 =.23, $p < .001$) to throwing velocity (3). Nonetheless, this approach has not been applied in more senior pitchers.

Considering the importance of shoulder IR and ER in pitching, along with the potential benefits of monitoring rotator cuff health, finding affordable, portable technologies for field use would be valuable. To adopt such an approach, it is critical to understand the variability of the measures (Fmax, Tmax, RFD and RTD) used to monitor the physiological status of the rotator cuff musculature. Previously shoulder rotator strength with this strain gauge was assessed with swimmers, and it was reported that ER force outputs were greatest in the supine position with the shoulder abducted to 90° (68). The greater ER force expression in this position was likely due to greater posterior deltoid recruitment, the likes of which is relevant for baseball pitchers during the throwing deceleration and follow through phases (19, 44).

With this in mind, the aim of this study was to establish the reliability of Fmax, Tmax, RFD and RTD using portable high sampling rate technology from a lying position with baseball pitchers (68).

4.2 Methods

4.2.1 Experimental Approach to the Problem

A within-subjects repeated measures design was used to quantify inter-session reliability of maximal shoulder IR and ER kinetics. Participants completed multiple maximal isometric contractions over three testing occasions separated by seven days.

4.2.2 Subjects

Collegiate (n = 5) and HS (n = 10) male baseball players (age = 18.8 $\pm$ 2.0 years) participated in this study. Subjects were dressed in athletic attire and assessed at the local training facility. Anthropometrics (height = 182.7 $\pm$ 5.6 cm; body mass = 82.1 $\pm$ 8.1 kg; forearm length = 29.2 $\pm$ 1.7 cm) were measured prior to testing during the familiarization session. Forearm length was measured by tape as the distance between the olecranon process and ulnar styloid process. We performed an a priori sample size calculation for detecting an estimated ICC of .9 (i.e., for Fmax), and a lower acceptable bound of threshold of ICC = .6 (as a conservative representation of 'poor' reliability). 14 subjects were deemed sufficient, with 80% power and alpha = .05, with subsequent interpretation focusing on the interpretation of the confidence intervals (12, 123). Athletes were free of any injuries that would affect their participation. Written informed consent was collected from each participant or their caregiver before testing. Institutional review board approval was obtained from the Auckland University of Technology Ethics Committee (AUTEC 19/445).

4.2.3 Equipment

Force-time data were measured (1,000 Hz) using a custom designed, wireless single axis S-beam load-cell strain gauge (Hawkin TruStrength, Portland, Maine), that was zeroed between trials (see Figure 5). Earlier models of this device have been used in several studies to assess isometric force

and shown to be valid compared to a gold standard (CV = 4.6-8.3%, ICC = .94-.98) (101). Trials in this study were completed via the compressive method and data were imported via Bluetooth for post-processing.

Figure 5. *Strain gauge capable of measuring compressive force at 1,000 Hz.*

4.2.4 Procedures

Subjects attended three sessions, seven days apart, repeating quasi-identical protocols. The initial session familiarized participants with the assessment protocol and technology, with the latter two sessions used to determine reliability. Subjects followed a standardized, shoulder-focused warm-up preceding five 3-second maximum isometric contractions measuring throwing shoulder IR and ER strength. Thus, 10 total trials were performed and analysed. Subjects were supine with the shoulder abducted to 90° (see Figure 6). The non-testing arm was relaxed with the hand placed on their stomach and the knees bent with feet flat on the floor. The elbow was elevated by a rolled towel placed on the floor, and the strain gauge was aligned with the subject's ulnar styloid process. The researcher initiated the trial with a 3-second countdown and verbalized "GO" and "RELAX" cues to start and complete data capture. Participants were encouraged to "rotate fast and hard" for three seconds.

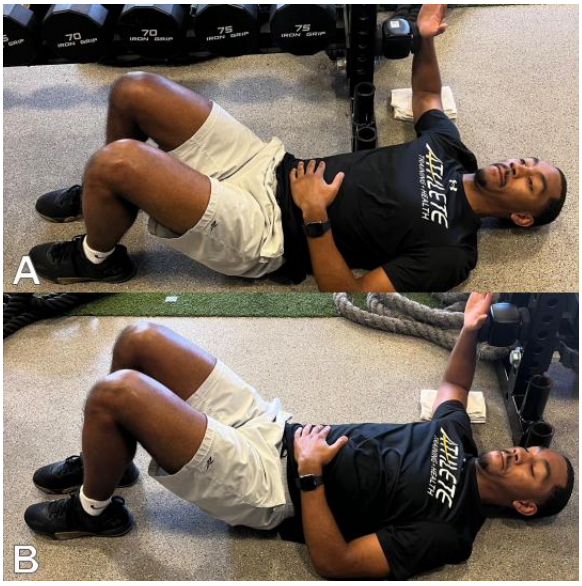

Figure 6. *Dominant arm internal rotation test (A) and dominant arm external rotation test (B).*

Raw, unfiltered force-time data were imported into MATLAB (version: 2019B, The MathWorks, Inc., MA USA), with trials screened and irregularities removed. Trial initiation was manually selected as the first point of increase from resting force pre-contraction, with Fmax and RFD identified as the instantaneous peak across the whole trial and the average force value over the 120-milliseconds following force onset, respectively (87). Tmax and RTD were calculated by multiplying the corresponding force outputs by forearm length (3, 106). These variables were identified for shoulder IR and ER and averaged for the final analysis. After exploring the noise profile of the strain gauge, we elected not to run a low pass filter so that we could observe any short duration, high frequency events throughout the testing protocol. Data were comprised of participants completing a familiarization, and two experimental sessions for intersession reliability.

4.2.5 Statistical Analysis

JASP (61) was used for all statistical analyses. Means and standard deviations represented measures of centrality and spread of data. Differences between IR and ER were tested using a variety of paired sample t-test between the corresponding outcome variables. Test-retest

reliability was quantified using percentage change in the mean (CIM), ICC estimate (3,1) and 95% confidence intervals (CI), and typical error as a CV between sessions. The CIM between sessions was also tested for statistical significance using additional paired t-test. Typical error was considered acceptable with CV < 10% (5), and ICCs representations of reliability as poor (< .50), moderate (.50-.74), good (.75-.89) and excellent (> .89) (73). We set the alpha level for statistical significance at $\alpha = .05$.

4.3 Results

Test-retest reliability and descriptive data for IR and ER kinetics can be found in Table 1. Force and torque outputs were not different between ER and IR ($p > .05$). Ratios (ER:IR) were 0.93 for peak measures and 0.88 for rate measures. Peak force and torque CIMs did not differ between sessions ($p > .05$), with all CVs < 6.0% and ICC estimates > .75. The CI lower-bound tended to be moderate (ICC > .55), except for IR Fmax (ICC > .39). For rate dependent variables, CIMs ranged from 11.2-25.9%, CVs from 16.0-28.5% and ICC estimates > .79. The CI lower-bound indicated poor reliability for ER (ICC > .41) and moderate for IR (ICC > .71).

Table 9. *Descriptive and reliability statistics from second and third testing sessions.*

	Session 2 Mean ± SD	Session 3 Mean ± SD	Change in Mean (%)	Coefficient of Variation (%)	ICC [95% CI]
Internal Rotation					
Fmax (N)	214.3 ± 30.8	218.0 ± 27.9	1.7	5.8	.85 [.56, .95]
RFD (N/s)	684.7 ± 275.0	764.5 ± 277.0	11.7	16.0	.90 [.71, .97]
Tmax (Nm)	62.7 ± 10.8	63.5 ± 8.3	1.3	5.8	.89 [.68, .96]
RTD (Nm/s)	200.1 ± 83.3	222.6 ± 80.6	11.2	16.0	.91 [.73, .97]
External Rotation					
Fmax (N)	197.6 ± 16.1	203.0 ± 17.4	2.7	4.3	.79 [.39, .93]
RFD (N/s)	537.0 ± 235.3	675.6 ± 231.1	25.8*	28.5	.80 [.41, .93]
Tmax (Nm)	57.6 ± 5.4	59.2 ± 5.5	2.8	4.3	.85 [.55, .95]
RTD (Nm/s)	156.5 ± 70.2	197.1 ± 68.6	25.9*	28.5	.81 [.43, .94]

Key: SD=standard deviation, Fmax=peak force, RFD=rate of force development, Tmax= peak torque, RTD=rate of torque development, ICC=intraclass correlation coefficient, CI=confidence intervals, N=Newtons, $N.s^{-1}$=Newtons per second, Nm=Newton meters.

*Difference detected between sessions one and two ($p < .05$).

4.4 Discussion

Rotator cuff strength assessments are useful for monitoring throwing performance and injury status, therefore assessment tools that are valid, reliable, of utility and are cost-effective, are important for implementation in practice. The main findings of this research were: 1) IR and ER Fmax/Tmax ranged between 198-218 N and 58-64 Nm respectively (ER:IR = 0.93); 2) IR and ER RFD/RTD ranged between 537-765 N/s and 157-223 Nm/s respectively (ER:IR = 0.88); 3) for peak values, typical error and ICC estimates were acceptable, and tended to be slightly better for IR versus ER; and, 4) while estimated ICCs for RFD/RTD were acceptable, typical error was unacceptable (CV > 10%).

The Fmax values reported in this study are comparable to those cited by other researchers for IR (137.4-232.5 N) and ER (122.3-179.5 N) which used similar protocols (35, 54, 59, 94, 98). It is difficult to compare the RFD/RTD as most research using portable technologies do not report these variables, most likely due to low-sampling frequencies (i.e., below the recommended 1,000 Hz (87). Notably, regardless of variable, testing position can influence force generation (68); this coupled with varying technologies and data processing complicate definitive comparisons.

To our knowledge only one other study in youth baseball players (3) has calculated torque using a similar approach. Exact results were unreported, and given age differences, results are problematic to compare to our cohort. Since expressing IR and ER outputs as torques potentially provides additional insight into pitching velocity, the results of this study provide normative values. Given torque calculation is quite simple as illustrated in this study, it might provide an easy and practical means of adjusting strength values for variations in forearm length, and subsequently better diagnostic information for coaches and athletes.

Differences between ER and IR (9.6-43%, ER:IR = 0.68-0.91) are relatively common (35, 54, 59, 94, 98), and logical given throwing heavily relies on the shoulder IR musculature (55, 70, 98). However, differences between ER and IR were non-significant in this study (~7-12%; $p > .05$). The position used in this study resulted in higher ER force production, compared to testing at 0° of shoulder abduction, and may explain the higher ER:IR ratios (0.88-0.93). Notably, four participants in this study exhibited greater ER force production, which might suggest specific adaptations from targeted ER training with these athletes.

Fmax and Tmax did not clearly change across sessions (CIM < 3.0%, $p > .05$), with acceptable typical error (CV < 6.0%) and reliability (estimated ICC > .75) across both shoulder rotation assessments. Fmax reliability was consistent with previous findings (ICC = .93-.96) (35, 54, 59, 94, 98) albeit across different protocols and technologies. This could be a product of a relatively small and homogenous athlete sample (e.g., quite low between-subject variability), but since reporting reliability in this fashion is uncommon, it is difficult to compare this to other studies. Similarly,

typical error is rarely reported by researchers; yet the low values observed render the practical utility promising.

With regards to RFD and RTD, there was a difference between sessions for ER (26%, $p < .05$), with no change for IR. The CIM may be a surprising product of the commonly reported variability associated with rate measures (87), or perhaps latent learning effects. Compared to ER, IR rate measures tended to be more reliable (estimated ICC > .80 versus .90, respectively) with lower error (CV% < 28.5 vs < 16%). Although ICC estimates were acceptable, 95% CI for IR was moderate where ER was poor (ICC < .43). Overall, the better reliability observed for IR compared to ER could be due to the different contractions and muscles associated with throwing demands. For example, shoulder ER musculature eccentrically contracts to decelerate the throwing arm (i.e. antagonist co-contraction). Conversely, IR while throwing is typically associated with concentric explosive muscle actions, which aim to maximize throwing velocity (i.e. agonist muscle activation). Typical error was deemed unacceptable (5), albeit better for IR (CV = 16.0%) versus ER (CV = 28.5%). The high variability associated with rate measures is well documented (87) and indicate the importance of considering strategies to reduce error (e.g., averaging over trials, rigorous familiarization) should the measures be used in practice. Due to mixed results, practitioners should be cautious using rate measures for monitoring shoulder rotation.

There are some limitations in this study that are worth mentioning. First, this study only included 15 participants, which were attained via an estimate of detecting reliability in maximum force measures. This small sample means our estimates for lower reliability were broad and reduces the transferability of our findings. Despite familiarization, underlying learning effects may have still been present throughout testing sessions. This could have impacted the reliability estimates, especially for participants who improved their performance over time. Finally, the assessment measured isometric strength and pitching or throwing is a dynamic action. Measuring concentric or eccentric strength could be valuable for these athletes, however, this may require more expensive and less portable equipment.

4.5 Practical Applications

Measuring IR and ER strength can inform shoulder health (15, 54) and performance (3). Given the acceptable reliability for Fmax it would seem that this technology is a cost-effective option for practitioners to utilize in the field. Notably, the protocols were easily implemented and given the device portability. Practitioners could utilize such technology to measure shoulder rotation Fmax or Tmax, appreciating that rigorous standardization and familiarization of athletes is needed.

The information can be used in a myriad of ways. For example, monitoring IR strength 48-hours post-game could inform recovery status between competitive appearances. Similarly, determining IR and ER force outputs and associated ratios could be used to guide return from injury, assist in training prescription and provide normative values to guide thresholds for training.

Chapter 5: The Relationship of Shoulder Internal and External Rotation Peak Force and Rate of Force Development to Throwing Velocity in High School and Collegiate Pitchers

5.0 Prelude

In the previous chapter, normative data were collected, and the reliability of throwing shoulder IR and ER Fmax and RFD was quantified with baseball pitchers. Reliability of strength characteristics within baseball pitchers was comparable to swimmers, where Fmax typically exhibited acceptable reliability, but the poor reliability of RFD makes its utility in practice questionable. Further, no clear advantages arose from integrating the forearm length to calculate shoulder torque. Moving forward, maximum force seems to have practical utility to broadly characterise and monitor pitcher rotator strength and ultimately measure the relationship between the shoulder rotators to throwing performance in subsequent chapters. For the following chapter, upper-body strength training has positively influenced throwing velocity therefore one focus of this study was measuring the strength of association between shoulder rotator strength and throwing velocity. Shoulder rotator strength and throwing velocity measures will be used to inform the effects of using throwing specific modalities like WR. Understanding the relationship of ER and IR strength (as characterised via the portable isometric assessment modality used in the previous chapter) to throwing velocity could help inform best training practices for pitchers.

This chapter comprises the following original publication:

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5.1 Introduction

Throwing is an athletic skill fundamental to numerous sports. In baseball it has evolved further into a more specialized form known as pitching, where a pitcher's main objective is to minimize opponent scoring ability. To this end, increasing throwing velocity is a prized attribute in pitchers, giving less time for opposing hitters to make solid contact. Strategies to improve throwing velocity have been heavily researched and consist of non-specific (i.e., various methods of resistance training) and specific methods (i.e., throwing weighted balls) (67). In tandem with training, it is important to have a better understanding of the measures associated with throwing velocity to provide guidance for these training interventions.

High-level pitching requires adequate anatomy, mobility, strength and coordination (19). Authors comparing high- and low-velocity pitchers reported the former have anatomical advantages such as height and forearm length and consistently produced more force throughout their delivery compared to low-velocity pitchers (89). The throwing motion is complex; forces created by the lower body and core compound throughout the throwing motion creating high forces on the shoulder joint leading to ball release (19, 49, 79). As a result, shoulder internal rotation (IR) velocity can exceed 6,500 degrees per second across youth to professional pitchers (49). Following ball release, deceleration relies on adequate strength from the external rotators (ER) and posterior shoulder musculature to dissipate large forces that may exceed bodyweight (19, 49, 70). Thus, strengthening the shoulder rotators to contribute to and withstand the demands of throwing are paramount for pitchers.

Researchers have reported generally modest positive associations of throwing velocity with throwing arm isometric IR peak torque in HS (r = .678, p = .004) (21) and college pitchers (r = .592-.613, p < .05) (26, 56), and isometric ER peak torque with college pitchers (r = .567-.727, p < .05) (26, 56). Such information could be useful to guide training, however, most research has used expensive in-lab isokinetic dynamometry, limiting integration into practice. Recently developed strain gauge technology (65, 101) might provide utility in characterizing qualities underlying throwing velocity, which can be easily integrated into training and monitoring practices. For

example, the ratio between ER and IR strength could be an interesting metric, with decreased ratios due to ER weakness having been associated with throwing arm injuries (15, 112). Moreover, other variables such as rate of force development (RFD) which are commonly assessed with isokinetic dynamometry, may provide additional insight into throwing performance. The relationship between shoulder rotator RFD and throwing velocity is currently unknown, however, more practical equipment like strain gauge technology has been used with acceptable relative consistency measuring RFD in baseball pitchers (65). Understanding the relationships of isometric shoulder rotator strength and throwing velocity with portable, high-sampling equipment provided the primary focus of this article.

Many HS baseball players strive to continue their playing careers at the collegiate level. Practically very large differences (Cohen's *d* = 1.25) (108) in throwing velocity have been reported between levels (29.1-33.0 m/s and 34.3-36.6 m/s for HS and collegiate pitchers, respectively) (26, 46, 49, 109, 114), therefore improving throwing velocity would seem critical for advancement. One explanation for the differences in velocity between the two levels could be attributed to greater muscular strength and anthropometric advantages (49, 89). Very large differences (Cohen's *d* = 1.65-1.75) in shoulder rotator strength measured with hand-held dynamometry (HHD) have also been noted between HS and collegiate pitchers. Shoulder IR Fmax ranged from 127.2-203.6 N and ER from 120.1-138.4 N for HS pitchers (58, 59, 112, 120). Expectedly, college and minor league pitchers (age = 21 $\pm$ 2 years) reported greater shoulder rotator Fmax production (IR = 232.5 $\pm$ 48.1 N, ER = 179.5 $\pm$ 37.3 N) (98). Understanding the relationship between throwing velocity and underlying physical characteristics (i.e., strength), and awareness of those relationships across pitching levels, may provide information to enhance training.

This study's purpose was to determine if shoulder rotator strength (i.e., IR and ER Fmax and RFD) is an important predictor of throwing velocity, and if HS and collegiate pitchers differed in throwing velocity and shoulder rotator strength. Also, of interest was the relationship between strength measures, and whether those with high IR Fmax and RFD had similarly high ER Fmax and RFD. Given the surrounding literature it was hypothesized that: 1) HS and collegiate pitchers

would differ in the variables of interest; 2) rotator strength would have a small to moderate relationship to throwing velocity; 3) those with strong IRs would have strong ERs (i.e. high correlation); and 4) the strength of association between Fmax and RFD would be relatively small. Understanding differences between HS and collegiate pitchers, the relationship of shoulder rotator strength with throwing velocity, and how strength measures are related should enable athletes and coaches to progress and individualize training programs to optimize performance and maintain arm health.

5.2 Materials and Methods

5.2.1 Design

A cross-sectional design was implemented, where participants from two different playing levels completed IR and ER strength testing in a supine position and throwing velocity testing from a standing position (i.e., "the stretch"). Outcome variables (Fmax, RFD and peak throwing velocity) from these analyses were used to characterize the difference between the levels, and the relationships between strength qualities and throwing velocity for IR and ER separately.

5.2.2 Participants

Competitive HS and college male pitchers (n = 26, see Table 10) volunteered to participate in this research during the off-season and with at least two days rest from high-intent throwing. All participants were injury free and written consent was provided by each participant and their respective parent or guardian before participation. Ethics was approved from the institutional ethics committee (AUTEC 19/445).

5.2.3 Procedures

Shoulder rotation strength and throwing velocity were assessed in a single session. Participants were familiarized with the assessment protocols one week prior to data collection. During the familiarization session, height, weight, and forearm length were recorded. Forearm length was measured as the distance between the olecranon process and ulnar styloid process, and was in the analysis given its reported influence on throwing velocity (89).

For strength measures, continuous force-time data was collected at 1,200 Hz with a custom, wireless strain gauge comprised of an S-beam load-cell (Hawkin TruStrength, Portland, Maine). Throwing velocity was measured by a radar gun at 47 Hz (Stalker ATS II Version 5.0.2.1, Applied Concepts Inc., Richardson, TX, USA).

Two warm-ups were performed to prepare the participants for maximal isometric shoulder rotator strength testing and maximal effort throwing, respectively. The shoulder rotator strength assessment, and preceding warm-up, were always performed before the throwing velocity assessment. First, participants tested shoulder rotator strength which was preceded by a shoulder rotator focused warm-up. The warm-up for shoulder strength testing included shoulder IR and ER exercises performed regularly in training with submaximal, rubber-based resistance. Participants were positioned supine with the shoulder abducted to 90 degrees; the elbow flexed at 90 degrees and kept their non-testing arm relaxed with their hand placed on their stomach (see Figure 7). The knees were bent with the feet flat on the floor and the elbow remained in contact with a rolled towel and the top of the strain gauge was aligned with the subject's ulnar styloid process. The device was set to measure compressive forces and was placed against a wall. An isometric test was chosen due to the simple and repeatable nature of the protocol, which resulted in acceptable typical error and relative consistency for Fmax and acceptable relative consistency for RFD (69). Additionally, testing in this position allowed for greater ER outputs compared to the shoulder being abducted to 0 degrees which is likely due to greater posterior shoulder muscle recruitment (44) which is advantageous for pitchers due to the throwing deceleration phase.

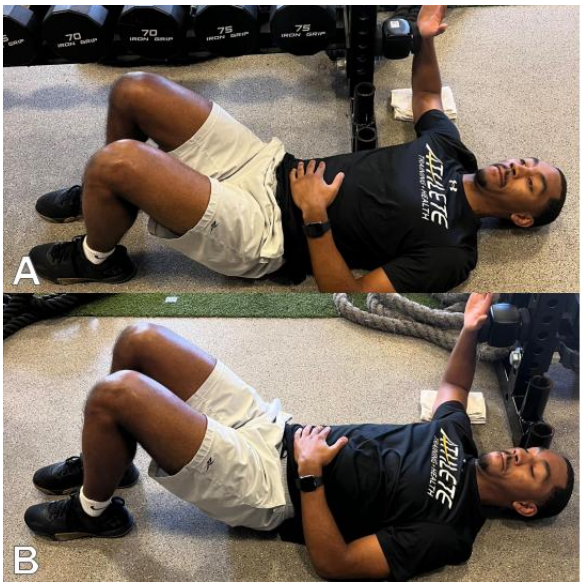

Figure 7. *Shoulder internal (A) and external (B) rotation strength testing set up.*

The researcher ensured proper set up and gave a three second countdown followed by "GO" and "RELAX" verbal cues to start and end the trial after a 3-second contraction. The researcher encouraged participants to "rotate fast and hard" for three seconds to assess RFD and Fmax. Five test trials were performed to collect Fmax and RFD for both shoulder IR and ER, respectively, totalling 10 trials. Participants were allowed 1-minute rest between trials. Trials were recorded using the manufacturer provided software and saved in raw form for later analysis.

Following strength testing, participants warmed up for the throwing velocity assessment, by jogging, skipping, and dynamic stretching followed by submaximal throws with a standard baseball. When ready, the subject performed five throws from the stretch in an indoor throwing lane. Peak throwing velocity was measured by radar gun mounted 0.9 m behind the target. Participants were allotted 30 seconds between trials. Radar gun settings were selected to display peak velocity which was recorded into a spreadsheet.

5.2.4 Data Analysis

Raw, unfiltered force-time data from the strain gauge were uploaded into MATLAB (version: 2019B, The MathWorks, Inc., MA USA), with trials inspected and irregularities (i.e., failure to

maintain pretension) discarded. The start of the trial was manually selected as first point of increase from resting force pre-contraction. Subsequently, Fmax was defined as the instantaneous peak across the entire trial and RFD as the average force value over the 120-milliseconds succeeding force onset. For Fmax and RFD IR and ER, and throwing velocity, all five trials were averaged for the final analysis.

5.2.3 Statistical Analysis

All statistical analyses were performed in JASP (61). Outlier analysis and normality testing preceded statistical analyses. Descriptive data are presented as means and standard deviations, representing centrality and spread of data. To address the first aim, a series of independent samples t-tests were used to measure differences in anthropometrics, strength and throwing velocity between the HS and college pitchers. To address the second aim two multiple linear regression models with stepwise selection criteria were built with raw force values and forearm length. This analysis was performed on pooled data (i.e., both cohorts) to both increase statistical power, and due to a lack of clear between group differences (see results section). Separate models were built for IR and ER due to different roles of the shoulder rotators while throwing, and include Fmax, RFD and forearm length for IR and ER, respectively. Inclusion and exclusion criteria for predictors were set at $p < .05$ and $p > .1$, respectively. To assess overall model fit, adjusted R^2 and comparison to the null model (using the p-value and F-statistic) were reported. To assess model contribution, unstandardized coefficients and 95% confidence intervals were reported, alongside standardized coefficients. Finally, the association between strength metrics within IR and ER (Fmax vs. RFD, for IR and ER each) and between (IR vs. ER, for Fmax and RFD each) was assessed using Pearson's correlation coefficient (*r*). The magnitudes of the correlation coefficients were interpreted using Cohen's scale (22): < 0.10, trivial; 0.10-0.29, small; 0.30-0.49, moderate; ≥ 0.50, large. For all tests, the significance level set to $p < .05$.

5.3 Results

There were differences in age ($p < .001$), and forearm length ($p < .05$) between HS and college pitchers, however, there were no other differences ($p > .05$) between the cohorts (see Table 10).

The similarity in throwing velocity between groups is evident (Figure 8), and in combination with the non-statistically significant between-group differences in shoulder rotator strength ($p > .05$) led to the pooling of participants for subsequent analyses.

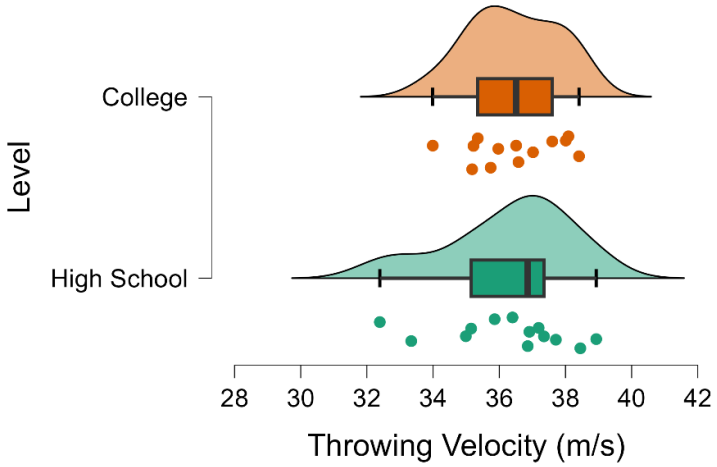

Figure 8. *Comparisons in throwing velocity between HS and college pitchers.*

In both IR and ER stepwise linear regression models, Fmax was the only variable retained; RFD and forearm length were removed (see Table 11). A positive association was observed in both models where a 30 N increase in IR Fmax resulted in a 0.51 m/s increase in throwing velocity (throwing velocity = 32.710 + 0.017 × IR Fmax; Figure 8), and a 30 N increase in ER Fmax resulted in a 0.72 m/s increase in throwing velocity (throwing velocity = 31.649 + 0.024 × ER Fmax; Figure 9).

Table 10. *Pitcher characteristics.*

	High school (mean ± SD)	College (mean ± SD)	Combined (mean ± SD)
n	13	13	26
Age (years)**	17.5 ± 0.9	21.3 ± 1.3	19.4 ± 2.2
Height (cm)	184.3 ± 6.6	181.8 ± 7.3	183.0 ± 7.0
Weight (kg)	80.6 ± 9.9	83.3 ± 9.5	81.9 ± 9.6
Forearm length (cm)*	29.6 ± 1.4	28.2 ± 1.9	28.9 ± 1.8
IR Fmax (N)	214.5 ± 38.1	218.4 ± 39.0	216.4 ± 37.9
IR RFD (N/s)	808.8 ± 346.3	749.2 ± 314.3	779.0 ± 325.5
ER Fmax (N)	192.8 ± 21.5	200.6 ± 33.2	196.7 ± 27.7
ER RFD (N/s)	594.5 ± 300.0	636.0 ± 323.7	615.3 ± 306.5
Throwing velocity (m/s)	36.3 ± 1.9	36.4 ± 1.3	36.4 ± 1.6

SD, standard deviation; n, sample size; cm, centimetres; kg, kilograms; IR, internal rotation; Fmax, peak force; N, Newtons; RFD, rate of force development; N/s, Newtons per second; ER, external rotation; m/s, meters per second.

*Significant difference between high school and collegiate pitchers $p<.05$.

**Significant difference between high school and collegiate pitchers $p<.001$.

Table 11. *Association between shoulder strength and throwing velocity for internal and external rotation.*

External rotation [1]				Internal rotation [2]			
Variable	Coefficient (95% CI)	Standardized Coefficient	p	Variable	Coefficient (95% CI)	Standardized Coefficient	p
Intercept	31.6 (27.2, 36.18)	--	< .001	Intercept	32.710 (29.079, 36.340)	--	< .001
Fmax	0.024 (0.002, 0.046)	0.410	.037	Fmax	0.017 (0.001*, 0.033)	0.394	.046
RFD	--	--	--	RFD	--	--	--
Forearm length	--	--	--	Forearm length	--	--	--

[1], F (1,24) = 4.855, p = .037; [2], F (1,24) = 4.418, p = .046. --, variable dropped from stepwise model. CI, confidence intervals; ER, external rotation; IR, internal rotation; Fmax, peak force; RFD, rate of force development. *Actual value = 0.0003047 (rounded to 3 digits for readability).

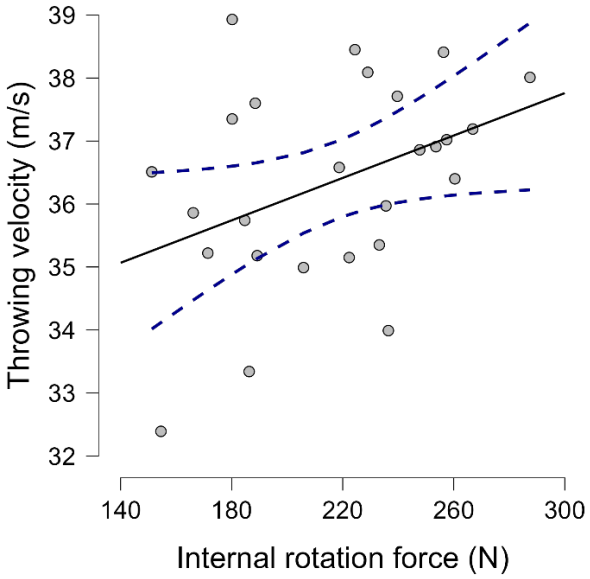

Figure 9. *Relationship between shoulder IR Fmax and throwing velocity with 95% confidence intervals (linear fit = black line, confidence intervals = dashed lines, points = individual data).*

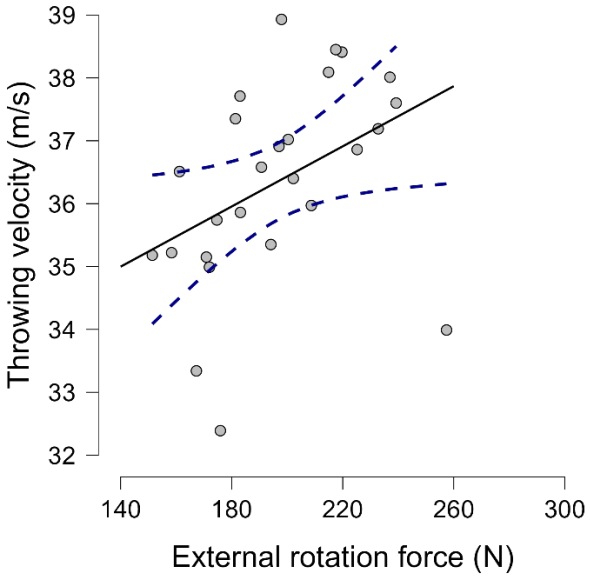

Figure 10. *Relationship between shoulder ER Fmax and throwing velocity with 95% confidence intervals (linear fit = black line, confidence intervals = dashed lines, points = individual data).*

Pairwise correlations were statistically significant between shoulder IR and ER for Fmax (r = .63, p < .001) and RFD (r = .71, p < .001). Similarly, the correlations between Fmax and RFD were also statistically significant for IR (r = .725, p < .001) and ER (r = .549, p = .004).

5.4 Discussion

The focus of this research was to understand the differences between HS and collegiate pitchers, the relationship of shoulder rotator strength with throwing velocity, and the relationship of strength measures to each other. The main findings were: 1) in our sample, HS and collegiate pitchers did not differ from each other in the principal variables of interest; 2) IR and ER Fmax appeared positively associated with throwing velocity, where RFD was not; and 3) finally, large correlations ($r \geq .50$; p < .001) were observed between the IR and ER force measures, and between Fmax and RFD capabilities for both IR and ER.

It was hypothesized that collegiate compared to HS pitchers would be stronger and throw faster, however, this was unsupported. Differences in age (19.6%, p < .001) and forearm length (4.8%, p < .05) did not discern throwing velocity between skill levels within these pitchers. Albeit statistically significant, the difference in forearm length is likely not meaningful. Collegiate pitchers in this study were primarily from the Division III level with similar throwing velocity to previous research (36.4 m/s versus 34.3-36.6 m/s, respectively) (26, 46, 49, 114). The HS pitchers in this study were better trained compared to existing research with greater throwing velocities (36.3 m/s versus 29.1-33.0 m/s, respectively) (46, 49, 109), which may explain the similarities between groups. Furthermore, heightened awareness of rotator strength importance and an emphasis on training these muscles earlier in a competitive career might explain the non-significant differences in throwing velocity. This contention somewhat supported as the shoulder rotator Fmax of the HS pitchers in this study were greater (IR = 214.5 $\pm$ 38.1 N, ER = 192.8 $\pm$ 21.5 N) compared to similar cohorts (IR = 127.2-203.6 N, ER = 120.1-138.4 N) (58, 59, 112, 120), albeit with differing methodologies. Furthermore, if training protocols are improving and becoming more common, the influence of shoulder rotator strength on throwing velocity across different competition levels may decrease.

Our hypotheses were supported regarding the influence of rotator strength on throwing velocity. The only variable entered into the regression models was Fmax which accounted for 12.0% ($p = .046$) and 13.4% ($p = .037$) shared variance for the IR and ER models, respectively. Previous researchers have reported higher common variance between throwing velocity and isometric IR peak torque (35.0-46.0%) and isometric ER peak torque (32.1-70.2%), although with smaller sample sizes (n = 12-18) of HS and collegiate pitchers (21, 26, 56). Comparing common variance among studies is difficult due to varying equipment, testing positions and sample sizes (69).

RFD was excluded from the models, which was somewhat surprising given the extraordinary arm speeds reported while throwing (49) seemingly indicating a necessity to develop and brake force quickly. One explanation might be that isometric RFD has little correspondence to the dynamic RFD needed for pitching (60). While isometric testing is simple and efficient, it does lack the stretch shortening cycle which contributes to RFD in dynamic actions. Another contention is that timing, muscle activation and force production increases of the shoulder rotators during the preceding phases influence arm acceleration, consequently making RFD less important (40). Additionally, submaximal shoulder rotator muscle activity during the deceleration phase and/or a gradual rise in force production from the preceding kinetic sequence (40) may influence the importance of RFD. It would seem of the two variables, Fmax is more important than RFD in characterizing throwing velocity.

It was thought that pitchers with high IR strength would have similarly high ER strength. Large correlations ($r \geq .50$; $p < .001$) were observed between the IR and ER strength measures. Intuitively, it makes sense that if you have strong throwing accelerators, or IRs, you need matching strength in the throwing decelerators, or ERs. Although the correlations were large, there was some unexplained variance between measures, suggesting cause to assess and monitor both. Given that preseason shoulder ER weakness and disparate ER:IR ratios have been associated with throwing arm injuries requiring surgery (15), regularly incorporating shoulder rotator strength assessment may provide value to athletes and coaches. A portable device, such

as the one used in this study, could be used throughout the competitive season to individualize training based on athlete needs. For example, if an athlete's ER Fmax declines, coaches could modify training to specifically target the ER musculature.

Large correlations were also observed between Fmax and RFD for IR and ER. Fmax and RFD seem to share similar strength qualities but also offer different insight into force capability, especially for ER RFD. The large correlations between Fmax and RFD were not surprising given that maximal strength (i.e., Fmax) is usually the cornerstone of most rehabilitation and sport performance programs, and explosive strength (i.e., RFD) is typically prescribed following maximal strength. However, it has been reported in the literature that the two measures are somewhat independent strength qualities and therefore the need to be assessed and probably trained independently (87, 117). Perhaps explosive rotator strength training is needed in this cohort to delineate more clearly between the two measures. The specific importance of RFD to the accelerators and decelerators of the arm for throwers seems negligible but further research should be considered.

In this cohort, HS and lower ranking collegiate level pitchers showed no differences ($p > .05$) in throwing velocity and shoulder strength. We speculated that this was due to better trained HS pitchers with greater shoulder rotator strength and pitching velocity in this cohort compared to similar cohorts previously reported. However, future research should aim to replicate these results in other athlete cohorts, and with larger samples. Indeed, increased power might uncover smaller but potentially interesting associations with other force metrics underlying throwing velocity. Shoulder IR and ER Fmax were associated with throwing velocity, albeit seemingly minorly, which might be explained by the cohort's homogeneity. Nonetheless, a 30 N increase in IR Fmax predicted a 0.51 m/s increase in throwing velocity, similarly a 30 N increase in ER Fmax projected a 0.72 m/s increase. RFD and forearm length were not clearly associated with throwing velocity. Although there is shared variance between shoulder IR and ER, it is likely important to specifically target each action for strengthening separately from throwing. Such improvements on shoulder IR and ER Fmax capability could have positive outcomes on throwing performance.

Finally, isometric testing could be an effective method of workload monitoring shoulder rotator strength for performance.

Chapter 6: Acute Effects of Wearable Resistance Applied to the Throwing Arm on Performance in Baseball Pitchers

6.0 Prelude

In the previous chapter, shoulder IR and ER Fmax were found to have statistically significant associations with throwing velocity, albeit the magnitude being somewhat small. Nonetheless, measuring and monitoring shoulder rotator strength could be useful for evaluating characteristics which appear to underlie throwing performance, and potential aspects of arm health. More specifically, these variables might provide a means of understanding adaptations via the application of WR. Training with WR is intended to be integrated without disrupting movement characteristics, however, the literature pertaining to load selection to develop throwing performance and associated physical characteristics is sparse. Therefore, this acute analysis will provide a better understanding of WR load and placement on throwing performance, which is currently unknown for baseball pitchers. Variables measured were gathered from radar gun, IMU and video technology. The learnings of this chapter will inform the impacts of WR on throwing velocity and arm speed, which in turn will inform the subsequent training intervention.

This chapter comprises the following original publication:

Job T. D. W., Cronin J. B., Crotin R., & Cross M. R. (2025). Acute Effects of Wearable Resistance Applied to the Throwing Arm on Performance in Baseball Pitchers. *The Journal of Strength & Conditioning Research*, 39(3), 340-346. doi: 10.1519/JSC.0000000000004991.

6.1 Introduction

Overhead throwing is an athletic skill used in many sports such as baseball, softball, handball and American football. The speed at which a ball can be thrown is often critical to success in these sports. For example, baseball pitchers with higher throwing velocities give batters less time to identify a pitch and its location. Given the competitive advantage associated with higher pitching velocities there is a great deal of research focusing on increasing it via technical and strength training, the latter providing the focus of this article.

Pitching performance can be maximized by optimizing mechanics to efficiently transfer energy from the lower body through the trunk and throwing arm. Pitchers need adequate mobility and strength to reach throwing-specific positions and transfer force throughout the throwing motion (19, 111). Sufficient total-body strength, and specifically in the throwing arm, is necessary to withstand the demands of throwing as shoulder and elbow injuries are common in these athletes (19, 20, 98). Training to improve throwing velocity in pitchers can be achieved via non-specific methods, such as gym-based resistance training (e.g., medicine balls, rubber-based, pneumatic, iron resistance), resulting in increases of 1.2-10.7% over four to 10 weeks (67). Non-specific methods also contribute to hypertrophy, and increased muscle volume, particularly in the upper and lower throwing arm is associated to throwing velocity (*partial r* = .30-.35, $p < .05$) (127). Nonetheless, it is important to note that developing muscle mass takes time and other factors, such as throwing mechanics and sequencing force still play a role (19, 111, 114, 127). Non-specific methods are characteristically different than throwing, and so there is interest in more specific means of targeted strength development that more closely mimic throwing mechanics – often by integrating load into the movement itself.

Throwing weighted balls, a specific training method, is also popular and has successfully improved throwing velocity over six to 15 weeks with balls 2- to 32-ounces (oz) by 3.1-7.3% (67). Standard baseballs are 5-oz and throwing balls lighter or heavier allows for under- or overloading of velocity and/or force production to elicit greater throwing arm accelerative power. Throwing balls 4- to 7-oz allowed high school and collegiate pitchers to maintain throwing technique (50).

Further, training with weighted balls within 20% of standard ball mass (i.e., 4- to 6-oz) has been shown sufficient to improve throwing velocity with high school and collegiate pitchers without injury (28-31). Ball masses within 20% of standard seem reasonable and are recommended. Normally, weighted balls are released, limiting decelerative overload to the throwing arm. Alternatively, weighted ball "holds" are utilized to train throwing deceleration by instructing athletes to keep an overweight ball secured in the hand past the release point. Although effective for overloading musculature around the elbow (50), this could potentially alter throwing mechanics or timing. It should be noted that among college and professional pitchers (n=376), 75% believe weighted balls improve performance, however, 73% also believe this tool poses risk of injury (25). Sufficient evidence suggests that weighted ball throwing protocols can be safely integrated into training (13, 28, 29, 31, 39, 50, 51), however, researchers in a six-week study utilizing a wide weighted ball range (2- to 32-oz) reported 24% of the weighted ball group participants sustained a throwing arm injury (105). Another form of specific training is wearable resistance (WR), where micro-loads are attached to upper and lower arm compression garments.

Using WR while throwing can overcome limitations associated with weighted balls by overloading deceleration mechanics, providing more variety for progression (i.e., load placement) and can be immediately applied or removed. Compared to the distal, hand-held weighted ball, WR load can be applied more proximally (i.e., above or below elbow), which directly influences the rotational inertia and overload experienced by the athlete. Mathematically, the rotational inertia (I) is a function of mass (m) and (more importantly) the distance of the mass from the axis of rotation which is squared (r^2). Thus, moving load proximally or distally will decrease or increase rotational inertia, respectively. Accordingly, load placement allows for specific musculature to be targeted. Particularly, loads applied above the elbow will target musculature surrounding the shoulder joint, while below elbow loading will target shoulder and elbow musculature. The addition of mass will have greater effects when placed farther away from the axis of rotation (i.e., shoulder) which may decrease throwing velocity and arm speed. However, increasing mass with WR above the elbow could allow for a tapering of segmental mass which may actually act to increase arm speed in the smaller, distal segments (i.e., forearm and hand) provided the athlete might still

effectively accelerate the mass, based on the conservation of angular momentum (45, 78, 113). Nonetheless, the acute effects of WR throwing with pitchers are unexplored. Investigating the effects of strategically placed throwing arm WR on throwing velocity, arm speed and temporal aspects of throwing could advise training protocols which could enhance throwing velocity, arm speed and arm strength.

Throwing a baseball can result in arm speeds over 7,000 degrees per second (deg/s) (48). Arm speed may be interesting to track during training and throwing rehabilitation, especially when utilizing specific strength training methods. In terms of WR, arm speed may be valuable to monitor because movement velocity is meant to be minimally disrupted with load (34). Traditionally this information is measured in a laboratory setting via motion capture, however, the use of inertial measurement unit (IMU) technology is becoming more prevalent in baseball to monitor throwing workload (17, 77, 81, 88, 100). An IMU device, comprised of an accelerometer and gyrometer, has reliably measured arm speed (17, 77, 81, 88) and no significant differences were reported when compared to marker-based motion capture technology (17). Using this device, it was reported that as ball mass increased ball velocity and arm speed decreased in a youth pitcher weighted ball study (100), however it has not been used with WR.

Temporal aspects of throwing have previously been reported from motion capture data in pitchers from youth to the professional level (38, 49, 89, 114). The time from front foot contact to ball release in these studies is known as pitch time. The range of this variable seems to be consistent (~139-150 ms) across skill levels (49), high and low velocity college and professional pitchers (89), comparatively between wind-up and stretch positions (38) and within pitcher variation (114). Deviations in pitch time may provide a broad indication of alterations in technique and provide insight into the effects and subsequent utility of WR.

The purpose of this study is to determine the change in acute temporal and mechanical measurements across WR loading (unloaded, 100-g, 150-g and 200-g) and placement (above and below elbow) of the throwing arm in baseball pitchers. The hypotheses of this study were: 1) the

magnitude of the WR loading will significantly impact arm speed and throwing velocity, 2) below elbow placement will have a greater effect on these variables compared to above elbow, 3) temporal phase mechanics will not be altered with the application of WR.

6.2 Methods

6.2.1 Experimental Approach to the Problem

An acute randomized cross-sectional design was used to examine effects of above and below elbow WR (unloaded, 100-g, 150-g and 200-g) applied to the throwing arm on throwing performance.

6.2.2 Subjects

Ten high school or college (19.5 ± 2.4 years) male baseball pitchers (height = 180.9 $\pm$ 7.7 cm; weight = 81.4 $\pm$ 10.0 kg) were recruited to participate in this study. Athletes were healthy and injury free. Written consent was obtained from each participant and their respective parent/guardian (where applicable) before participation. The sample in this study was one of convenience; however we estimated with a feasible sample of 10 athletes we would be able to detect a large effect (η_p^2) = .14) from at least one of the factors within the models, with acceptable alpha error rates and power (.05 with 80% power)—this size effect seemed likely, based on the incremental and clear conceptual difference between conditions (i.e., load and placement) and that from piloting. The institutional ethics committee approved the study (AUTEC 19/445).

6.2.3 Equipment and Procedures

Subjects participated in three testing sessions (familiarization and two testing sessions) that used Velcro micro-loads (unloaded, 100-g, 150-g and 200-g) affixed to arm sleeve compression garments (Lila Exogen Exoskeletons, Sportboleh Sdh Bhd, Malaysia). Anthropometrics (height and weight) were recorded prior to familiarization. Height was measured via stadiometer and weight by scale.

For each session, participants performed a standardized warm-up of jogging, skipping and dynamic stretching, and rotator cuff exercises with banded resistance. Self-selected submaximal throws were also permitted before testing. Subjects were familiarized with the WR during the first session during which they were encouraged to ask questions and give feedback upon completion. In the second and third sessions, participants were randomized into a WR above or below elbow loading protocol with randomized loads (see Figure 11; 100-g, 150-g or 200-g) which also included unloaded trials. The spectrum of loading adopted in this study was based on pilot testing, and anecdotal feedback with athletes and coaches of what would be applicable within the field. It was determined the upper limit of load that would remain attached and not inhibit athletes' experience was 200-g, in 50-g increments; these former and latter concerns were mostly applicable to the lower and upper arms, respectively, and were then standardized for both placements. Loads were placed at the midpoint of the dorsal forearm or lateral upper arm to avoid the loads rubbing against other parts of the body (i.e. torso). Loads would occasionally detach from the sleeve because of the high-speed action and sometimes moved during testing. The sleeve's integrity was checked after each throw and if sliding occurred during testing, or loads detached, participants were asked to repeat the throw.

Figure 11. *Throwing with WR applied above elbow (left) and below elbow (right).*

Data collection started once the participant communicated that he was ready for testing to begin. Data was recorded on three throws with each load (nine throws) and included three unloaded throws to start and finish the assessment, thus session workload consisted of 15 throws. Participants were allowed 30 seconds rest between throws during the testing session. During the throws, athletes wore an IMU sensor (6.9-g, Driveline, Kent, Washington, USA), which provided data on arm speed (see Figure 12). These sensors are used in baseball circles and reported to reliably quantified arm speed (CV = 2.9-4.3%, ICC estimate = .79-.86) (17, 77, 88). The sensor was placed two finger widths below the participants medial humeral epicondyle, per manufacturer instructions.

Figure 12. *IMU sensor within strap worn with upper arm sleeve (left) and total arm sleeve (right).*

Throwing velocity was measured via radar gun (Stalker Pro II, Applied Concepts Inc., Richardson, Texas, USA) mounted 0.9 m behind the throwing target. For each throw, peak throwing velocity was recorded into a spreadsheet along with data from the IMU sensor (i.e., arm speed). During the throwing trials an Apple iPad (Apple, Cupertino, CA, USA) was set up perpendicular to the

throwing area directly in line with the participant. The stride phase was defined as the instant the front foot lifted off the ground to the point of front foot contact, and the pitch phase was defined as the point of front foot contact to ball release, where the ball separated from the hand. Videos were filmed at 240 frames per second, stored in a cloud system and managed by the researcher.

6.2.4 Data Analysis

Trials recorded from the radar and IMU were averaged for each placement and load for analysis. Video captured during trials allowed for a two-phase analysis of the throwing motion; first, when the pitcher lifted his foot off the ground to front foot contact (i.e., the stride phase); and second, from front foot contact to ball release (i.e., the pitch phase). Time spent in each phase was averaged across trials for each WR condition.

6.2.5 Statistical Analysis

Means and standard deviations (mean ± SD) were calculated for variables in each testing session. To address our aims, separate two-factor [placement (2) x mass (4)] within-subjects repeated measures ANOVAs were performed on arm speed, throwing velocity and pitch and stride phases as dependent variables. Particular interest was paid to the interaction effect in the models (placement × mass) in testing our initial hypotheses. Model assumptions were tested, with violations of sphericity addressed using Greenhouse-Geisser correction (arm speed and throwing velocity). Normality was violated for throwing velocity and below elbow placement ($W = .78\text{-}.85$, $p < .05$), which was caused primarily by a few outliers (normality was restored upon their removal); however, since the primary results did not appear sensitive to their removal (such models are typically robust to such violations), and we lacked a clear case for their removal (e.g., they were not clearly an error), we opted to retain them in the final model. To interpret magnitude of effect on the dependent variables, partial eta-squared (η_p^2) was reported. Magnitude of effect was interpreted using the following thresholds: small (η_p^2 = .01-.059), medium (η_p^2 = .06-.13) or large (η_p^2 > .14). Pairwise comparisons were performed between loads within placements, for the various dependent variables, and interpreted as raw difference, 95%

confidence intervals, and Cohen's d effect sizes (*d*). Bonferroni correction was used to adjust for multiple comparisons, and d was interpreted using trivial (<0.1), very small (0.1-0.19), small (0.2-0.49), moderate (0.5-0.79), large (0.8-1.19) or very large (>1.2) thresholds of effect (22). The alpha value for all tests was considered as .05.

6.3 Results

Descriptive data and the effects of WR load and placement on throwing are displayed in Table 12. Overall, load had a large effect (η_p^2 = .32-.41) on arm speed and throwing velocity ($p < .05$). Placement of WR had no statistically significant effect on the variables of interest. The effect of load on velocity varied to a large degree on where it was placed on the arm (η_p^2 = .64; $p < .001$).

Table 12. *Descriptive data and effects of different load and placement patterns while throwing.*

	Descriptive data (mean ± SD)								Analysis of variance					
	Above elbow (g)				Below elbow (g)				Load		Placement		Load x placement	
	0	100	150	200	0	100	150	200	*p*	η_p^2	*p*	η_p^2	*p*	η_p^2
Arm speed (deg/s)*	5,723 ± 427	5,528 ± 273	5,577 ± 313	5,573 ± 312	5,619 ± 385	5,466 ± 281	5,338 ± 377	5,264 ± 356	.011	.405	.216	.164	.097	.225
Throwing velocity (m/s)*	36.32 ± 1.15	36.26 ± 1.27	36.50 ± 1.31	36.31 ± 1.28	36.21 ± 1.46	35.57 ± 1.66	35.25 ± 1.79	35.32 ± 1.48	.047	.321	.071	.318	<.001	.641
Stride phase (ms)	836 ± 249	829 ± 250	839 ± 257	831 ± 242	833 ± 225	833 ± 231	840 ± 236	840 ± 236	.748	.043	.909	.002	.836	.031
Pitch phase (ms)	152 ± 28	153 ± 27	154 ± 30	152 ± 32	152 ± 35	151 ± 36	152 ± 36	154 ± 38	.747	.044	.85	.004	.583	.068

SD, standard deviation; deg/s, degrees per second; Nm, Newton meters; m/s, meters per second; ms, milliseconds; *Greenhouse-Geisser correction applied due to violation of sphericity.

When examining the differences between loads with unloaded trials, no significant differences were observed for any variables between loads placed above elbow. Large differences in arm speed were observed when comparing unloaded trials to 150-g and 200-g below elbow loads (d = 0.82, p = .030 and d = 1.03, p = .002, respectively). Small to moderate decreases in throwing velocity were observed between unloaded trials and all below elbow loads: 100-g at d = 0.45, p = .009, 150-g at d = 0.67, p < .001, and 200-g at d = 0.62, p < .001.

Table 13. *Percent differences, 95% CI for mean difference for loaded throwing compared to unloaded throwing.*

	Above elbow (%, [95% CI])			Below elbow (%, [95% CI])		
	100	150	200	100	150	200
Arm speed	-3.5 [-12.1, 76.9]	-2.6 [-20.3, 68.7]	-2.7 [-19.5, 69.5]	-2.8 [-19.1, 69.9]	-5.1* [2.3, 91.3]	-6.5** [14.6, 103.6]
Throwing velocity	-0.2 [-0.5, 0.6]	0.5 [-0.7, 0.4]	-0.4 [-0.5, 0.6]	-1.8** [0.1, 1.2]	-2.7*** [0.4, 1.5]	-2.5*** [0.3, 1.4]
Stride phase (ms)	-0.9 [-28.2, 43.4]	0.4 [-39.1, 32.5]	-0.6 [-30.5, 41.1]	-0.1 [-35.3, 36.3]	0.8 [-42.5, 29.1]	0.9 [-43.0, 28.6]
Pitch phase (ms)	0.3 [-6.7, 5.9]	1.1 [-7.9, 4.7]	0.2 [-6.6, 6.0]	-0.9 [-5.0, 7.6]	-0.1 [-6.2, 6.4]	1.1 [-7.9, 4.7]

CI, confidence intervals; Nm, Newton meters; ms, milliseconds.

*p < .05, **p < .01, ***p < .001

6.4 Discussion

In this study investigating the effects of WR on baseball throwing performance, the main findings were: 1) the effect of loading on throwing velocity varied by its placement, with small to moderate decreases in throwing velocity detected with below elbow loading exclusively, 2) large decreases in arm speed were shown with below elbow loading of 150-g and 200-g compared to unloaded conditions, and 3) otherwise, neither WR placement nor load affected temporal phase mechanics.

Unloaded throwing in this study resulted in arm speeds of 5,619-5,723 deg/s and throwing velocity at 36.2-36.3 m/s. Researchers investigating similar cohorts using the same IMU have reported comparable ranges for arm speed (5,053-5,952 deg/s) and similar throwing velocities using radar gun (33.5-38.1 m/s) when throwing from a pitching mound (16, 77, 81, 88). This is somewhat surprising, since throwing from a mound compared to flat-ground was found to have differences in arm speeds (16, 50). It is probable that these differences are simply a product of cohort specific characteristics.

Throwing velocity was the only variable to which the effect of loading strongly varied by placement (~64% variance explained by the interaction between load and placement). Accordingly, small to moderate standardized decreases (d = 0.45-0.67) in throwing velocity with below elbow loads were recorded (see Figure 13) which were smaller than the moderate to large decreases observed in the weighted ball research (-3.2 to -7.0%, d = 0.55-1.3) (50). This is intuitive, since the placement of weighted balls are further from the axis of rotation compared to the placement used for the WR in this study, resulting in greater rotational inertia and therefore decreased outcome effects. Decreases in throwing velocity with below elbow loading ($p \leq .004$) were also reported in female handball athletes (52), albeit difficult to compare given differences in the throwing motion for the two sports (i.e., ball mass, controlled vs dynamic throwing, arm speeds, throwing velocity) (49, 122). Nonetheless, although statistically significant, the practical magnitude of changes observed as a product of loading was practically small (e.g., ~1 m/s decrease, from the heavier below elbow loads). Whether such small changes in throwing

velocity – or otherwise the rotational overload that is not otherwise captured in macroscopic performance outcomes – signals sufficient overload to stimulate positive adaptations needs to be investigated.

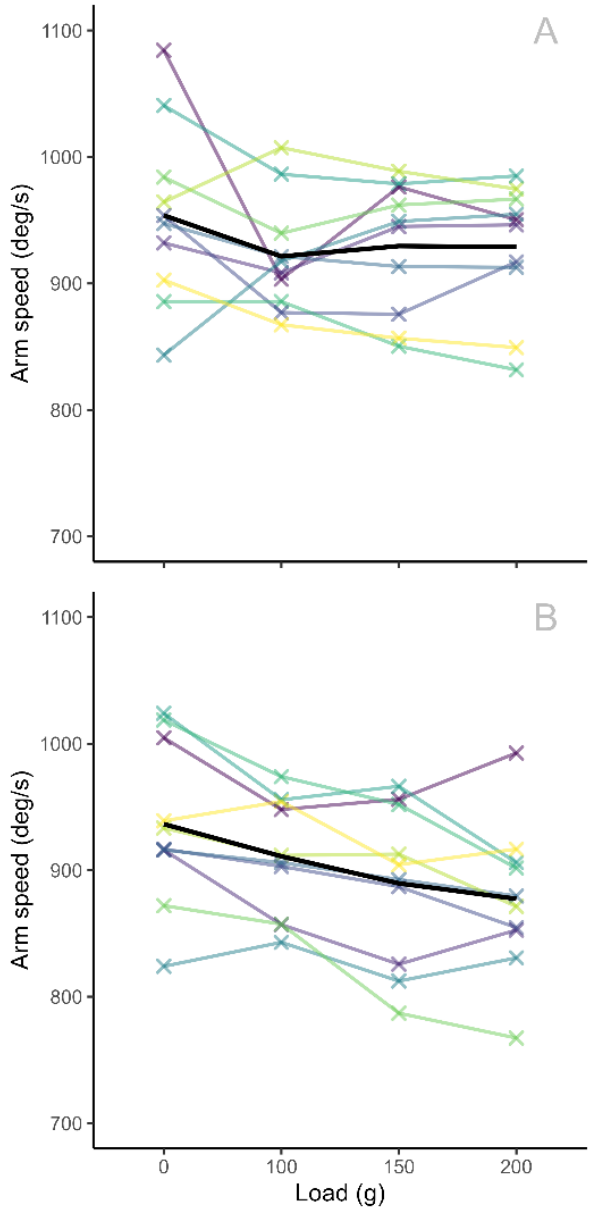

Figure 13. *The individual effects of above (A) and below (B) elbow WR loading on throwing velocity.*

The effects of WR on arm speed did not clearly differ ($p > .05$) as a product of above elbow loading. This lack of change might be due to the proximity of WR loading to the axis of rotation resulting in a minor overload that we were unable to clearly detect within the constraints of our study design. While load applied above the elbow decreased arm speed on average (albeit non-statistically significant), there was notable individual variation (see Figure 14). The apparently favourable response of some athletes to the stimulus might indicate leveraging the additional mass to conserve momentum and increase their subsequent throwing performance to a minor degree. Nevertheless, measurement error is another plausible explanation, and future researchers could investigate proximal loading strategies to optimize arm speed in baseball pitchers (45, 78, 113).

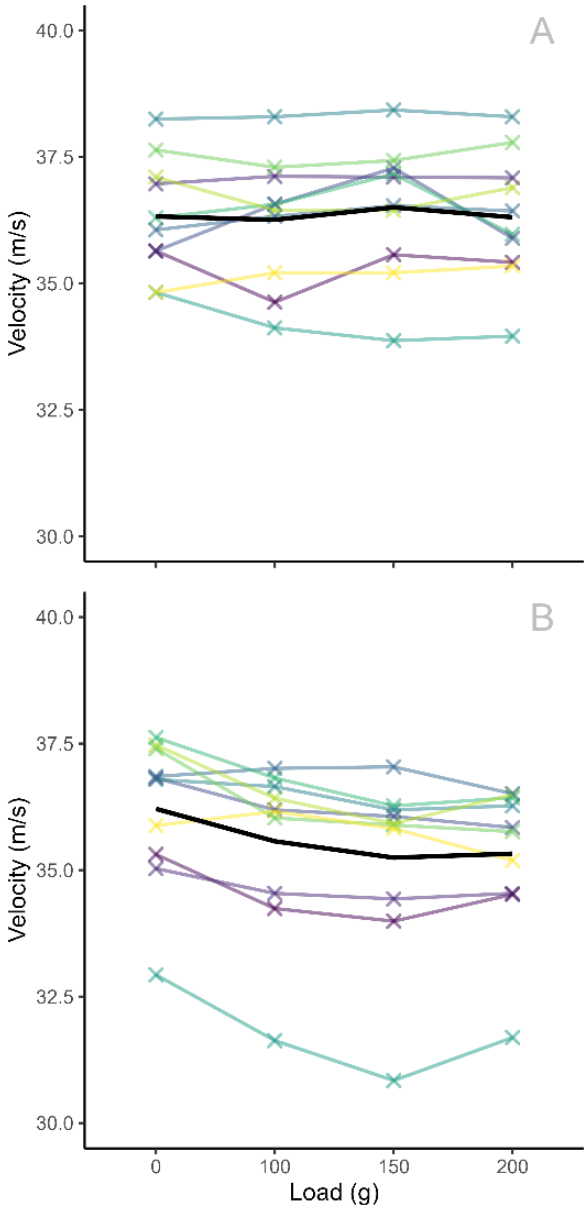

Figure 14. *Individual responses to above (A) and below (B) elbow placements to arm speed.*

Large decreases in arm speed during below elbow loading were observed with 150-g and 200-g (*d* = 0.82-1.03). Ultimately, these findings were not surprising given that the increased segmental mass from WR loading is exponentially affected by distance from the throwing shoulder and can alter the torque required to accelerate the throwing arm forward. Despite increased load applied to the throwing arm, decreased arm speed in this study can be indicative of reduced elbow varus

torque, like other observations noted with weighted balls (50). Overload from WR resulting in slower arm speeds may have positive benefits in throwing performance with repeated use over time. The micro-load arrangement distal to the shoulder joint, results in a greater disruption in arm speed given the increased rotational inertia. This increase in resisted overload requires greater force production in the arm musculature and if repeated over multiple training occasions should theoretically increase shoulder strength. Nonetheless, at present it is unknown whether the magnitude of decreases observed in this study are practically meaningful for stimulating longitudinal training adaptations.

Macroscopic throwing mechanics were analysed via video as the time spent during the stride phase (i.e., front foot lift to front foot strike) and the pitch phase (i.e., front foot strike to ball release). No difference ($p > .05$) in time spent during these two throwing phases across a range of loads (100-g to 200-g) and placement (above and below elbow) were observed. During the stride phase, a pitcher will raise the front leg to a height that noticeably varies among pitchers and will reach front foot strike by various strategies such as staying tall and falling down the mound or driving the body directly toward home place. Stride phase timing has not been reported in existing literature although it is expected this aspect of throwing may have more variability. Pitch phase duration (151-154 ms) was comparable to previous research (139-150 ms) (38, 49, 89, 114) suggesting that WR may not unduly disrupt sequencing compared to unloaded conditions. A common concern of many coaches is the disruption to temporal sequencing when overload is introduced into the throwing motion. Albeit low granularity, the loading and placement strategies and outcome measures used in this study do not support this concern. Indeed, the lightweight and seemingly non-invasive nature of WR allows pitchers to generally maintain technical proficiency with load at high speeds (34).

No differences ($p > .05$) were noted in temporal phase mechanics suggesting that movement sequencing with load, with either placement, was not disrupted. Training with WR is intended to maintain movement velocity similar to competition or training speeds (34). Above elbow WR load resulted in small to moderate decreases in arm speed (d = 0.42-0.57), although non-significant,

these effects may accumulate into a training effect with repeated exposure. As hypothesized, below elbow load produced more distinct differences in arm speed (-5.1% to -6.5%, $p < .05$) and throwing velocity (-1.8% to -2.5%, $p < .05$). Below elbow loading could also be considered because sequencing was not disrupted, despite more distinct decreases in arm speed and throwing velocity. Accordingly, the influence of forearm length warrants consideration with below elbow loading because pitchers with longer forearms will have greater moments of inertia which could more distinctly differentiate between below elbow proximal and distal loading.

Several questions arose during this project, which would be interesting to explore in the aim of better scoping the utility of WR for pitching: 1) loads were placed exclusively on the throwing arm; however, it would be interesting to examine the effects of WR on the non-throwing arm and other parts of the body such as the trunk and legs; 2) the researchers exclusively sourced baseball pitchers, the effects of WR on throwing performance for other position players in baseball and other throwing athletes (i.e., softball, American football quarterbacks, javelin) warrants investigation; and, 3) high-intent throwing was the focus of this study, however understanding the effects of WR on other throwing activities such as long-toss or throwing exercises commonly used with weighted balls, would be beneficial to coaches. Furthermore, a distinctive advantage of throwing with WR is overloading the deceleration phase of throwing, which is difficult with weighted ball training. High forces are generated by the entire body while the arm accelerates forward which are absorbed, primarily by posterior shoulder musculature, during deceleration (19, 111). Progressive overload with WR could prepare the body for the demands of high intensity throwing exhibited in baseball pitchers to handle the proximal compression loads for the shoulder that can exceed body weight for highly competitive pitchers (47).

There are some limitations that warrant discussion. First, while we planned to use a broader range of loading, during piloting it became apparent that athlete arm size, sleeve integrity, and detaching loads were a problem with the commercially available units. Future researchers could investigate strategies to overcome these issues, potentially using updated securing methods, and

access greater ranges of loads for analysis. Nevertheless, the practical issues encountered may signal a lack of practical utility of such loading protocols. Absolute loads were used in this study to prioritize weights that maintained placement throughout the entire throwing motion. Individualizing loads relative to body mass is worthy of examination with amended securing methods. Further, forearm length is worth consideration as relative load and distance from the shoulder could be used to normalize inertial loads. High-speed video was utilized in determining temporal features for the delivery, with the idea of using practically available tools and a macroscopic measurement. Perhaps differences may be seen in performing this work within an optical 3D tracking environment that incorporates time normalization between trials to identify differences in front foot lift off and stride foot placement. Stride time, the time by which the lead foot is airborne, could be potentially more granular for statistical interpretation with the use of force plates to determine when the lead foot unloads the ground and then when it contacts the ground a second time to denote the end of the stride phase.

6.5 Practical Applications

Loaded throwing with WR applied to the throwing arm, within the ranges in this study appears to influence throwing velocity and arm speed – contingent on where it is applied. Specifically, below elbow loads from 100-g to 200-g appear to reduce throwing velocity to a degree which might indicate potential for training adaptation over repeated bouts. Loads applied above elbow, did not appear to influence throwing performance but may deserve consideration in training the shoulder girdle without limiting arm speed, and interesting phenomenon observed in the unique responses of some athletes who actually increased their throwing speed. Nonetheless, both contentions are speculative, and require further investigation. Ultimately, further investigation into the mechanical disruption resulting from the implementation of WR is needed; however, from a macroscopic temporal perspective, mechanical integrity was not clearly changed with the loads used in this study. WR may offer unique strategies to incrementally overload the throwing motion in a more targeted fashion than weighted balls. Applying overload in this way may be beneficial during return to throwing rehabilitation since the shoulder can be targeted while leaving the elbow and wrist joints unloaded.

Chapter 7: The Training Effects of Wearable Resistance on Throwing Performance in Collegiate Baseball Pitchers: A Pilot Study

7.0 Prelude

In the previous chapter, minimal clear effects were observed across the loads added to the upper arm within the ranges used in the previous study. A primary theory underlying the use of WR more broadly is that it leverages the addition of micro-loads without unduly disrupting aspects of movement technique but nonetheless should represent some degree of measurable overload (e.g., altered movement velocity); therefore, above elbow placement with increased loads from the previous chapter were selected for the training study. Additionally, a primary interest of the thesis was targeting the shoulder rotator musculature and there were practical concerns regarding the application of below elbow loading. Shoulder rotator Fmax, using previously established strain gauge protocols, and throwing velocity, measured by radar, were assessed to provide a comprehensive understanding of potential adaptations pre- and post-training. Additionally, the assessment included arm speed by IMU and shoulder rotation ROM by goniometer before and after the WR intervention. Due to high error and possessing a lower association with throwing velocity, RFD was not explored as part of this analysis. This pilot study provides a gateway for application of WR training for throwing athletes.

This chapter comprises the following published paper:

Job T. D. W., Cross M. R., & Cronin J. B. (2025). The training effects of wearable resistance on throwing performance in collegiate baseball pitchers: a pilot study. *International Journal of Sports Physiology and Performance.* In press.

7.1 Introduction

Throwing is a fundamental skill in baseball, with pitching being a specialized form of throwing. The speed at which a pitcher can throw is advantageous by decreasing a batter's time to recognize a pitch, making it a key goal for training programs at all competition levels (67). Throwing is a total-body effort where energy is transmitted and sequentially increased from the lower-body through the shoulder (19). Improving force production capability can enhance throwing performance (99); however, since pitching relies on technical proficiency (e.g., throwing mechanics) and throwing arm injuries are common (19, 20, 79, 111), long-term success likely depends on balancing the development of physical and technical skills, and accordingly adopting appropriate training methods.

All else being equal, increased throwing velocity (TV) requires greater neuromuscular demands—the product of the shoulder internal rotators (IR) accelerating and external rotators (ER) decelerating a faster arm (19). There is evidence of a positive relationship between shoulder IR and ER peak force (Fmax) and TV (R^2 = 12-13%, $p < .05$) (64). With different throwing responsibilities, it seems logical to develop strength in both actions to contribute to and withstand the demands of throwing while reducing injury likelihood (15, 39, 54). Various training methods exist to enhance TV, and can be divided into non-specific and specific training methods (67), with the latter the focus of this article.

Weighted balls have traditionally been used in specific training methods. Weighted balls (57-907-grams) used over six to 15 weeks with youth, high school, and college baseball athletes have effectively increased TV 3.1-7.3% (67). This specific method loads the throwing arm with the weighted ball in the hand, distal to the shoulder, overloading the arm accelerators. Typically, the throw becomes unloaded at ball release limiting overload of the arm decelerators. Weighted ball "holds" can overcome this limitation by retaining an overweight ball past the release point. Holds can effectively overload elbow flexion torque and the biceps as an elbow extension decelerator (50), although potentially disrupting throwing mechanics. Moreover, some caution the use of weighted balls due to injury concerns and ER range of motion (ROM) increases (25, 105). Indeed,

increases in shoulder ER ROM are linked with TV improvements (1, 124), but are also associated with increased medial elbow torque whilst throwing, which has been associated with injury (1, 79). Clarity is needed regarding necessary strength levels, ROM, and ball mass or throwing volume progression when applying weighted ball and adjacent techniques. Alternatively, securing loads along the throwing arm, otherwise known as wearable resistance (WR) could be implemented. Loads placed above or below the elbow, rather than the hand, could overload the throw following ball release without disruption of timing while throwing (63).

Securing WR to the throwing arm is relatively unexplored. Similar to throwing with a weighted ball, a primary rationale is an ability to integrate load at throwing-specific speeds e.g., 7,000°+/second (48). Moreover, unlike weighted balls, since WR remains affixed to the arm, WR could overload arm accelerators and decelerators, before and after ball release, respectively (52, 63). Accordingly, the athlete can distribute WR in specific locations (i.e., above- or below-elbow), which could allow for targeted muscular overload. There is a paucity of research quantifying the effects of WR. Throwing with below-elbow loads (150-g and 200-g) acutely decreased arm speed (5.1-6.3%) and TV (100-200-g, 1.8-2.7%, $p < .05$) (63). Above-elbow loading, up to 200-g, did not significantly affect arm speed or TV, and loads could likely be increased due to the proximal load placement. Therefore, research is needed that quantifies greater above-elbow load effects and whether throwing with WR can produce meaningful adaptations over a block of training (34). Above-elbow WR could be strategic for baseball players where less rotational overload occurs, possibly target the shoulder musculature and minimise ER ROM increases. Practically, this approach would load the entire throwing motion, including post-ball release.

Given the treatise of the literature, the aim of this study was to determine if a throwing program using WR applied above-elbow could improve shoulder rotator strength and TV in baseball pitchers compared to non-loaded throwing. We hypothesized that applying WR while throwing should increase both shoulder ER and IR Fmax and TV. Additionally, we hypothesised that no significant changes in ROM would be observed. Although the optimal prescription of

training load and placement is unknown, this study should enhance our understanding of the utility of WR training for throwing performance.

7.2 Methods

7.2.1 Experimental Approach to the Problem

Participants took part in a parallel groups trial, where both groups performed the same volume of throws, the only difference being that an intervention group integrated WR applied to their upper arm during 12 practices (twice weekly) over a six-week period. Participants completed a pre- and post-training battery of tests, which quantified throwing performance, shoulder rotator strength, and flexibility.

7.2.2 Subjects

Healthy, male collegiate baseball players (see Table 14) volunteered to participate in this study and provided written consent. While this was primarily a sample of convenience, the probable participant numbers were judged sufficient to detect medium-to-large effects with sufficient power (67). To be included in the analysis participants needed to attend 80% or more of the training sessions. Subsequently, two participants were removed from the intervention group (one attended 42% of sessions, and another due to a non-throwing injury). In the control group, two participants missed the post-testing throwing assessment, but their data was retained for other analyses. In the final analysis, the control group included eight participants, and the intervention group included nine. This sample left us somewhat underpowered compared to our original estimates. To achieve 80% power with an alpha of .05 a partial eta squared (η_p^2) of ~.12-considered borderline 'large'-would be required; note this was based on a simplified repeated-measures design (excluding random effects). We discuss the implications of this in the interpretations of our results. The study was approved by the institutional ethics committee (AUTEC 22/304).

Table 14. *Participant descriptive data.*

	n	Age (years)	Height (cm)	Weight (kg)
Control	8	20.3 ± 1.8	180.7 ± 4.6	86.4 ± 11.7
Intervention	9	19.6 ± 1.6	179.4 ± 5.4	84.6 ± 9.7

7.2.3 Procedures

7.2.3.1 Initial processes: Familiarization

Participants completed a health questionnaire (PAR-Q+ 2022) prior to any testing to determine possible risks of exercising based on health history and current symptoms. An explanation of the pre- and post-training procedures was presented as an information sheet and any questions regarding these procedures were answered. The familiarization session occurred two weeks prior to pre-testing and consisted of introducing the testing protocols and throwing with the WR. While all athletes and coaches were briefed on testing procedures and familiarized with the WR, they were blinded to the hypotheses of the study.

7.2.3.2 Pre-testing (and post-testing): Specific procedures, group allocation

Pre-testing occurred one week prior to the start of the training study and post testing occurred in week seven after the training intervention finished. Testing sessions occurred in the middle of the day at a convenient time chosen by the subjects around their class schedules. Pre- and post-testing took place over a two-day period. The first day included recording height, weight, passive shoulder ER and IR ROM and shoulder ER and IR Fmax. The second day included an assessment of unloaded throwing performance. Without resistance, TV was tested from the "stretch" position and was measured by radar gun (Stalker ATS II Version 5.0.2.1, Applied Concepts Inc., Richardson, TX, USA) mounted behind the target. Participants did not engage in upper body resistance training 24-hours prior to testing.

Passive shoulder ER and IR ROM was measured with a goniometer (Elite Medical Instruments, Orange County, California, USA). For this test, participants were supine on a training table with

the shoulder placed at 90° of abduction and 10° of horizontal shoulder adduction, the scapula secured and the elbow at 90° of flexion. Consistent positioning and measurement techniques were used across all participants and testing sessions. Two testers completed standardized passive ROM assessment training and were consistently used to minimize variability. Two trials were performed, with one tester placed the participant into position, with the other aligning and measuring ROM using the goniometer [intra-rater intraclass correlation coefficient (ICC) = .62] (2).

Shoulder rotator strength was measured as described previously (65). Athletes performed maximum isometric contractions (see Figure 15) to measure throwing arm shoulder ER and IR strength. Force-time data was collected at (1,000 Hz) using a custom, wireless strain gauge (Hawkin TruStrength Tech, Portland, Maine). Once athletes were set into position, they were verbally instructed to start and complete the trial to capture Fmax (CV = 4.3-5.8%, ICC estimate = .79-.85). Five trials for each action were performed, with three seconds per trial to minimize fatigue. Participants were given one-minute rest between trials.

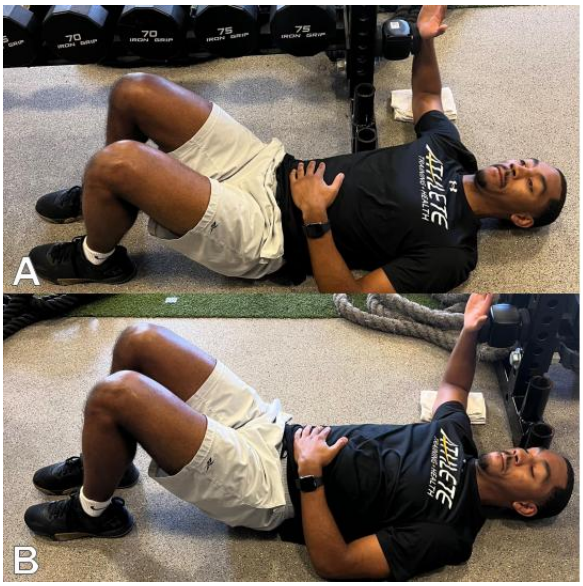

Figure 15. *Strength assessment of Fmax during shoulder internal rotation (A) and external rotation (B) in the supine 90 testing position.*

On day two of testing, throwing velocity without load was measured to provide a practical measure of performance. Participants performed maximum effort throws into a target from 6.1 meters. Peak throwing velocity was measured via radar gun (Stalker Pro II, Applied Concepts Inc., Richardson, Texas, USA) set directly behind the target. In addition, an inertial measurement unit (IMU) (Figure 16A. PULSE Throw workload monitor, Driveline, Kent, Washington, USA) was worn on the throwing arm below the elbow of participants (attached via strap) for each throw. Arm speed was measured during testing and recorded for analysis (CV = 2.9-4.3%, ICC estimate = .79-.86) (17, 77, 88).

Figure 16. *Above elbow arm sleeve featuring PULSE throw workload monitor (A) and above elbow loading with 200-g (B).*

7.2.3.3 Training

Group allocation and adherence: Following pre-testing, athletes were randomly allocated to either a control or intervention group. Independent t-tests were used to determine if any statistical differences existed in Fmax and throwing velocity between groups after pre-testing. Data analysis was conducted following the intervention period. The primary researcher

supervised training during the study to account for attendance and adherence to proper arm loading protocols.

The training intervention occurred during baseball practice and required no additional time from the participants. It consisted of two sessions per week over six weeks, with 48 hours between loaded throwing sessions. During training sessions, athletes performed three sets of five throws with a standard baseball while securing wearable resistance to a Velcro sleeve (Lila Exogen Exoskeletons, Sportboleh Sdh Bhd, Malaysia) on the throwing arm (see Figure 16B). Each session started with a standardized dynamic warm-up followed by a self-selected number of unloaded throws prior to applying the WR. Load increased over the six-week intervention while volume (as total throws) remained constant (see Table 15). Subjects rested 30-seconds between throws and one-minute between sets. After the throwing intervention, subjects continued with their coach led baseball training. The control group followed the same practice structure, including warm-up and throwing volume, but did not use WR during any part of their training.

Table 15. *Training intervention loading progressions.*

Week	Session	Load (g)	Sets	Total Throws
1	1	100	3	15
	2	200	3	15
2	3	200	3	15
	4	200	3	15
3	5	300	3	15
	6	300	3	15
4	7	300	3	15
	8	400	3	15
5	9	400	3	15
	10	400	3	15
6	11	400	3	15
	12	100	3	15

7.2.4 Data Analysis

Key variables of interest were throwing velocity, arm speed, and shoulder ER and IR Fmax and ROM. Arm speed and TV were averaged from three trials. Shoulder rotator Fmax was averaged across five trials for ER and IR, respectively. Shoulder ROM used the greatest measurement of two trials.

7.2.5 Statistical Analysis

Statistical analyses were performed using the R language and environment for statistical computing (104), and associated packages. Specifically the *tidyverse* (125) environment for data treatment, the *lmerTest* (74) package for models, *ggeffects* (84) to estimate marginal means, and the *easystats* (85) framework (e.g., *performance*, *parameters*, and *effect size*) were implemented.

Descriptive statistics (mean ± 95% CI) were calculated for all dependent variables extracted from pre- and post-training testing sessions. To address our primary aim and assess the impact of training using WR (control versus intervention) and testing (pre- and post-training) on throwing performance, strength, and ROM metrics, linear mixed-effects models were used. This approach was selected in favour of the planned repeated-measures analysis, due to their more nuanced handling of missing data and robust nature to some assumptions, described below in more detail. These models employed restricted maximum likelihood estimation with nloptwrap optimization. Distinct models for each dependent variable were developed, as throwing velocity, arm speed and Fmax, and ROM for ER and IR, respectively. Each model included group, time, and their interaction as fixed effects, with individual participants serving as random effects.

Prior to interpreting these models, assumptions were fully explored. Deviations from normal residuals (ROM internal, Shapiro wilks, $p = .007$) and differences in variance between the groups (throwing velocity and arm speed, Barlett test, $p = .026$-$.041$) were observed, which were primarily attributed to a few outliers across the various models. Following sensitivity analysis, and comparing model fit and coefficients to those from robust models (using *rlmer* from *robustlmm* (72)), the impact of these violations was judged negligible (i.e., did not meaningfully

change the results). We progressed with the original model, but this should be considered when interpreting the results.

An analysis of variance was performed on each model, reporting the F statistic, p-values, and η_p^2 values to estimate effect size. The magnitude of the effect was interpreted using the following thresholds: very small ($\eta_p^2 < .01$), small ($\eta_p^2 = .01$-$.059$), medium ($\eta_p^2 = .06$-$.13$) or large ($\eta_p^2 > .14$).

In addition, the differences over time within each group were analysed via pairwise contrasts on the estimated marginal means, expressed as mean differences in raw units alongside 95% CI and p-values. Particular attention to this analysis was placed when statistically significant interaction effects were observed. The significance level for all statistical tests was set at alpha = .05.

7.3 Results

Statistical models showed modest contributions from training group and time (marginal $R^2 = .04$–$.29$), and greater variability explained by individual differences (conditional $R^2 = .42$–$.76$). Relatively little variance was explained by IR Fmax (marginal $R^2 = .08$, conditional $R^2 = .13$, respectively).

Key comparisons between WR and control groups are summarized in Table 16. No significant differences in arm speed or TV were observed over time or between groups. Changes in IR Fmax (~17 to 19 N) and ER Fmax (~6 to 14 N) were noted but were not significant. A significant interaction effect was observed only for ER ROM ($\eta_p^2 = .261$, $p = .047$), primarily driven by increases in the control group (+18.9^o).

Table 16. *Training effects of wearable resistance on throwing performance and physical traits.*

	Estimated marginal means				Analysis of Variance								
	Control		Intervention										
	Pre	Post	Pre	Post	Group			Time			Group x Time		
	$\bar{x}$ [95% CI]	$\bar{x}$ [95% CI]	$\bar{x}$ [95% CI]	$\bar{x}$ [95% CI]	p	η^2_p	Effect	p	η^2_p	Effect	p	η^2_p	Effect
Arm speed (deg/s)	5,439 [5,119, 5,759]	5,493 [5,174, 5,813]	5,691 [5,392, 5,990]	5,571 [5,272, 5,870]	.397	.056	*Small*	.728	.010	*Very small*	.358	.065	*Medium*
Throwing velocity (m/s)	35.6 [34.5, 36.8]	36.0 [34.9, 37.2]	36.6 [35.5, 37.7]	36.3 [35.2, 37.4]	.416	.051	*Small*	.906	.001	*Very small*	.233	.107	*Medium*
IR Fmax (N)	214.6 [193.6, 235.7]	233.8 [212.8, 254.9]	224.2 [203.2, 245.3]	235.6 [214.6, 256.7]	.599	.020	*Small*	.147	.144	*Large*	.699	.011	*Small*
ER Fmax (N)	196.0 [173.4, 218.6]	202.1 [179.5, 224.7]	194.2 [171.7, 216.8]	208.9 [186.3, 231.5]	.861	.002	*Very small*	.099	.182	*Large*	.478	.037	*Small*
IR ROM (°)	40.3 [33.0, 47.5]	41.6 [34.4, 48.9]	36.6 [29.4, 43.9]	37.9 [30.2, 45.6]	.396	.051	*Small*	.645	.016	*Small*	.983	.000	*Very small*
ER ROM (°)	119.8 [109.2, 130.4]	138.6 [128.0, 149.2]	138.8 [128.2, 149.4]	142.8 [131.7, 153.9]	.094	.186	*Large*	.005	.456	*Large*	.047	.261	*Large*

Mean, $\bar{x}$; 95% confidence intervals, 95% CI; partial eta squared, η^2_p; internal rotation, IR; external rotation, ER; range of motion, ROM; peak force, Fmax; rate of force development, RFD; Newtons, N; Newtons per second, N/s; degrees per second, deg/s; meters per second, m/s. Bold denotes a significant effect.

7.4 Discussion

This was the first training study to investigate the effects of throwing arm WR on throwing performance. It was thought that above elbow loading may offer a training stimulus that could improve shoulder rotator strength and TV. After a six-week program the main findings were: 1) no significant changes in arm speed or TV were observed in the control or the WR groups; 2) rotator strength did tend to improve within the groups, albeit non-significant either for group, time or their interaction, 3) a significant within group change in the control ER ROM was noted.

The hypothesis that above-elbow WR loading would provide a sufficient training stimulus to increase arm speed and TV, was not supported by our results. Somewhat surprisingly, no statistically significant changes were detected following six weeks of training in either group. Nonetheless, some large effects were observed (e.g., in shoulder rotator strength $\eta^2_p > .14$, $p > .05$), which may be clarified with a larger cohort, Overall, the paucity of research investigating WR throwing makes comparing results problematic, however, researchers using weighted balls (113- to 170-grams) have reported improvements (4.4-6.7%, $p < .05$) in TV with greater throwing volumes (150-232 throws/week) over 10 weeks (28, 29). Another six-week study with similar throwing volume to this WR study (15-35 throws per week using weighted balls of 57- to 907-grams) reported a small increase (1%, $p = .01$) in TV with youth pitchers (105). The increased velocity with the lesser throwing volume may be attributed to increased intensity from greater ball masses and the distal placement (i.e., in the hand), however 24% of the weighted ball group dropped out due to injury pitchers (105). Therefore, in future loaded throwing studies, load and placement should be considered in overall intensity prescription. In the present study, one explanation is that the college pitchers in this study may have possessed an athletic background that required more individualized training, or higher volumes. Overall, it seems that the interaction between load placement and volume to produce training adaptation, is more complex than anticipated, particularly when considering better trained athletes. Further research is required.

The proximal WR placement likely did not sufficiently increase rotational inertia to produce a training adaptation (50, 63). Considered alongside the weighed ball studies with greater rotational inertia (i.e., load more distal to the shoulder axis of rotation), the intensity of the overload and/or the volume in these studies could explain the unclear nature of TV increases. Overall, the lack of clear group adaptation may have several explanations. The team's pre-determined training load from which the sample were recruited might have been insufficient to yield a training effect. It is possible that the WR load was insufficient in terms of placement and/or load, or volume (30 throws/week) to differentiate the training stimulus between the two groups; however, further research is needed to determine the minimum effective dose for WR adaptations in throwing athletes. Additionally, results may have been smaller effects that expected, and increased power from more participants and measurement points may have clarified our interpretations.

Strengthening the shoulder rotators is important to improve pitching performance and injury resilience (15, 54, 64). Determining ways to increase shoulder rotator strength, while maintaining efficient throwing mechanics is essential to increase TV. It is difficult to conceive 100-400-g as adequate overload to increase shoulder strength, however, when light loads are moved quickly, they produce increased angular kinetic energy and resultant muscular work (i.e., work-energy relationship). Thus, it was hypothesized that a WR throwing program would increase shoulder rotator strength due to high velocity, sport-specific strength training. Although not statistically significant ($p = .099$), we observed small improvements in ER Fmax with greater mean increases from the intervention group ($\eta_p^2 = .037$, +7.6% vs +3.1%, respectively). While unclear whether this result is meaningful, greater increases in ER strength with WR has a conceptual basis, attributed to loaded deceleration. Nonetheless, our hypothesis was unsupported, no changes in shoulder rotator Fmax were observed in either group following the intervention. Similar ambiguous results have been observed in the literature with a weighted ball training study with high school pitchers reporting no improvements in TV compared to a control group, despite increases in strength (116). Therefore, the relationship between training, strength and TV can be complicated and needs more research to clarify the WR dose-response relationship.

The only change detected between groups over time was a large increase in ER ROM (η^2_p = .261, p = .047), primarily attributed to ROM increases in the control group (+19 degrees), seemingly somewhat counterintuitive. For example, increased layback during the arm cocking due to weighed balls might have increased ROM in a study which showed increases in ER ROM (+4.7%, p = .01) significantly different to a control group (p = .02) accompanied with an increased TV (105). In this study the non-significant effects associated with the WR group can likely be attributed to the loading proximal to the shoulder therefore having little effect on the layback and ER ROM, however, further investigation is required. In our experiment, the mean value for pre-test ROM for those in the control group was lower (119.8^o vs 138.8^o, respectively), which might explain some degree of adaptation in this group. No changes in IR ROM were observed, consistent with previous weighted ball research (105). One unique aspect of WR is the ability to manipulate load placement. More distal load placement on the forearm would produce greater rotational inertia, and may have resulted in greater increases in ER ROM, similar but likely less than the weighted ball study (105). Regardless, it does seem that above-elbow WR using similar loading to this study, can be integrated into training without increasing ER ROM. However, whether this holds in a more substantial sample, or when manipulating factors to increase training efficacy (e.g., increasing the load or position of loading) remains unknown.

There are some limitations to consider regarding this study. Despite the a-priori information regarding the size effects we might observe, ultimately the study was likely underpowered following subject loss. Thus, a larger sample might have clarified potentially interesting differences between the cohorts and over time, which we were unable to detect. Future studies might opt to collect data from a larger cohort, albeit at the risk of decreased standardization via recruitment from likely different teams (and surrounding activities). Similarly, it is possible that training adaptations had not yet been realized (96), and having a second post-testing session allowing for longer recovery and supercompensation. Additional post-testing occurrences were considered, but unfortunately untenable due to team scheduling. Future research should consider multiple time-points of assessment where possible, and multiple post-test occasions to

bolster the understanding of potential adaptations at play and identify a minimum effective WR dose. Finally, this study used absolute loads throughout the intervention and future WR prescriptions could consider loads relative to body mass.

7.5 Practical Applications

Training with WR, as prescribed in this study, may not be sufficient for increasing TV or shoulder strength in well-trained athletes. Coaches should consider increasing loaded throwing session volume, load, frequency or duration to elicit a training effect. Furthermore, applying loads below-elbow should be considered to provide substantial overload. As the first WR throwing-specific training study, above-elbow placement was selected to maintain velocity and minimize joint loading (i.e., excluding elbow and wrist). Low throwing volume was selected with the athletes' safety in mind, particularly due to injury concerns with weighted ball training (25, 105); however, volume with above-elbow loading might be increased to elucidate WR effects. Given that proximal loading may have minimal impact on ER ROM, WR potentially offers a safer option to increase training intensity without exacerbating injury risks associated with increased ROM.

7.6 Conclusion

Applying above-elbow WR over a six-week, twice per week throwing program was ineffective in improving TV and shoulder rotator strength in collegiate baseball pitchers. Nonetheless, our findings provide important guidelines for future research regarding how this method might be better adapted, notably regarding magnitude of overload and volume of the dose-response relationship.

Chapter 8: New Perspective on Shoulder Rotator Assessment and Training in Baseball Pitchers

8.0 Prelude

The previous chapter was the final experimental chapter in this thesis and provided evidence of the usefulness of WR applied during training to improve throwing performance and underlying physical qualities, guided by the preceding chapters. The outcome was relatively ambiguous, with lacking evidence for positive effects of the method. This chapter provides a broad perspective of the practical learnings of this thesis and how they may be employed in the future to target the development of throwing performance. The results from the training intervention complicates interpretation, and so some consideration is given as to where it fits into the strength training plan of pitchers. Where WR conceptually provides some unique benefits and a different loaded throwing stimulus to other methods like weighted balls, preliminary results report subtle effects and therefore some recommendations for future use are provided. The aim of this chapter is to provide practical applications for professionals interested in throwing performance and arm health.

This chapter is in preparation for submission to *Strength and Conditioning Journal*.

8.1 Introduction

Pitching is a specialized form of throwing in baseball and throwing velocity is regarded as one of the key components to a pitcher's success. A total body effort, throwing relies on well-organized sequencing of kinetic energy from the ground up through the body and arm and into the baseball to maximize throwing velocity (19). The shoulder understandably receives substantial attention as energy generated by the body funnels through the shoulder into the throwing arm, and ultimately, transferring extensive force into the ball (19, 40). Shoulder musculature therefore requires adequate strength to contribute to and endure the demands of throwing, particularly muscles responsible for shoulder external (ER) and internal rotation (IR) (19, 79). Muscles that perform shoulder ER are the posterior deltoid, infraspinatus and teres minor. Meanwhile, the IRs are pectoralis major, latissimus dorsi, anterior deltoid, teres major and subscapularis. It is important for clinicians and coaches to understand the stresses of throwing on the upper extremity to maximize performance and understand mechanisms of injury. Regularly assessing and monitoring shoulder rotator strength in pitchers, integrated into training, could inform understanding of injury mechanisms (15, 35, 54, 64, 94, 98, 112, 120).

Pitchers can enhance throwing performance by a variety of means from non-specific to specific training methods (67). Key distinctions between the two methods are the movement performed and the speed at which movement is executed. Non-specific methods are typically slower and utilize a range of equipment (e.g., barbells, dumbbells, medicine balls, rubber-based resistance [RBR], etc.) to perform general compound (i.e., squat, hinge, push, pull) or isolated (e.g., ER, IR, flexion, extension, etc.) movements. Non-specific methods encompass traditional resistance training, plyometrics and rehabilitation exercises resulting in increased strength and power capabilities. Specific methods replicate the throwing motion without compromising technique which traditionally involve throwing a variably weighted implement. However, wearable resistance (WR), a novel training tool has emerged as another option. Rather than being thrown and released by the athlete, WR throwing involves micro-loads applied to the throwing arm which maintain overload throughout the entire throwing motion.

This commentary is divided into four sections. In the first section, the biomechanics of the throwing motion are reviewed. New perspectives on shoulder strength assessments that are relevant for baseball pitchers are discussed in section two. In section three, non-specific and specific training strategies to increase throwing velocity are detailed. In the final section, a new method of specific training, WR applied to the throwing arm, and its potential utilization for pitchers is explored. The scapulothoracic musculature plays a critical role in allowing the shoulder rotators to work effectively, and the orchestrated effort of the scapulothoracic and glenohumeral musculature should not be overlooked. With that said, however, this article will focus on the shoulder rotators, colloquially referring to the shoulder ERs as the decelerators and the IRs as the accelerators.

8.2 Part I: The Biomechanics of Throwing

Throwing is characterized by six phases: wind-up, stride, arm cocking, acceleration, deceleration and follow-through (see Figure 17) (19, 40, 48, 49). The wind-up (17A) and stride (17B) phases utilize lower body strength to create a stable base and develop kinetic energy that will be transferred to the subsequent phases of throwing. The arm cocking phase (17C) begins at front foot contact and ends at maximum shoulder ER (MSER) where the shoulder externally rotates allowing the forearm and hand to lag behind the trunk. During this phase, energy is transmitted up the kinetic chain to the throwing arm where the accelerators are lengthening under tension (19, 40, 79). Once the arm reaches MSER the acceleration phase (17D) begins initiating humeral IR and ends at ball release (19, 40, 49). The deceleration phase (17E) begins at ball release and ends when the shoulder reaches maximum IR as the decelerators eccentrically contract and withstand tremendous forces to slow the arm (19, 40, 48, 49). During the follow-through phase (17F), the throwing arm continues to decelerate, and the pitcher finishes in a fielding position (19, 79).

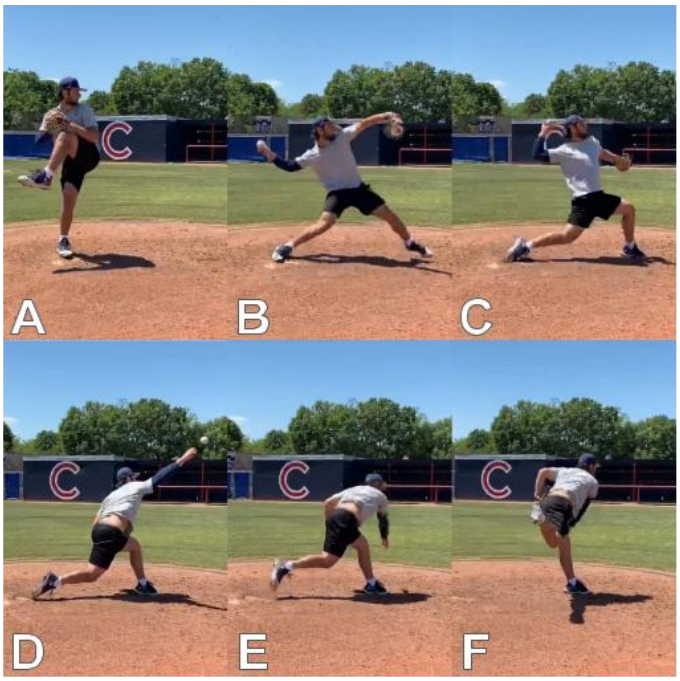

Figure 17. *The throwing phases: wind-up (A), stride (B), arm cocking (C), acceleration (D), deceleration (E) and follow-through (F).*

Kinetic energy generated from the legs and trunk during the wind-up and stride phases is transferred into the throwing arm during arm cocking and acceleration, both of which substantially load the accelerators (32, 40, 55, 98). Following foot strike, the pelvis rotates at 600+ degrees per second (deg/s), the trunk rotates at 1,000+ deg/s and flexes forward (19, 40, 48, 111)—all being funnelled into the shoulder musculature, and subsequently resulting in arm speeds over 7,000 deg/s (48). The accelerators are highly active (50-99% maximum voluntary isometric contraction, MVIC) during arm cocking as they contract eccentrically while the throwing arm lays back to MSER (40). Large forces at the shoulder are observed at this point with college and professional pitchers: 380 N of anterior shear force and 660 N of compressive force (47). During the acceleration phase the arm redirects to internally rotate and muscle activity increases (54-115% MVIC) (32, 40). It is imperative that the humeral head maintains its position on the glenoid fossa to avoid injury to the labrum and rotator cuff musculature due to the mentioned forces acting on the joint (19, 79). Therefore, strengthening the shoulder rotators is a high priority to baseball coaches and pitchers. Considering the significant role of the shoulder musculature

while throwing, enhancing force production capabilities could potentially complement performance outputs such as throwing velocity.

Prior to ball release, the decelerators assist the throwing arm to reach MSER where infraspinatus is most active (74% MVIC) (40). The posterior shoulder resists anterior translation of the humeral head during arm cocking, which may help relieve the anterior side of the joint (32, 40). Primarily serving as the brakes of throwing, the decelerators experience high forces following ball release: 400 N of posterior shear force, 310 N of inferior shear force and 1,090 N of compressive force (47). During the deceleration phase, teres minor is the most activated shoulder muscle (84% MVIC), and similarly, the posterior deltoid is highly activated (60% MVIC) (32, 40). The decelerators contract eccentrically to slow horizontal adduction and IR, resist shoulder distraction forces which may exceed body weight (47), and resist anterior shoulder subluxation forces (40-50% body weight) (40). The large eccentric demand on the decelerators and posterior shoulder are likely the causes of labral tears and muscular injuries (i.e., teres minor) (19). Injuries could occur due to capsule laxity or muscular weakness around the joint (47, 92). While deceleration requires effort beyond what the ERs provide, this muscle group plays a significant role (32, 40) and ER peak force (Fmax) has provided valuable insight into pitchers' arm health (15, 54). Ensuring strength is being improved or maintained is critical, therefore best practices for monitoring shoulder rotator strength should be considered.

8.3 Part II: Throwing Shoulder Assessment

There are a variety of interesting variables to assess for baseball pitchers, both in terms of allocating and monitoring the effects of ongoing training, but also in the interest of injury prevention. Bilateral differences in pitchers are common such as increased shoulder rotator strength, ER range of motion (ROM) and decreased IR ROM in the throwing arm (54, 76, 119). Shoulder ROM should be monitored regularly throughout the year, particularly, increased shoulder ER ROM can potentially be beneficial for increasing throwing velocity but simultaneously poses a risk of elbow injury (1, 79, 124). Isometric shoulder rotator Fmax in baseball pitchers has been widely researched, notably due to being safe, simple and efficient,

and found to be important for arm health and throwing performance (15, 35, 54, 64, 94, 98, 112, 120). Decreases in rotator strength, particularly ER, have been associated with throwing arm injuries (15, 54, 112, 120). Additionally, shoulder rotator Fmax is associated with throwing velocity (r^2 = 12-13%, $p < .05$) in collegiate and HS pitchers (64). In terms of performance, IR Fmax has been shown to decline by 18% ($p < .05$) following a pitching outing, underscoring the demand of this musculature in throwing (98) and the need for monitoring. Moving forward, this article will primarily focus on force production assessment methods for baseball pitchers. Unlike lower-body strength assessments, which are commonplace and receive substantial attention in the body of research, upper body assessments are comparatively rare. This complicates selecting appropriate assessment procedures and associated technology for implementation in pitchers, focusing on understanding the force production qualities of the shoulder musculature.

8.3.1 Variable Choice

Commonly reported and apparently valuable for athletes, Fmax is easily calculated and has been found reliable with a variety of technologies (4, 15, 35, 54, 57, 59, 64, 65, 94, 98, 112, 120), which in part explains its popularity. Some technologies, such as a force plate, have higher sampling rates and can quantify over 150 variables which can be overwhelming to many users. Arguably, using a few important variables that are confidently understood by the practitioner will allow for better training prescription (see Figure 18). Along with Fmax, other variables such as mean force, impulse and RFD could be informative throughout a macrocycle.

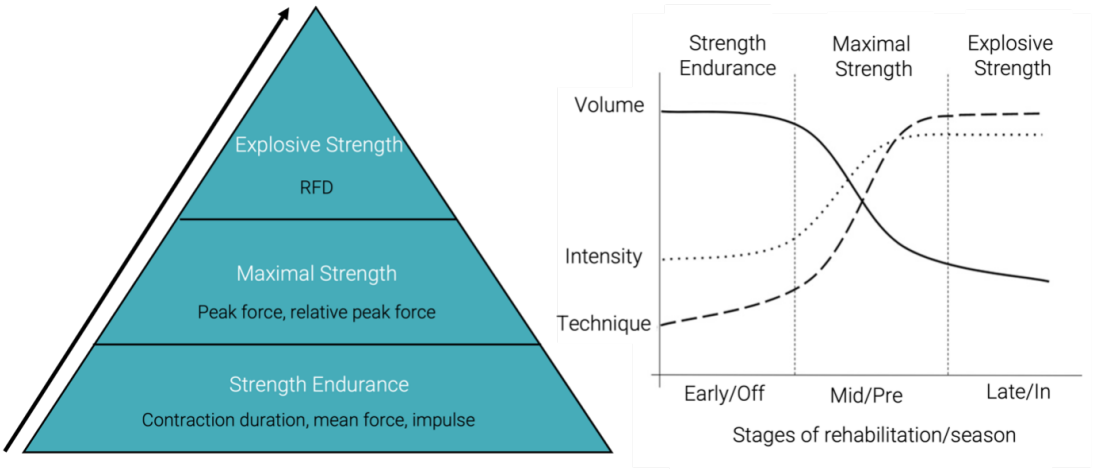

Figure 18. *Assessment and training pyramid of relevant strength qualities.*

Over the course of a macrocycle, volume and intensity will fluctuate (see Figure 17) and training goals will change. During a general strength phase, characterized by lower intensity and higher volume (11), variables such as mean force or impulse may be informative. Mean force is simply the average force of the signal and reflects the athlete's ability to sustain force over a given epoch. Impulse represents the magnitude of the force applied over the time of the signal, or the area under the force-time graph. Increases in mean force or impulse in the same timeframe indicate greater force production. Alternatively, maintaining predetermined force thresholds over longer time periods (i.e., increased impulse) might help characterize aspects of strength endurance. These variables may be informative during earlier phases of training or rehabilitation when individuals are deconditioned or injured. Once a foundation of general strength is established, maximal strength (i.e., Fmax) becomes the focus of a training program.

Typically, after maximal strength is developed, a shift in training focus will move towards applying force quickly at speeds relevant to the sport (11). Explosive strength assessment and training could be a focus of late-stage rehabilitation and in-season training, best quantified by rate of force development (RFD). The reader needs to be cognizant that there are many ways to calculate RFD, from the instant of force onset to the contraction's peak to finding the peak RFD over the entire force-time signal or RFD over specific time epochs. Given this information, care must be

taken when calculating and comparing RFD. Furthermore, the reader should be aware that quantifying RFD reliably is difficult, so rigidly standardizing procedures is fundamentally important, when using this variable.

Reliability should be considered when deciding on a measurement and metric in practice. This will allow practitioners to make better informed decisions by accounting for the consistency typically associated with each variable. Work from our lab with swimmers, reported acceptable typical error (coefficient of variation, CV) and reliability (95% confidence intervals intraclass correlation coefficient, ICC [lower, upper]) for Fmax in three testing positions: seated at 0^{o} of shoulder abduction, supine at 0^{o} of shoulder abduction and supine at 90^{o} of shoulder abduction (CV = 5.2-8.8%, ICC [.69, .98]) (68). In terms of RFD, error was unacceptable (CV > 10%), and reliability mixed (ICC [.34, .96]), however, results were encouraging in the supine 90^{o} position (CV = 11.5-15.2%, ICC [.68, .96]). Subsequently, pitchers were assessed in the supine 90^{o} position with acceptable Fmax typical error reported (CV < 6%) for both ER and IR, however, reliability was acceptable for IR (ICC [.56, .95]) and unclear for ER (ICC [.39, .93]) (65). Additionally, shoulder rotator RFD showed acceptable relative consistency for the accelerators (ICC [.71, .97]), however, unclear regarding the decelerators (ICC [.41, .93]) and absolute consistency for both was unacceptable (CV > 10%) (65). With regular implementation, consistency should improve, and RFD could be a valuable measure of explosive strength. Although interesting to consider, shoulder rotator reliability for mean force and impulse in pitchers is unknown and should be explored in future research.

8.3.2 Assessment Choice

A range of testing positions (see Figure 19) have been used with high-sampling technology (1,000 Hz) to measure shoulder rotator strength. Though reliability was similar between positions, force production was influenced by the positions used. Greater IR outputs (13.7-26.7%, $p < .05$) were found with the seated 0^{o} position and the greater ER outputs (12.5-13.9%, $p < .05$) with the supine 90^{o} position with swimmers (68). Thus, multiple testing positions can be selected based upon relevance to the sport/activity or the importance of the involved musculature, however,

comparing data between different testing positions is problematic and the positions should not be used interchangeably. Greater ER force outputs were observed in the supine 90^{o} position because the posterior deltoid is in a more favourable position to contribute to force production (44). In terms of assessing pitchers, because the posterior deltoid displays very high muscle activity during the deceleration phase of throwing (40), the supine 90^{o} position is recommended for shoulder rotator assessment. When assessing the shoulder musculature, tensile (pulling) or compressive (pushing) forces can be measured, with no clear advantages in terms of shoulder rotator force output reliability observed using either method (65, 68).

Figure 19. *Shoulder IR and ER testing in three testing positions: seated with the elbow at 0 degrees abduction (A and D), supine with the elbow at 0 degrees abduction (B and E) and supine with the elbow at 90 degrees abduction (C and F).*

8.3.3 Normative Data

Normative shoulder rotator Fmax in high school (HS), college and professional pitchers (see Table 17) has been informative for health and performance practitioners (15, 35, 54, 58, 59, 64, 65, 94, 98, 112, 120). For HS pitchers, IR Fmax is greater than ER Fmax, 127.2-203.6 N and 120.1-138.4 N, respectively (58, 59, 112, 120). A similar trend was observed in collegiate and professional pitchers with IR Fmax ranging 178.5-232.5 N and ER Fmax ranging 130.2-179.5 N (35, 94, 98).

Baseball pitchers have an ER:IR ratio less than 1.0 (ER:IR = 0.62-0.94) (15, 35, 54, 58, 59, 64, 65, 94, 98, 112, 120). It should be noted that a variety of testing positions were used in the literature and therefore reflected in the ratios. With the shoulder at 0^{o}, ratios ranged from 0.62-0.76 (58, 59, 94) and at 90^{o} the ratios ranged from 0.77-0.94 (35, 59, 64, 98, 112, 120), further emphasizing the need for consistency in choice of assessment method. The IR dominance is likely credited to muscular throwing demands, however an ideal ER:IR ratio is unclear. Nonetheless, increasing and maintaining ER strength is desired as weaker decelerators have been associated with injuries requiring surgeries (15, 112). While ER:IR ratios are helpful it needs to be noted that a ratio provides little diagnostic value unless the variables are viewed individually because the ratio is affected by changes in either value. Considering this, comparing IR and ER to normative data in tandem with the ratios is recommended and will better guide training.

Table 17. *Shoulder strength reported in HS, college and professional baseball pitchers.*

Study	n	Level	Technology	Action	Position	Fmax (N)
Shoulder rotator tests						
Donatelli et al. 2000 (35)	39	Pro	HHD	ER	Supine 90º	147.6
				IR		178.5
			HHD	ER	Plane of Scapula	130.2
				IR		192.0
Garrison et al. 2016 (54)	33	HS and college	HHD	ER	Seated 0º	122.3
				IR		174.9
Hurd et al. 2011 (59)	50	HS	HHD	ER	Seated 0º	122.7
				IR		181.2
				ER	Supine 90º	125.4
				IR		137.4
Hurd et al. 2012 (58)	27	HS	HHD	ER	Seated 90º	138.4
				IR		203.6
Job et al. 2024	26	HS and college	Strain gauge	ER	Supine 90º	196.7
				IR		216.4
Michener et al. 2021 (94)	135	Pro	HHD	ER	Seated 0º	138.6
				IR		194.0
Mullaney et al. 2005 (98)	13	College and pro	HHD	ER	Supine 90º	179.5
				IR		232.5
Shitara et al. 2015 (112)	105	HS	HHD	ER	Prone 90º	120.1
				IR		127.2
Tyler et al. 2014 (120)	166	HS	HHD	ER	Supine 90º	124.0
				IR		139.0

Athletic Shoulder ('ASH') tests						
Trunt et al. 2022 (119)	12	College	Force plate	Adduction	Prone 0^{o}	138.2
					Prone 90^{o}	136.7
					Prone 135^{o}	142.6
					Prone 180^{o}	170.0
Merfield et al. 2024 (93)	35	HS and college	Force plate	Adduction	Prone 0^{o}	114.3
					Prone 90^{o}	133.6
					Prone 135^{o}	113.4
					Prone 180^{o}	105.5

N, Newtons; HHD, handheld dynamometry; ER, external rotation; IR, internal rotation; HS, high school; athletic shoulder, ASH.

8.3.4 The Athletic Shoulder Test

Other simple upper extremity tests could provide valuable information for baseball pitchers and other throwing athletes such as the athletic shoulder (ASH) test (4, 93, 97, 119). The ASH test is a single-joint shoulder test measuring horizontal adduction in three positions: 180^{o} (I-position), 135^{o} (Y-position) and 90^{o} (T-position) (see Figure 20) (4), the latter two most similar to common arm angles while pitching (43). At ball release, the elbow is within 25^{o} of full extension (49) across multiple skill levels (i.e., youth, HS, college, professional) therefore a long lever test may provide unique information alongside shoulder rotator strength, typically assessed at 90^{o} of elbow flexion. The assessment was originally used with rugby athletes and was found to have acceptable Fmax reliability (90% CI ICC = .92-.99, CV = 5.0-6.7%). Although reliability for pitchers is lacking, normative ASH values for healthy HS and college pitchers can be observed in Table 17 (93, 119). Researchers reported greater throwing arm Fmax compared to the non-throwing arm in the Y- and T-positions ($p < .01$) similar to other throwing shoulder research (119). Furthermore, over a college season pitchers decreased Fmax 7-11% in the Y- and T-positions, respectively (93). Maintaining shoulder strength during the season should be a priority and regularly implementing testing into training could help minimize decreases. In summary, while normative ASH test values

are available, more research is still needed to establish reliability with pitchers and assess for associations to throwing performance.

Figure 20. *The ASH test in the T-position (A), Y-position (B) and I-position (C).*

8.3.5 Technology Choice

Optimally, assessing and monitoring shoulder strength should happen regularly as part of training, and historically upper-body strength assessments have been conducted with isokinetic dynamometry or force plates (4, 18, 21, 56, 93, 97, 119, 126). While these technologies provide valuable and high-quality data, they are often accompanied by restrictive barriers such as cost or immobility. Thus, are likely difficult to access for most athletes and practitioners. Portable technology such as load cells allow testing to be administered in a more practical environment such as a baseball field. These devices are typically relatively low cost, portable, durable, include high-sampling frequency and can typically be operated wirelessly. These factors allow the devices to be implemented within a working environment, have a low barrier to entry to use (with caveats discussed below), and can be adapted for multiple testing positions to target specific musculature.

There are a variety of manufacturers providing similar devices on the market, which are increasingly equipped with high-level capabilities. Of the various technologies, handheld dynamometry (HHD) is portable and commonly used to measure isometric Fmax with baseball pitchers (15, 35, 54, 58, 65, 94, 98, 112, 120). These devices are relatively low cost but suffer from several limitations. Notably, they are typically limited in sampling rates which reduces access to potentially interesting variables such as RFD (15, 35, 54, 58, 94, 98, 105, 112, 120). Further, HHD

is associated with two forms of biological variability: the person being tested and the tester. The person being tested needs to be assessed in the same physiological state and be familiarized with standardized protocols to ensure consistency of data. Likewise, when using HHD the tester needs to be in a consistent physiological and psychological state, replicate the exact testing positions and range of motions, provide the same resistance, cueing, etc., otherwise greater variability in the data will result over repeated testing occasions. Where possible avoiding HHD is advised, and fix a dynamometer to a baseplate, rack, or plinth (portable fixed dynamometry, PFD; see Figure 19) which will eliminate the biological variability introduced by the tester (64, 65, 94).

Technological variability should also be considered when assessing the shoulder musculature, especially with technology using high sampling rates. Technological variability may be affected by temperature, device aging, attachment method and manufacturing. Using devices that have a "zeroing" function can eliminate many of these biases and ensure that trials start from a known, constant value at baseline (i.e. zero). Using PFD to reduce biological variability would allow for testing to take place regularly, and the practitioner to be more confident in the veracity of the data they are collecting over time.

In terms of pitcher shoulder strength assessment, isometric shoulder rotator testing provides insight into throwing arm performance and health, specifically with Fmax. However, it should be noted that other variables may provide value throughout a calendar year if protocols can provide acceptable consistency. Shoulder rotator strength can be assessed in multiple positions, although the supine 90^{o} position is recommended for pitchers which is favourable to recruit the posterior deltoid. Shoulder ER:IR are expected to be less than 1.0, however, careful consideration of ER Fmax should be noted. Finally, PFD should be implemented regularly, similar to popular pre- and post-throwing RBR training, for monitoring purposes to increase testing opportunities and minimize protocol variability. In addition to providing valuable diagnostic information, isometric strength testing should be considered in overall training volume of the athletes. Isometric exercises are commonly prescribed by coaches and have proven to increase strength with positive effects on dynamic actions and have a low energy cost (86).

8.4 Part III: Non-Specific and Specific Strength Training with Weighted Balls

Pitchers, compared to position players, are more likely to experience throwing arm injuries, injuries requiring surgery, and miss more games during non-operative injuries (20). Missed playing time due to injury could inhibit advancement to higher levels and cost professional teams millions in salary, thus, supporting the notion of strengthening the shoulder rotators and upper-body for arm health and performance.

8.4.1 Non-Specific Resistance Training

Throwing velocity can be enhanced through various non-specific methods accredited to a general increase in general force production (67). Compared to baseball position players, pitchers have weaker shoulder rotators (14-20%, $p < .001$) which is puzzling (94). Researchers studying the effects of non-specific methods have reported 1.2-10.7% throwing velocity increases with youth, HS, collegiate and professional athletes after four to 10 weeks of resistance training (13, 18, 41, 42, 75, 83, 90, 99, 102, 116, 126). Heavier loads (3-12-repetition maximum, RM) were commonly used with compound movements, which recruited more musculature, while lighter loads (>12-RM) were used for power development or in isolated exercises specifically targeting muscle groups like the shoulder rotators. Both heavy and light loading strategies were performed at slower speeds than throwing specific methods. The lightest loads (~2-kg) prescribed in non-specific training are greater than the heaviest loads (~0.9-kg) utilized in throwing specific training modalities.

Researchers investigating HS, college and professional pitchers have reported throwing velocity increases after training with heavy loads (1.2-4.1%, $p < .05$) (42, 75, 90, 99, 102) and light loads (2.4-10.7%, $p < .05$) (18, 83, 126). Increases in throwing velocity (4.0%, $p < .01$) in youth athletes have been reported using RBR for 20-25 repetitions per exercise which may be appropriate as youth are learning to train (41). The bench press has been commonly used to increase throwing velocity (1.8-4.1%, $p < .05$) (75, 90, 99), however, using a barbell may be troublesome for some pitchers due to the previously mentioned bilateral differences in ROM and strength developed in

these athletes. For these reasons alternative variations that can independently load each arm are recommended like a landmine press (see Figure 21) or using dumbbell press variations. These independent loading strategies may allow for individualized and more comfortable joint alignment in the wrists and elbows, greater ROM, and better stabilization and coordination of musculature at the shoulder joint compared to bilateral barbell exercises. Because of the aforementioned imbalance between IR and ER strength, any loss of ER Fmax raises injury concerns, and it is recommended that non-specific training should bias training to target the decelerators and posterior shoulder musculature. This can be simply achieved by prescribing at least two posterior shoulder exercises for every anterior shoulder exercise.

Figure 21. *The kneeling landmine press starting (A) and finishing (B) positions.*

Training with RBR is commonly practiced with baseball athletes, normally performed pre- and post-throwing. However, this method of training is subjective, therefore difficult to progressively overload resistance and ultimately develop strength and power qualities. More objective training, particularly after throwing, could make a difference in strength outcomes. A potential solution could be the integration of PFD into the RBR training of pitchers, where the resistive

overload can be monitored and progressed in a systematic fashion (see Figure 22). For example, pitchers can be prescribed ER force targets such as an ER isometric contraction at 180 N for 12 seconds (Figure 22A) or 180 N for 10 repetitions (Figure 22B).

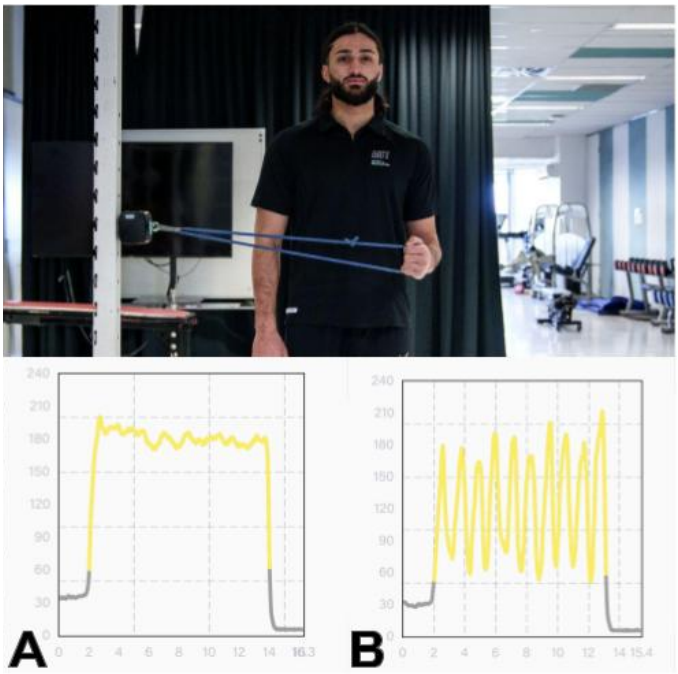

Figure 22. *Integration of PFD in RBR training: (A) a 12-second isometric contraction at 180 N and (B) 10 repetitions with a target of 180 N.*

Non-specific methods enhance athletic performance by increasing general force production by enhancing lean muscle mass, neuromuscular coordination and movement ability and injury resilience (11). Integrating specific training methods allows for prominent joints (i.e., shoulder) to be overloaded at key moments of the throwing motion (i.e., MSER) and has proven to enhance sport-specific qualities (i.e., throwing velocity).

8.4.2 Specific Resistance Training

Specific methods allow for training at higher movement velocities in a manner biomechanically similar to throwing. Integrating load directly into the throwing motion has been commonly practiced with variably weighted balls. Throwing weighted balls (2- to 32-ounces, oz) improved

throwing velocity 3.1-7.3% in youth, HS and college pitchers over six-to-12-week training durations (13, 28, 29, 39, 80, 105, 128). Typically, heavier balls (> 5-oz) are used to overload force production and lighter balls (< 5-oz) are used to overload velocity. Weighted balls 4- to 6-oz have been integrated into training (150-234 throws per week), with 4.4-6.7% increases ($p < .05$) in throwing velocity in HS and college pitchers with no injuries after 10 weeks of training reported (28, 29). These loads are recommended; however, further progressions could be made over time and with added training experience. Throwing both 5- and 7-oz ball have been shown to produce similar throwing mechanics with HS and college pitchers (50), however, greater loads (16- and 32-oz) have resulted in injury with youth pitchers (105). Progressing weighted ball training beyond 7-oz should be approached with caution.

Weighted balls are typically thrown leaving the deceleration and follow through phases unloaded. Weighted ball "holds" may be utilized where the ball is held to overload the throwing arm decelerators (50, 53). Holds have been shown to effectively increase elbow flexion torque ($p < .05$), which could develop strength in the biceps and help stabilize the elbow joint which is also commonly injured in pitchers (20, 50). However, this type of training may alter throwing mechanics or timing (50). It is also unknown if regularly implementing holds into training will increase ER Fmax. Interestingly, in a survey of collegiate and professional baseball players (n = 376), 75% of baseball players implementing weighted ball training (199/276) consider this modality beneficial despite 73% believing that this training increased injury risk (275/376) (25).

8.5 Part IV: Specific Resistance Training – Throwing with Wearable Resistance

Another potential specific training method to improve throwing velocity is the use of WR secured to the throwing arm (63, 66). Similar to throwing weighted balls, WR allows the shoulder to experience overload at key moments of the throwing motion (i.e., MSER) but with more variability in load placement (i.e., above or below the elbow). Furthermore, because load is attached to the arm and not added to the projected implement, the arm will experience overload following ball release. This approach could allow for the shoulder rotators to be loaded in an individualized manner to the throwing motion of each pitcher. A sport-specific method of

resistance training, WR incorporates micro-loads with the intentions of minimally disrupting speed (34).

To use WR effectively and safely, practitioners must be familiar with concepts of rotational inertia and rotational kinetic energy (RKE). Rotational inertia (I) is the product of mass (m) and the exponential effect of distance of the mass from the axis of rotation (r^2). Simply, the further the load from the axis of rotation the greater the rotational inertia or resistance to change in motion. Therefore, above elbow loading would have the least rotational inertia and overload the shoulder joint only, and below elbow loading would have greater rotational inertia given the increased distance from the shoulder axis of rotation, overloading both the shoulder and elbow joints (see Figure 23). Finally, a weighted ball with the same relative WR load will have the greatest rotational inertia given the distance from the shoulder and overload the shoulder, elbow and wrist but will become unloaded after ball release unless holds are prescribed. The increased inertia observed as the load moves down the arm will also influence RKE, the product of inertia halved and angular velocity (ω) squared (RKE = ½I x ω^2), and thus increase the muscular work required to accelerate and decelerate the arm (i.e., work – energy relationship). Movement velocity has an exponential effect on RKE which is notable, as light loads moved quickly produce greater kinetic energy which is generated and controlled by the accelerators and decelerators, respectively.

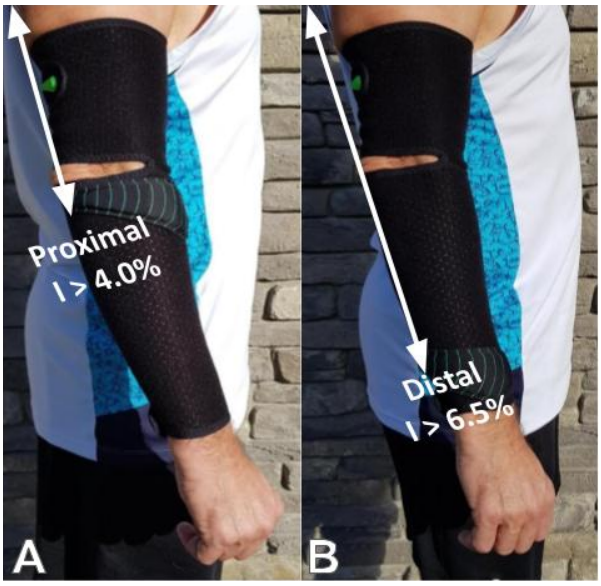

Figure 23. *Increased inertia from moving WR farther away from the shoulder's axis of rotation.*

There are four aspects of loading with WR for consideration when progressing/regressing WR training: mass, placement, orientation and velocity. Work in our own lab has determined that the entire arm could be loaded with up to 600-g, with up to 400-g placed above the elbow and 200-g placed below. On the arm, WR can be placed above or below the elbow, or across the entire arm. As mentioned, placement will have a greater effect on the inertia and RKE of the loads while throwing. For example, when throwing a 7-oz, or 198-g, ball increases rotational inertia ~14% meaning ~14% more effort is needed to accelerate the throwing arm. By comparison, a similar load of 200-g placed more proximally below the elbow will increase inertia ~5%. Therefore, the arm is overcoming less inertia with WR below the elbow compared to a 7-oz ball, but the load remains secured following ball release with WR. The orientation of the waterdrop-shaped weights will also affect the inertia and the forces the arm experiences. For example, the medially arranged weights can promote humeral IR (see Figure 23). Finally, the athlete can regulate the overload by simply progressing or regressing velocity of movement.

8.5.1 Above Elbow Loading

Above elbow WR loading targets the musculature around the shoulder while minimally affecting distal musculature. From work in our lab we were unable to ascertain a clear effect of WR loads

of 100-g to 200-g applied above the elbow on arm speed, throwing velocity or temporal phase mechanics ($p > .05$) (63). Further, when above elbow loading (see Figure 24) was implemented into a 6-week training study, no improvements ($p < .05$) in shoulder rotator strength or throwing velocity were observed overall or compared to a group performing throws without WR. The results of this study are potentially be due to loads being insufficient to provide a stimulus, the WR throwing volume, or the underpowered sample size used ($n = 17$) (66). However, it should be noted that the loads used were intentionally selected to minimally disrupt throwing biomechanics. This was a seminal study, so throwing volume (15 throws per session, two sessions per week) was conservative because training effects were unknown and participant safety was a priority (25, 105). While balancing potential injury risk, moving forward the authors believe that the stimulus needs to be increased in some manner. Given the short distance between the shoulder and the elbow it is difficult to affix more mass or alter WR placement or orientation, therefore other aspects of programming need to be considered by increasing volume (i.e. more throws per session or using WR three times per week).

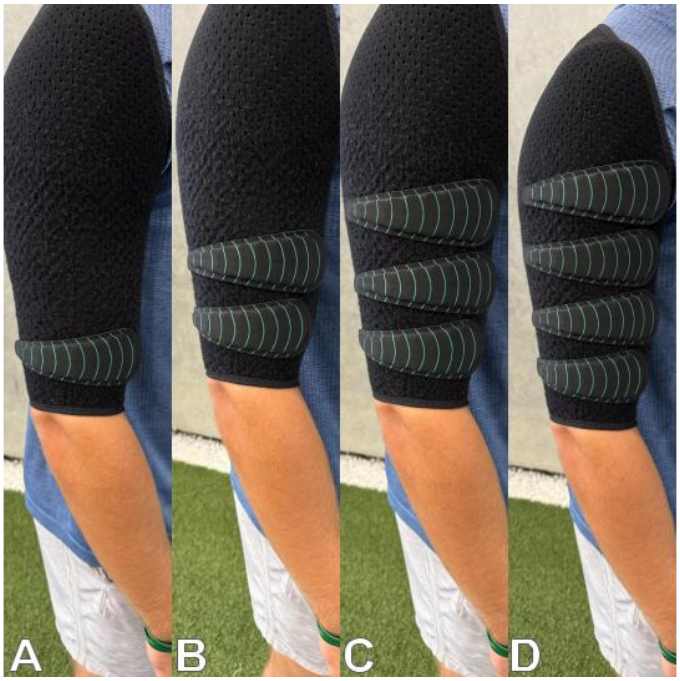

Figure 24. *Above elbow loading using 100-g weights: 100-g (A), 200-g (B), 300-g (C) and 400-g (D).*

8.5.2. Below Elbow Loading

Below elbow WR loading (see Figure 25) targets the musculature across the elbow and the shoulder. Work in our lab has shown the same loading below the elbow to have greater effects compared to above elbow loading, which is expected because the distance to the shoulder axis of rotation is greater. Below elbow loads have resulted in large decreases in arm speed with 150-g and 200-g ($d = 0.82\text{-}1.03$, $p < .05$) and small to moderate decreases in throwing velocity with 100-g, 150-g and 200-g loads (-1.8% to -2.7%, $d = 0.45\text{-}0.67$, $p < .01$) (63). Similar research was conducted with handball athletes using 150-g to 500-g depending on the athletes' body mass (52), the WR resulting in throwing velocity decreases of -2.6% to -2.7%, ($p < .01$) and no changes in throwing accuracy were reported (52). Further, no changes in shoulder, elbow or wrist kinematics were reported apart from increased elbow extension velocity (84.9-89.1%, $p < .05$) when below elbow loads were applied (52). Decreases in elbow extension velocity (-3.0 to -4.9%, $p < .05$) were reported with 6- and 7-oz balls in baseball pitchers (50), therefore supporting the notion that throwing arm WR can overload the deceleration phase of throwing. Future research could expand on WR effects on throwing deceleration with measures of elbow flexion torque and shoulder proximal force. Additionally, arm segment lengths might be considered (notably forearm with below elbow loading) since athletes with longer arms possess greater moments of inertia and more range for proximal and distal load placement.

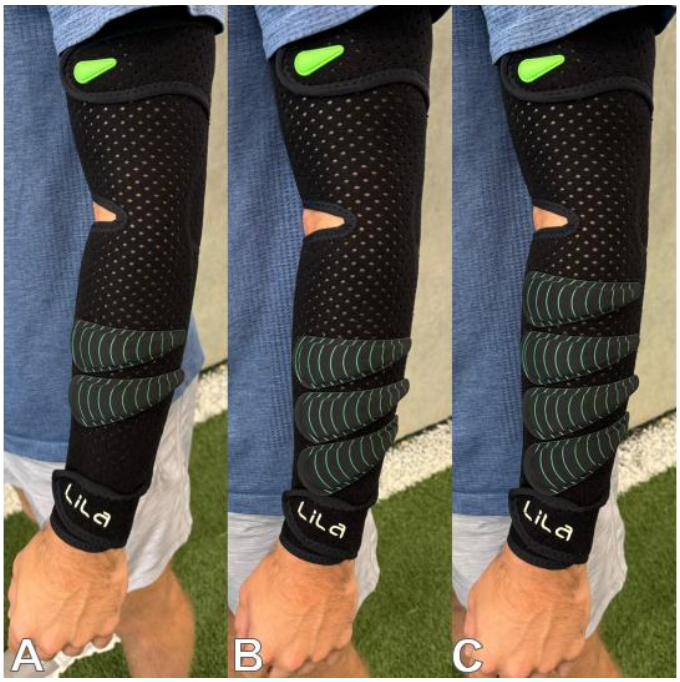

Figure 25. *Below elbow loading using 50-g weights: 100-g (A), 150-g (B) and 200-g (C).*

8.5.3 Wearable Resistance Limitations

Throwing with WR comes with some practical limitations for practitioners to contemplate. Due to high arm speeds while throwing, if WR is not fitted tightly the micro-loads can detach, and/or the compression garment sleeves can slip downwards. The detachment of the micro-loads can be mitigated with a light sleeve worn over the WR arm sleeve. The slipping of the compression garments is difficult to resolve given the shape of the arm musculature. A long sleeve version that wraps around the shoulders connecting both arms is a potential solution but only an upper arm shoulder sling exists at this stage. Placement of the weights needs consideration to avoid rubbing against the body while throwing, placing the loads laterally on the upper arm or on the dorsal forearm was best to avoid this problem. From practical experience and piloting for experiments with the WR product utilised (e.g., see chapters 6 and 7), it was determined that individual 50-g weights were best for below elbow loading, and 50-g or 100-g could be used above elbow. Additionally, the orientation of the weights needed to be applied with the larger end of the weight placed medially above the elbow or medio-inferiorly closer to the wrist–other orientations of the WR were prone to detachment while throwing.

8.5.4 Future Perspectives for Wearable Resistance

While a principle underlying WR is its minimal effect on aspects that could change technique, methods of increasing load and volume could be an interesting avenue to explore. For example, below elbow loading could not only increase the overload provided to the shoulder but feasibly overload the elbow decelerators. Positive results from handball research could be applied to baseball pitchers, and vice versa, however, there are noticeable differences to consider: ball mass, peak ball velocity, shoulder IR velocity, MSER, movement variability, and differences in throwing environment (i.e., controlled vs dynamic) (49, 122). Research investigating the influence of throwing at higher loads, notably on the longitudinal degradation of technique (if any), would be valuable to bolster our understanding of loading application. Training variables of interest would be throwing velocity, shoulder rotator Fmax, shoulder ROM and record shoulder and elbow kinematics and kinetics if appropriate technology is available. Further, understanding the effects of fatigue and how pitchers recover from WR throwing would be insightful for determining where WR best fits in the training of baseball pitchers throughout the calendar year (i.e., off-, pre-, in-season).

Weighted ball training and WR are not mutually exclusive training methods but rather should be used in combination to address athlete needs. Better diagnostics could inform a more granular approach to individualized training prescription. For example, identifying IR or ER needs, or targeting the shoulder joint only (i.e., above elbow loading), targeting the shoulder and elbow joints (i.e., below elbow loading), or the entire arm, can be addressed with WR or weighted balls or a combination of both. Research into how these specific training methods can complement each other is needed, however, the potential is exciting, nonetheless.

8.6 Practical Applications

Constant monitoring of pitchers can become easier to implement as more portable technology is regularly integrated into practice. PFD allows for more testing/monitoring opportunities of pitchers and testing in the supine 90^{o} position to recruit more posterior shoulder musculature

(40) is recommended. Regular shoulder rotator assessment would inform arm health, readiness and performance for baseball pitchers. While ER:IR ratios are beneficial to inform training, particular focus should be placed on the decelerators. It is recommended that high sampling rate PFD be used where possible, to reduce biological and technological variability, and increase the number of variables that can be measured in addition to Fmax (e.g. mean force, total impulse, and RFD). The other variables that could provide valuable information on shoulder force capability and guide exercise prescription to better effect, however, practitioners should be mindful of reliability as some variables such as RFD are prone to unacceptable error (65, 68). Each of these variables will differ in relevance to the stage of rehabilitation journey, or the needs of the athlete or time of season. Pitchers regularly perform shoulder rotator exercises before and after throwing, therefore, a simple isometric test should be feasibly integrated into pre-existing routines. This assessment could give awareness to daily fluctuations in strength and the impact of a throwing session which could guide workload management.

Increasing upper body strength via non-specific training methods for pitchers is crucial to improve the critical attribute of throwing velocity. Coaches should be mindful of unique imbalances observed in throwing athletes such as greater IR strength, increased overall rotator strength, increased shoulder ER ROM and decreased IR ROM in the throwing arm while training these athletes. Therefore, it is recommended to independently load the upper limbs to developing strength. Further, because ER strength is important for arm health, practitioners might consider biasing posterior shoulder exercises (e.g., two for each anterior shoulder exercise). Finally, a mixture of heavy and light loads should be used. Heavy loads will increase force production, and light loads will allow for general strength development, power development and specific musculature of smaller muscles (i.e., rotator cuff) to be targeted.

Specific training with weighted balls can be employed with balls 4- to 6-oz with HS and collegiate level pitchers. Progressions beyond this range could be made albeit with caution and shoulder rotator strength monitoring is recommended for guidance. The effects of WR training for shoulder rotator strength and throwing performance are unclear, and additional research is

needed in this area. Specifically, increased throwing volumes with above elbow loading and training effects with below elbow loading should be investigated. Currently, WR training to improve throwing performance has only utilized high intensity throwing. Loaded throwing during long-toss may be a feasible way to train with moderate to high effort throwing while increasing throwing volume. Progressing WR placement more distal on the throwing arm, below the elbow, will increase the rotational inertia and subsequently muscular work. While there is currently lacking evidence to support such changes in throwing, positive outcomes from other applications signal interest for future research.

Chapter 9: Summary

9.1 Summary

The purpose of this research was to answer the overarching question, “What are the effects of WR training on shoulder strength and throwing performance in baseball pitchers?” This involved understanding whether a strain gauge device could reliably measure shoulder rotator force capability, how force measures were related to performance, and how the placement and magnitude of WR applied to the arm affected throwing performance, acutely and longitudinally.

At the onset of the thesis, a narrative review (Chapter 2) was performed to better understand the current modes of training to improve throwing performance. The reviewed research focusing on baseball athletes, utilised various approaches of resistance training and throwing variably weighted balls, which was categorised as non-specific and specific methods, respectively. The results of these studies provided background information for training that successfully increased throwing velocity in baseball pitchers. Non-specific training with heavy loads (3- to 12-RM) increased throwing velocity in college and professional baseball players however, lighter loads (>12-RM) also proved to be effective with youth and high school baseball athletes. For physically developed baseball athletes, a combination of heavy and light loads could be used to develop strength and power. Specific training methods can be used to enhance throwing velocity in baseball players across multiple levels. Underweight ball (3- to 4.75-oz) training has been used with success across most age ranges, and weighted balls 4- to 6-oz should be a safe option for most pitchers and could be introduced at the HS level while underweight balls can be utilised with youth. Broadly, a variety of non-specific and specific training methods appear beneficial to improve throwing performance. However, targeted training and testing to determine load selection had not been clarified and throwing with WR was unexplored. It was concluded that training and testing could be refined by assessing shoulder rotator Fmax to provide better diagnostic information of the effects of various types of training. One testing suggested solution could be the strain gauge given the portability and ability to capture force with high sampling

rates. It was thought improvements to training prescription may arise from regularly monitoring shoulder rotator strength.

The reliability of shoulder rotator strength assessments with a strain gauge were investigated in two chapters (Chapters 3 and 4). Initially, swimmers were recruited (Chapter 3) to measure the reliability and differences between IR and ER Fmax and RFD across three positions (seated-0°, supine-0° and supine-90°) using a strain gauge, due to limits in accessing populations during the global coronavirus pandemic. A variety of testing positions were selected due to the potential interest for varying sporting applications, and the lack of relative comparison of protocol differences within and across the existing literature. Significant between limb differences were noted in seven out of 12 conditions with greater values (d = 0.12-0.92) observed in the dominant arm and IR force outputs were greater (d = 0.57-2.2, $p < .05$) than ER. Testing positions differed in that IR outputs were greatest in the seated-0° position and ER outputs were greatest in the supine-90° position. Generally acceptable reliability for Fmax were observed [CV = 5.2-8.8%, ICC 95% confidence intervals (CI) = .69-.98], across all positions whereas RFD exhibited questionable typical error scores (CV = 11.5-18.1%, ICC 95% CI = .34-.96).

Next, baseball pitchers were recruited to provide normative Fmax, Tmax, RFD and RTD, and quantify the reliability of shoulder IR and ER kinetics in the supine-90° position (Chapter 4). Baseball pitchers provided the focus of this thesis and the supine-90° position is biomechanically similar as the shoulder is abducted while throwing. In this cohort, IR and ER Fmax/Tmax ranged between 198-218 N and 58-64 Nm respectively (ER:IR = 0.93), and IR and ER RFD/RTD ranged between 537-765 N/s and 157-223 Nm/s respectively (ER:IR = 0.88). For peak values, typical error and ICC estimates were acceptable, however, for RFD/RTD estimated ICCs were acceptable but typical error was unacceptable (CV > 10%). The two reliability studies established: 1) shoulder rotator testing positions should not be used interchangeably; 2) IR force capability is greater than ER in swimmers and pitchers; 3) Fmax has acceptable absolute consistency for ER and IR, acceptable relative consistency for IR and mixed relative consistency with baseball pitcher during

ER; and, 4) RFD only has acceptable relative consistency with the exception of pitchers during ER which has mixed results.

The focus of Chapter 5 was to understand the distinctions between HS and collegiate pitchers, the correlation of shoulder rotator strength with throwing velocity, and the association of strength measures to each other. The main findings were: 1) HS and collegiate pitchers did not differ in the primary variables of interest; 2) IR and ER Fmax seemed positively associated (r^2 = .12-.13, $p < .05$) with throwing velocity, however RFD was not; and 3) finally, large correlations ($r \geq .50$; $p < .001$) were noted between the IR and ER force outputs, and between Fmax and RFD capabilities for both IR and ER. The findings from this chapter should encourage athletes and coaches to assess shoulder rotator strength regularly, to inform injury and fatigue status to performance changes.

Identifying changes in acute temporal and mechanical measures across different combinations of WR loading and placement on the throwing arm in baseball pitchers was important base knowledge for this thesis. In Chapter 6 the acute impacts of WR loading were tested, with the original idea that this information could be used to subsequently direct training implementation in a longitudinal study. The effect of loading on throwing velocity varied by its placement as small to moderate decreases in throwing velocity (-1.8 to -2.7%, $p < .01$) were detected with below elbow loading. Additionally, large decreases in arm speed (-5.1 to -6.5%, $p < .05$) with 150-g and 200-g below elbow loads compared to unloaded conditions were observed. Finally, temporal phase mechanics were not affected by WR across the conditions used in this study. Collectively, Chapters 5 and 6 informed the training study: 1) shoulder rotator Fmax would be interesting to measure alongside throwing velocity in a specific training intervention; and 2) above elbow loading was selected to specifically target the shoulder musculature and minimize joint loading while throwing.

A throwing programme was implemented to determine if WR applied above elbow could improve shoulder rotator Fmax and throwing velocity (Chapter 7). Using a randomised control design, it

was thought that above elbow loading with WR on the throwing arm would stimulate adaptation, increasing shoulder rotator strength and throwing velocity compared to a control group. After the six-week WR intervention the main findings were: 1) no significant changes in throwing performance were observed in the control or the WR groups; 2) no significant changes in shoulder rotator strength were observed over the intervention. However, non-significant within group changes (7.6%) in ER Fmax were noted in the intervention group ($p = .099$); and 3) significant increases in ER ROM were observed over time ($p < .01$) and differences between groups were noted over time ($p < .05$) which were primarily attributed to increases in the control group (+15.8%). It was concluded that the utility of WR remains unclear and further research with adapted training protocols is needed.

The focus of Chapter 8 was to reflect on the learnings from the PhD and synthesize the findings into a review that could be used by practitioners to enhance their understanding, assessment and exercise prescription pertaining to throwing performance for baseball pitchers. In this review, a focus on the shoulder rotators was maintained to discuss training for improved throwing performance and the potential utility of WR, therein. Although specific training methods were the focus of this chapter, non-specific methods were still mentioned as this type of resistance training still deserves consideration in the wider scope and periodised plan for training baseball pitchers. While WR adds another throwing specific means of training, non-specific training for throwing athletes should still be utilised.

9.2 Practical Applications

The findings from this work have practical applications which are grouped into those pertaining to assessment and training.

9.2.1 Assessment

- Assessing shoulder rotator health and injury status is important for many professionals, therefore implementing technology that is affordable, portable and useful is desirable for practitioners.

- Force monitoring assessments can take place in a variety of testing positions in practical settings with high-sampling technology such as the portable strain gauge used in this thesis.
- Greater IR (seated-0°) and ER (supine-90°) force production was observed in different positions, therefore the measures quantified should not be used interchangeably by practitioners or researchers. Testing positions could be selected based upon relevance to the athletes' sport or activities.
- The reliability of Fmax across all positions was acceptable however, RFD protocols need refinement.
- Measures of maximal force detected via strain gauges may have interesting utility, such as:
    - Monitoring shoulder rotator strength between competitions and training sessions.
    - Determining IR and ER force outputs and accompanying ratios to inform return from injury, assist in programme design and provide normative data to guide training.
- Shoulder IR and ER Fmax were associated with throwing velocity, and it seems important to monitor (and train) the associated musculature for the rigors of performance.

9.2.2 Training

- Although shoulder IR and ER strength appear quite strongly related, the magnitude of unexplained variance to throwing, and given their different roles in arm acceleration and deceleration, it is important to specifically target each action and associated musculature for strengthening.
- Baseball pitchers displayed greater IR force outputs compared to ER, however, ER strength seems critical for arm health. Disparate ER:IR ratios could signal the need to emphasize ER strengthening in an individual's training plan. Further understanding regarding the magnitude of disparity in this ratio and the call for action, needs investigation.
- Temporal sequencing seems to remain unchanged with the loads used in the acute study (100-200-g), therefore (while not explicitly explored within the bounds of this study) deleterious impacts on throwing technique are probably unlikely. Accordingly, due to maintained timing while throwing, below elbow loads from 100-g to 200-g appear suitable

for training and promoting greater throwing overload (i.e. based on reductions in arm speed and throwing velocity).

- Throwing with WR over six weeks of training allows for an application of loaded throwing without inducing an increase ER ROM. This may be advantageous when trying to minimize additional anterior forces on the shoulder and elbow, which are associated with ER ROM increases. This may be useful during return to throwing rehabilitation or managing throwing loads between competitions.
- Above elbow loading was selected to minimize joint loading (i.e., excluding elbow and wrist) in tandem with a low volume of throws with athlete safety in mind. Since unclear effects were observed over the course of a 6-week study, two means of progression (with the caveat of monitoring arm health) are suggested: increase the volume of upper arm loading or utilise below elbow loading.

9.3 Limitations

The limitations of this research are outlined here:

- This thesis specifically focused on shoulder rotator strength; however, other shoulder strength measures such as shoulder abduction or adduction strength should be investigated. In a similar fashion, isometric strength assessment was selected because … Other measures (e.g., dynamic measures of strength) might provide diagnostic value.
- Pitchers from the HS and lower-level college ranks participated in this study and proved to be a homogenous group. The relationship between shoulder rotator strength and throwing velocity should be investigated with youth, high-level college and professional pitchers, in which a broader and more diverse group may potentially be more insightful.
- Training outcomes might have been influenced by the specific characteristics of the team involved and might be repeated with other teams.
- Greater ranges of load might have been interesting, however, the movement and speed of the throwing arm restrained loading options. Specifically, WR attachments were restricted to the lateral upper am and dorsal forearm, and orientation was limited to having the largest part of the micro-loads attached medially. Other arrangements resulted in the weights

detaching due to contact with the body or inability to maintain placement due to high arm speeds.

- Although very practical and accessible, two-dimensional video analysis cannot provide granular information that would improve understanding of the alterations to throwing mechanics induced by WR. A motion capture system and force plates could provide valuable data to inform mechanical changes due to WR.
- A larger sample size would have been desirable to clearly understand the training effects of loaded throwing with WR, given the adaptations may have been smaller than expected. Moreover, (specifically for the training study) additional post-testing opportunities may have been beneficial as adaptions from the intervention may not have yet been realised.

9.4 Future Research

The opportunities for future research on assessing shoulder rotator strength and the use of WR as a training method for throwing performance are extensive. Ultimately, research utilising lightweight WR for improving throwing performance is in its infancy and a great deal of research is needed before it can be used confidently to improve throwing performance safely. Some of the opportunities emerging from this research include:

- Traditionally, a mixed approached of non-specific and specific training methods is used by baseball coaches, however there is no scientific comparison of the efficacy of combination training.
- Research is needed on when it may be appropriate to introduce specific strength training methods, specifically heavier weighted baseballs in combination with WR, as adequate strength throughout range of motion may be necessary to mitigate risk of injury.
- Above elbow loading seemed to increase arm speed in some individuals. A more in-depth investigation of proximal loading, focusing on optimising arm speed could prove valuable for athletes and coaches.
- There is a plethora of research opportunities around optimizing the WR dose-response relationship.

    - It may be that higher frequencies (three sessions per week) using the same loading parameters might have elicited increases in throwing velocity.
    - Perhaps longer training durations (eight-week) or higher pitching volumes are needed in well trained pitchers.
- Establishing the dose-response relationship associated with below elbow WR loading (100- to 200-g) warrants investigation. There is greater scope to progress and regress the magnitude of the overload given the distance from the shoulder's axis of rotation to the forearm compared to the upper arm, and the use of proximal to distal forearm loading.
- While pitchers were the focus of this thesis, the implications of WR applied to the throwing arm could be investigated for other overhead throwing athletes such as other baseball position players, American football quarterbacks, javelin and softball athletes.
- Loading other areas of the body beyond the throwing arm, such as the trunk or non-throwing arm, may provide additional WR strategies to enhance throwing performance.

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Appendices

Appendix 1. Ethics approval for acute studies

Auckland University of Technology Ethics Committee (AUTEC)

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

14 October 2022

Matthew Cross
Faculty of Health and Environmental Sciences

Dear Matthew

Re Ethics Application: **19/445 The acute effects of wearable resistance on throwing velocity in baseball players**

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

Your ethics application for studies one and two has been approved for three years until 14 October 2025.

Non-Standard Conditions of Approval

1. Amendment of the Information Sheet:
    a. Update the date of Privacy Act to 2020.
    b. Replace "chosen" to "invited".

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

Standard Conditions of Approval

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

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

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

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

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: trey.job2012@gmail.com; mcahill@athleteth.com; john.cronin@aut.ac.nz; Jonathon Neville

Appendix 2. Ethics approval for training study

Auckland University of Technology Ethics Committee (AUTEC)

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

17 October 2022

Matthew Cross
Faculty of Health and Environmental Sciences

Dear Matthew

Re Ethics Application: **22/304 The training effects of wearable resistance on the throwing velocity, shoulder strength and biomechanics of baseball players.**

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

Your ethics application has been approved for three years until 17 October 2025.

Non-Standard Conditions of Approval

1. Include in the Coach Information Sheet advice about how the coach agrees to participate.

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

Standard Conditions of Approval

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

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

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

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

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: trey.job2012@gmail.com

Appendix 3. Consent to participate in acute studies

Consent to Participation in Research
Participant Consent Form

Title of Project: *RELIABILITY OF A STRAIN GAUGE AS A SHOULDER STRENGTH ASSESSMENT AND THE EFFECTS OF WEARABLE RESISTANCE ON THROWING BIOMECHANICS*

Project Supervisor: **Dr. Matt Cross, PhD**

Researchers: **Mr. Trey Job**

- I have read and understood the information provided about this research project in the Information Sheet dated June 13, 2022;
- I certify that I am in good health and able to participate in maximal isometric shoulder strength;
- I certify that I am willing and able to participate in a throwing velocity assessment;
- I certify that I am willing and able to wear an IMU sensor to measure arm speed, elbow torque and arm slot during the throwing velocity assessment;
- I certify that I am willing and able to participate in an acute wearable resistance analysis;
- I have had an opportunity to ask questions and to have them answered;
- I agree to participate in the research;
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way;
- I understand that in the event of a medical situation the information obtained as part of this research project may be used to assist in my medical care and that my identified legal guardian, next-of-kin or parent will be informed of the situation;
- I understand that if I withdraw from the study then I will be offered the choice between having any data 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 wish to participate for the full three-week duration (or wearable resistance only) Yes O No O
- I understand that video analysis will be used as part of this research Yes O No O
- Do you consent to your coach having a summary of your results? Yes O No O
- A modified PAR-Q form has been completed Yes O No O
- I wish to receive a copy of the report from the research: (tick one): Yes O No O
- I wish to be contacted about participating in a training study utilizing these methods Yes O No O

Participant Signature: .....

Participant Name: .....

Date: .....

Project Supervisor Contact Details:
Dr. Matt Cross, PhD
Sports Performance Research Institute New Zealand
Auckland University of Technology
matthew.cross@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *INSERT HERE*

Appendix 4. Consent to participate in training study

Consent to Participation in Research
Participant Consent Form

Title of Project: *THE TRAINING EFFECTS OF WEARABLE RESISTANCE ON THE THROWING VELOCITY, SHOULDER STRENGTH AND BIOMECHANICS OF BASEBALL PLAYERS*

Project Supervisor: **Dr. Matt Cross, PhD**

Researchers: **Mr. Trey Job**

- I have read and understood the information provided about this research project in the Information Sheet dated September 6, 2022;
- I certify that I am in good health and able to participate in maximal isometric shoulder strength assessments;
- I certify that I am willing and able to participate in a throwing velocity assessment;
- I certify that I am willing and able to wear an IMU sensor to measure arm speed, elbow torque and arm slot during the throwing velocity assessment;
- I certify that I am willing and able to participate in a training study involving throwing with wearable resistance, or otherwise continuing my current training (without substantial alteration) for the duration of the study;
- I have had an opportunity to ask questions and to have them answered;
- I agree to participate in the research;
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, 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 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 understand that in the event of a medical situation the information obtained as part of this research project may be used to assist in my medical care and that my identified legal guardian, next-of-kin or parent will be informed of the situation;
- I consent to the use of video analysis as part of this research Yes O No O
- A modified PAR-Q form has been completed Yes O No O
- I wish to receive a copy of the report from the research: Yes O No O
- Do you consent to your coach having a summary of your results? Yes O No O

Participant Signature: .....

Participant Name: .....

Date: .....

Project Supervisor Contact Details:

Dr. Matt Cross, PhD
Sports Performance Research Institute New Zealand
Auckland University of Technology
matthew.cross@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *INSERT HERE*

Appendix 5. 2022 PAR-Q+ health questionnaire

2022 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

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

GENERAL HEALTH QUESTIONS

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

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

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

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

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

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

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

Delay becoming more active if:

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

01-11-2021

2022 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

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

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

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

2. Do you currently have Cancer of any kind?

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

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

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

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

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

4. Do you currently have High Blood Pressure?

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

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

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

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

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

2022 PAR-Q+

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

_____

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

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2022 PAR-Q+

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

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

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

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

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

PARTICIPANT DECLARATION

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

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

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

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

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

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

Key References
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2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.
3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

01-11-2021

Appendix 6. Chapter 2 Abstract

Throwing velocity is a crucial component to success in baseball athletes, especially at the position of pitcher. Through practice and proper instruction, pitchers can refine their pitching mechanics to maximize efficiency and throwing velocity in tandem with improving injury resistance. Non-specific training such as gym-based resistance training has been used concurrently with baseball skills training to enhance athletic abilities, including throwing velocity. Increases in throwing velocity have been observed while training with lighter (greater than 12 repetition maximum [RM]) and heavier (3–12 RM) loads. Specific training such as variably weighted baseballs has also been utilized to facilitate increases in throwing velocity. Throwing velocity has also been successfully increased using balls overweight and underweight than the standard five-ounce baseball. More clarity is needed regarding necessary strength levels, range of motion, and progressions in ball mass or throwing volume when applying this training mode. Training methods to increase throwing velocity in baseball athletes should include resistance training with a variety of loads and throwing variably weighted baseballs within the athlete's capability.

Appendix 7. Chapter 3 Abstract

Context: Advancements in portable load-cell technology have enabled high-quality assessment of shoulder internal- (IR) and external rotation (ER) peak force (Fmax) and rate of force development (RFD). This study's purpose was to explore the reliability and differences between IR and ER Fmax and RFD in different testing positions using a novel load-cell device. Design: A within-subjects repeated measures design was employed to compare the intersession values and reliability of Fmax and RFD for both shoulder IR and ER across three positions: seated-0°, supine-0° and supine-90°. Methods: National-level swimmers (n=19; age=16.8±1.0 years) completed three testing occasions of each condition (combination of arm, rotation, and test position) separated by seven to 14 days. Results: IR superseded ER in all testing positions. The association between these positions across IR and ER was typically strong for both Fmax and RFD ($r>.85$, $p<.001$), except IR RFD ($r=.56$-$.73$, $p<.05$). For session two to three for Fmax intraclass correlation coefficient (ICC) and coefficient of variation (CV) (ICC=.89-.96, CV=5.2-8.8%) were typically within acceptable ranges, whereas RFD (ICC=.74-.90, CV=11.5-18.1%) often exhibited inflated error. Conclusion: The supine-90° position was the most consistent position across both measures. Load-cell technology can be confidently used to assess shoulder rotation Fmax in three different positions, whereas RFD should be used with caution without protocol refinement.

Appendix 8. Chapter 4 Abstract

Rotator cuff strength assessments are valuable for monitoring throwing athlete injury and performance status. Portable technology enables 'in-field' assessment and therefore increases utility. The purpose of this study was to quantify the reliability of strain gauge (SG) technology for measuring shoulder rotator strength and provide normative strength values for high school and college pitchers. Subjects (n=15) participated in three testing sessions consisting of five maximal isometric shoulder internal rotation (IR) and five external rotation (ER) trials separated by seven days. Variables of interest included peak force (Fmax), peak torque (Tmax), rate of force development (RFD) and rate of torque development (RTD). Session three averaged outputs for IR were Fmax=218.0±27.9 N, RFD=764.5±277.0 N/s, Tmax=63.5±8.3 Nm and RTD=222.6±80.6 N/s, while ER resulted in Fmax=203.0±17.4 N, RFD=675.6±231.1 N/s, Tmax=59.2±5.5 Nm and RTD=197.1±68.6 Nm/s. Coefficient of variation ranged from 4.3-5.8% for peak values, and 16.0-28.5% for rate measures. Intraclass correlation coefficient estimates ranged from .79-.89 for peak values, and .80-.91 for rate measures, with IR typically marginally better than ER. While practitioners need to be mindful of managing error (e.g., via familiarity), peak measures of rotator cuff strength assessed using portable SG are promising for simple field-based monitoring of shoulder health for throwing athletes.

Appendix 9. Chapter 5 Abstract

The purpose of this research was to characterize the difference between high school (HS) and collegiate pitcher's throwing velocity, shoulder internal (IR) and external rotator (ER) maximum strength (Fmax) and rate of force development (RFD) and explore relationships between these measures. Competitive HS and collegiate pitchers (n=26) participated in a single session assessment in which shoulder rotator isometric Fmax and RFD were quantified via a portable strain gauge device and throwing velocity via radar. Paired t-tests, stepwise linear regression models and correlational analyses were used to answer the questions of interest. No significant differences ($p>.05$) in pitching velocity were observed between HS and collegiate pitchers, and all pitchers were pooled into one sample for subsequent analyses. For both IR and ER models, the explained variance of Fmax with throwing velocity was small (R^2=.12 to .13). RFD and arm length did not contribute to the models. Large correlations ($r\geq.50$; $p<.001$) were observed between IR and ER for Fmax and RFD measures, as well as between Fmax and RFD for IR and ER. In terms of throwing velocity, having strong IR and ER Fmax capabilities would seem more important than the ability to express force quickly in this cohort.

Appendix 10. Chapter 6 Abstract

This research examined the acute effects of wearable resistance (WR) placed above and below the elbow of the throwing arm of baseball pitchers on throwing characteristics. Ten high school or collegiate baseball pitchers (19.5 ± 2.4 years) performed a randomized throwing assessment with and without WR (100-g, 150-g and 200-g) secured to the throwing arm above and below the elbow. Participants wore an inertial sensor at the elbow to record arm speed, throwing velocity was measured by radar and temporal aspects (stride phase and pitch phase) measured by video. A repeated measures ANOVA with post-hoc analyses was used to test the influence of load magnitude and placement, with statistical significance set at $p<.05$. On average, loading significantly influenced arm speed and throwing velocity ($\eta p^2=.32$-$.41$, $p<.05$), and the effect of loading varied by placement (i.e., above and below elbow) for the latter ($\eta p^2=.64$, $p<.001$). Above elbow loading had no significant effect on the throwing variables measured. For below elbow, there were large decreases in arm speed for 150-g and 200-g loads compared to the unloaded trials (-5.13 to -6.52%, $d=0.82$-1.03, $p<.05$) and small to moderate decreases in throwing velocity with all loads (-1.8 to -2.7%, $d=0.45$-0.67, $p<.01$). Overall, WR did not significantly alter phase timing. Our results may indicate the effects of WR differ by placement and may have utility in providing graduated overload to throwing musculature, without clearly influencing timing while throwing.

Appendix 11. Chapter 7 Abstract

The objective of this study was to explore the effects of training using wearable resistance (WR) applied above the elbow of the throwing arm on throwing velocity, arm speed, shoulder internal (IR) and external rotation (ER) strength and range of motion (ROM) in baseball pitchers. College baseball pitchers (n=17) participated in a matched volume six-week throwing program, twice per week, unloaded (quasi-control) and with WR added to the upper arm (intervention). Arm speed was measured with an inertia sensor, throwing velocity via radar gun, shoulder rotator peak force (Fmax) with a strain gauge and ROM by a goniometer, pre and post training. Linear mixed effects models were used to examine the main effects of group, time (pre and post) and their interaction, with a random effect intercepts for participants. A significant effect from pre- to post-testing was observed in ER ROM (ηp^2=.456, p=.005) and tended to increase more in the control group (ηp^2=.261, p=.047). Otherwise, there were no other statistically significant differences observed. This was the first WR training study with pitchers and the lack of clear improvement using above arm WR loading was notable. Future researchers should explore the efficacy of lower arm loading and/or potentially increase training volume, as a means of stimulating adaptation.

Appendix 12. Chapter 8 Abstract

Throwing is an athletic skill that transmits tremendous forces throughout the body and increasing throwing velocity is commonly pursued by baseball pitchers. The forces generated from throwing can increase risk of injury as throwing velocity increases, therefore developing upper-body strength to contribute to and withstand the demands of throwing is a necessity for long-term development and arm health. The ability to routinely measure shoulder rotator strength could unduly prove valuable for athletes and coaches to maximize performance. This article reviews the biomechanics of the throwing motion, shoulder strength assessments relevant for baseball pitchers and training methods to enhance throwing velocity. New insights with novel technology and training techniques and where they fit in to proven, existing strategies are discussed. In terms of assessment integrating portable fixed dynamometry into shoulder strength testing is thoroughly discussed. Additionally, a loaded throwing technique where wearable resistance is applied above or below the elbow of the throwing arm is analysed.