# Eccentric Motorised Cycling as a Re-Warm-Up Strategy for Trained Male Baseball Pitchers

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School of Sport, Exercise and Health

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# Ethical Approval

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference was 25/181, with approval granted originally on the 10th of July 2025.

# Abstract

In most sports, intermissions during the games are common. These breaks in the game can reduce muscle temperature and neuromuscular readiness, subsequently affecting performance. Re-warm-up (RWU) strategies are important to mitigate these declines for a variety of sports. Although the physiological aspects of RWU have been investigated in the literature, the connection between perceived readiness and physiological readiness remains unexplored. While traditional RWU methods have shown benefits for performance, there is a distinct gap in the literature for the application of eccentric motorised cycling (EMC) as a RWU modality in overhead throwing athletes. This thesis aimed to (1) review the literature on RWU strategies and eccentric exercise in relation to ballistic performance, and (2) investigate the effects of EMC as an RWU intervention on throwing velocity, shoulder range of motion (ROM), and perceived readiness in baseball pitchers following a simulated intermission. Based on the gap identified in the literature review, a randomised repeated-measures design was employed, with 13 club-level male baseball players performing a throwing test, a shoulder ROM test before and after completing three RWU protocols: passive, plyoball, and EMC. A Likert scale for perceived readiness (Perceived Readiness Scale (PRS)) was also included to understand the participants' subjective readiness prior to the second bout of throwing. The results showed no significant main effect for condition on throwing velocity ($p = .150$, $\eta p^2 = .158$); however, EMC demonstrated the smallest decline in throwing velocity (−1.20%; mean change: −2.98 ± 3.61 km/h) and was significantly greater than the plyoball condition by 1.83 km/h ($p = .045$, $d = 0.54$). The lack of significance between EMC and control may be explained by the lack of sample size or wider variation from pre-post intervention in the control group. No significant differences were observed in shoulder ROM across conditions. A moderate negative correlation between external rotation (ER) change and throwing velocity was identified in the control condition ($r = -.525$). Additionally, PRS differed significantly between conditions ($p = .023$), with EMC producing the highest median scores (Mdn = 4.0) compared to control (Mdn = 3.0) and plyoball (Mdn = 3.0). A moderate positive trend between perceived readiness and velocity change was observed in the plyoball condition ($\rho = .482$).

EMC shows potential as an effective RWU strategy to attenuate declines in throwing velocity and enhance perceived readiness following short intermissions. Although findings were limited by a small sample size and environmental variability, results provide some support for incorporating EMC into RWU protocols for overhead athletes. Further research with larger samples and controlled conditions is required to confirm these findings and explore mechanisms further.

# Chapter 1: Introduction and Rationale

## 1.1 Background

In sports, there is often an intermission in activity, whether that be during a half-time or in between innings. During these intermissions, athletes will remain seated or inactive, leading to reductions in body and muscle temperature and a decline in neuromuscular readiness (McGowan et al., 2015; Mohr et al., 2004). Understanding the physiological responses to passive rest and the impact on subsequent performance is therefore essential, particularly in sports requiring repeated high-intensity efforts following brief inactivity.

In baseball specifically, pitchers experience frequent passive rest periods between innings while their team is batting, which varies depending on offensive inning length and game pace. Evidence indicates that such intermissions can negatively influence pitching performance, with reductions observed in throwing velocity following rest (Baseball Savant, 2025). Research in baseball pitching biomechanics demonstrates that ball velocity and joint kinetics are strongly related to movement mechanics and neuromuscular readiness, with higher levels of velocity typically associated with optimised mechanics (Fortenbaugh et al., 2009). Observational Major League Baseball data indicate that fastball velocity is reduced immediately following between-inning breaks. Analysis of the publicly available 2024 MLB statcast data (Baseball Savant, 2025) conducted for the purpose of this thesis revealed that, excluding the first inning, the first fastball thrown at the start of a new inning is, on average, approximately 0.86 mph slower than following fastballs within the same inning. Although the magnitude of this difference isn't significant, this decrement is practically meaningful, as even a one mph decrease in fastball velocity has been associated with an approximately .040 increase in opponent batting average, highlighting the sensitivity of performance outcomes to small changes in velocity. The temporary reduction in velocity could suggest a short-term reduction in neuromuscular readiness, potentially caused by lower muscle temperature from incomplete RWU, along with cumulative fatigue from the extended repetitive motion of throwing (Whiteside et al., 2016). Additionally, experimental research has linked alterations in pitching mechanics due to fatigue with reductions in ball velocity over the course of games (Fortenbaugh et al., 2009). Biomechanical analysis also identifies the deceleration phase as particularly vulnerable to changes under fatigue (Escamilla & Andrews, 2009).

The shoulder musculature of an overhead throwing athlete is put under extreme forces during the act of throwing. Within this throwing motion, it is said that the deceleration phase is where athletes are most prone to injury when the athlete is either fatigued or has not appropriately prepared for the sheer forces involved with this action (Diffendaffer et al., 2023; Escamilla & Andrews, 2009; Mayes et al., 2022). Eccentric muscle actions play an important role in this process as they allow the musculature of the posterior shoulder to decelerate the arm and stabilise the joint following ball release (Diffendaffer et al., 2023). In overhead throwing athletes such as in baseball, these properties are essential not only for performance outcomes such as velocity, but also for maintaining joint integrity and reducing injury risk (Mayes et al., 2022).

Eccentric muscular movements are often characterised as a yielding function, where the muscle lengthens as the load overcomes the muscle. Unlike concentric actions, where muscle shortening results in joint movements, or isometric contractions where joint angles are consistent, eccentric contractions occur when the external load drives joint motion despite ongoing muscle activation. A defining characteristic of eccentric muscle actions is their capacity to generate greater force compared to concentric actions at the same level of neural drive (Enoka, 1996). This property of eccentric movements allows eccentric contractions to decelerate limbs, absorb impact forces, and control high-velocity movements (Hody et al., 2019; Lindstedt et al., 2001). While chronic adaptations of eccentric exercise have been studied in-depth, the acute impacts of eccentric exercise on performance have not been investigated thoroughly. In sporting contexts, eccentric exercise has been proposed to be used as a priming exercise in order to prepare or enhance athletes' subsequent performance (Beato et al. 2019). Importantly, very few studies have examined the application of eccentric exercise in sport RWU scenarios, with limited studies showing inconsistent results (Beato et al., 2019; McGowan et al., 2015).

Eccentric motorised cycling (EMC), represents a novel modality that may address this gap, as it promotes high-force eccentric loading with relatively low metabolic and cardiorespiratory strain (Elmer, Marshall, et al., 2013). This has been demonstrated in arm and lower-limb eccentric cycling models, where acute bouts elicit unique physiological responses compared to concentric cycling conditions (Beaven et al., 2014; Elmer, Danvind, et al., 2013; Elmer, Marshall, et al., 2013).

During sports activity, increases in muscle temperature may enhance ROM in joints by reducing musculotendinous stiffness (Stewart & Sleivert, 1998). However, these effects are temporary and passive rest may attenuate them. Temperature-related mechanisms are likely to play a role in changes of ROM during intermissions (Bishop, 2003). Altered ROM may have effects not only on performance, but also on injury risk for an overhead thrower (Bullock et al., 2018). Reductions in shoulder ROM following inactivity may therefore compromise throwing velocity and increase mechanical stress on the shoulder complex.

In addition to physical readiness, psychological readiness plays an important role in athletic performance. Perceived readiness reflects an athlete's subjective sense of preparedness, including psychological factors such as confidence, focus, and physical activation (Weinberg & Gould, 2023). Warm-up (WU) activities have been shown to positively influence perceived readiness, and changes in perceived readiness may occur independently of objective performance outcomes (McGowan et al., 2015). To capture this psychophysiological component, the experimental study in this thesis includes a simple Likert-scale perceived readiness measure to assess how RWU influences athletes' subjective readiness to throw following an intermission.

Eccentric cycling is a relatively novel training modality that enables high mechanical loading at a comparatively low metabolic cost (Barreto, 2021; Beaven et al., 2014). While eccentric exercise has been widely studied in the context of rehabilitation and chronic training adaptations, limited research has examined its application as a WU or RWU strategy. Emerging evidence suggests that eccentric exercise may enhance neuromuscular activation and muscle tendon stiffness regulation without inducing excessive fatigue, making it a potentially effective RWU modality (Beaven et al., 2014; Blazevich & Babault, 2019).

## 1.2 Significance and Purpose

The work in this thesis may help fill gaps in the literature around RWU protocols for baseball athletes and the utility of eccentric cycling as a RWU strategy for overhead throwing athletes. Therefore, the aim of this thesis is to review the available literature pertaining to RWU protocols for overhead athletes and determine whether eccentric cycling can preserve throwing velocity, shoulder ROM, and perceived readiness in baseball players following an intermission. The results of this thesis may help inform RWU coaching practices for intermittent overhead throwing sports, with a particular emphasis on baseball players.

## 1.3 Thesis Aims

The specific aims of the thesis were to:

1) Evaluate the current literature on RWU practices and the effects of eccentric exercises on ballistic activities.
2) To investigate the effects of eccentric motorised cycling as a RWU after an intermission on throwing velocity, shoulder internal and external rotation ROM, and to understand the impact of the perception of readiness on baseball-related performance.

## 1.4 Thesis Structure

This thesis consists of four chapters. The first chapter will be the introduction of the thesis. Chapter 2 of the thesis is a review of the current literature on the RWU effect on ballistic performance. Chapter 3 of this thesis is an experimental cross-sectional study on the effects of eccentric cycling as part of a RWU protocol for the velocity of a baseball throw among experienced baseball pitchers. Chapter 4 is the final chapter, and it includes a summary and conclusion of the thesis's overall findings. It also includes practical recommendations, limitations of the present study and potential areas for future directions. References are presented at the end of the final chapter as required by AUT for thesis submission. The structure of the thesis is shown as a schematic in Figure 1.

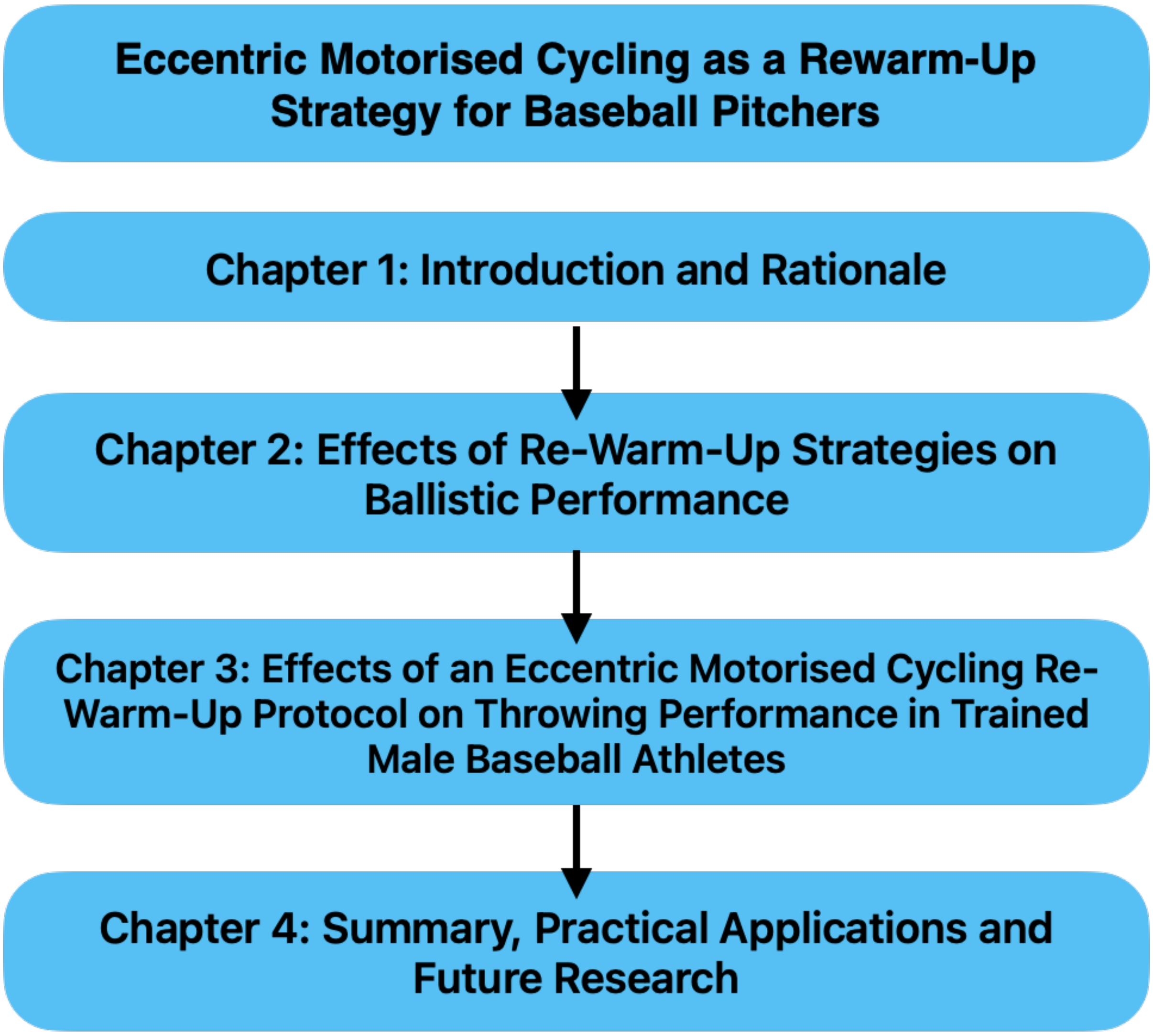

**Figure** *1***.** A schematic of the flow of chapters in this thesis

# Chapter 2: Effects of Re-Warm-Up Strategies on Ballistic Performance

## 2.0 Prelude

The previous chapter introduced the negative effect that periods of passive rest have on athletic performance and the potential for RWU strategies to account for it. While individual study findings demonstrate potential benefits of RWU strategies, the evidence remains scarce and highly context-dependent across different sports and protocols. As there is no comprehensive synthesis of the physiological, mechanical, and psychological effects of RWU in a performance context, the following chapter looks to synthesise the available literature on RWU interventions and eccentric exercise. The physiological, mechanical, and psychological effects will be examined to identify key mechanisms underpinning performance maintenance following periods of passive rest.

## 2.1 Abstract

Passive rest periods during training and competition can negatively affect athletic performance by reducing muscle temperature, neuromuscular activation, ROM, and psychological readiness. Re-warm-up (RWU) strategies have therefore gained increasing attention as practical interventions to mitigate these performance decrements. The aim of this literature review was to synthesise the current evidence examining the physiological, mechanical, and psychological effects of RWU interventions implemented following passive rest. The available literature (n = 12 studies) indicates that RWU strategies of 1 to 8 minutes are effective at maintaining or enhancing performance outcomes such as sprinting, jumping, change-of-direction ability, and sports-specific performance metrics. Passive rest typically results in performance decrements of approximately −3% to −7.6%, whereas RWU interventions can reduce these losses to near-zero or produce small-to-moderate improvements ~0–6% in most sport-specific outcomes, with some measures such as acceleration showing larger increases. The enhancements are primarily attributed to the preservation of muscle temperature, sustained neuromuscular activation, and improved movement efficiency. In addition to physical performance, RWU interventions have been shown to positively influence perceived readiness, a subjective indicator of psychological readiness encompassing confidence, focus, and arousal. Perceived readiness is also responsive to brief, time-efficient RWU protocols and may change independently of

objective performance measures, underscoring the importance of assessing both subjective and objective outcomes. Collectively, the evidence supports the integration of context-specific RWU strategies as effective tools for maintaining performance and psychophysiological readiness during periods of passive rest, particularly in sports requiring explosive and multidirectional movements

## 2.2 Introduction

Most field and court-based sports are intermittent in nature, characterised by repeated high-intensity activity alongside periods of passive rest, such as quarters, half-times, and inning breaks. These structured intermissions are typically a part of competition and training environments. However, during these periods of inactivity, athletes may experience reductions in muscle temperature, neuromuscular activation and overall physiological readiness (Mohr et al., 2004; Russell et al., 2018; Sargeant, 1987). Thus, even relatively short passive rest periods can impact subsequent performance output, especially in activities requiring explosive force production and high neuromuscular coordination (Koutsouridis et al., 2024; Yanaoka et al., 2018).

Warm-ups have consistently been shown to improve subsequent sports performance across a range of sporting contexts (Bishop, 2003). However, passive intermissions and breaks during competition have been shown to decrease performance through reductions in physiological temperature, particularly muscle temperature, which is strongly associated with impairments in contraction velocity, power output, and neuromuscular efficiency (McGowan et al., 2015; Sargeant, 1987). In addition to muscular cooling, declines in core temperature may reduce metabolic readiness and cardiovascular activation, while reductions in central nervous system activation may influence alertness, reaction speed and perceptual readiness (Bishop, 2003; McGowan et al., 2015). Collectively, these temperature-related changes contribute to the observed reductions in high-intensity performance output following passive rest (McGowan et al., 2015; Racinais & Oksa, 2010; Sargeant, 1987).

Essential components to returning to play after an intermission are actively engaging muscles under controlled strain, thereby inducing greater muscle activation and increasing core temperature

(Koutsouridis et al., 2024). Exploring re-warm-up (RWU) strategies, particularly during these passive intervals, is essential to mitigate performance losses and injury risks, ensuring athletes maintain optimal readiness throughout the competition (Silva et al., 2018; Yanaoka et al., 2021). Various modalities, such as moderate-intensity dynamic movements, short sprints, and aerobic activity, have been successfully employed for preserving sprint speed, ROM, change of direction ability (COD), and power-based actions in team sport athletes (Flórez-Gil et al., 2025; Koutsouridis et al., 2024; Matsentides et al., 2023). While direct evidence examining psychological readiness following RWU protocols is limited, WU activities have been shown to positively influence psychological readiness, provided that the duration and intensity of the protocol are managed to avoid neuromuscular fatigue (McGowan et al., 2015; Romaratezabala et al., 2018).

The traditional WU has long been a part of mainstream preparation for physical activity and is considered vital for performance and injury prevention perspectives (Bishop, 2003; Hammami et al., 2017; McCrary et al., 2015; McGowan et al., 2015; Shellock & Prentice, 1985). Although warming-up has been a part of regular physical activity for some time, RWU strategies have not received as much attention, even though in sports, there is often an extended intermission within play. RWU has been used to re-elevate heart rate and muscle temperature, enzymatic activity, adenosine triphosphate turnover, and neural transmission of athletes to mitigate performance loss in athletes after an intermission (Mohr et al., 2004; Russell et al., 2018; Sargeant, 1987). Several authors have argued that RWU is essential for decreasing the effect of passive rest between performances during intermissions (Mohr et al., 2004; Russell et al., 2018; Sargeant, 1987). These arguments have been supported in the literature through assessing athletes between passive rest and RWU interventions across sports codes. RWU interventions have been shown to maintain or improve performance outcomes through their effects on physiological and neuromuscular responses, including the preservation of body temperature, enhanced power output (e.g., sprinting, jumping, and change-of-direction ability), ROM, and improved psychological readiness (Flórez-Gil et al., 2025; Koutsouridis et al., 2024; Mohr et al., 2004; Yanaoka et al., 2018, 2021). With an understanding of the importance of RWU, the identification of RWU strategies that most efficiently mitigate the performance loss after an intermission may assist practitioners in identifying those strategies and implementing them across sporting codes. Therefore, the purpose of this review is to understand the effects of RWU protocols on athletic performance and psychological readiness in ballistic sport athletes (e.g., throwing, sprinting, jumping and striking sports).

## 2.3 Literature Review Search Methods

An electronic-based search for peer-reviewed articles was conducted using the search engines Pubmed, Taylor & Francis Online, Google Scholar, Ovid, Scopus, ResearchGate and SPORTDiscus. Search terms included combinations of keywords: 're-warm up', 'running', 'performance', 'change of direction', range of motion', 'body temperature', psychological readiness', 'warm-up', 'perceived readiness', 'intermission', and 'half-time'. Further articles were obtained from electronic-related article searches and by manually cross-referencing studies. Articles focused solely on rehabilitation or published in languages other than English were excluded.

## 2.4 Effects of RWU Strategies on Temperature

Current literature examining passive rest during sport (n = 12) indicates that reductions in muscle and core temperature during intermissions are central to the physiological decline observed, contributing to impairments in power output, ROM, and overall neuromuscular coordination (McGowan et al., 2015; Mohr et al., 2004; Racinais & Oksa, 2010; Sargeant, 1987). Reductions in muscle and core temperature are widely proposed as the primary mechanism underpinning performance decrements observed following half-time or intermission periods. As a result, strategies to maintain or restore body temperature during these breaks have become an area of increasing interest in sports science and applied practice (McGowan et al., 2015; Mohr et al., 2004). Given the crucial role of muscle and core temperature to mediate these performance decrements, the following section will examine the relationship between temperature and explosive performance, as well as the effectiveness of RWU strategies to mitigate temperature-related declines.

From a physiological standpoint, elevated muscle temperature enhances enzymatic activity, ATP turnover, and neural transmission, which are particularly important for type II muscle fibres involved in high-force, high-velocity movements (Sargeant, 1987). Increases in muscle temperature are also associated with faster muscle fibre conduction velocity, contributing to improved rate of force development and coordination during explosive actions (Racinais & Oksa, 2010; Sargeant, 1987). The decline in performance observed following passive intermissions has therefore been largely attributed to reductions in core and muscle temperature, as the benefits induced by the initial WU dissipate during inactivity (McGowan et al., 2015; Racinais & Oksa, 2010; Sargeant, 1987). Increases in muscle temperature have also been linked to greater anaerobic glycolytic flux and muscle glycogenolysis, facilitating higher short-term power output (Edwards et al., 1972; Fink et al., 1975). However, elevated temperatures may accelerate fatigue over prolonged durations due to metabolic by-product accumulation. Moderate temperature maintenance during RWU periods appears beneficial for preserving explosive performance capacity (Edholm et al., 2015; Racinais & Oksa, 2010).

Several studies have identified the negative impact of passive rest in between performances and showed evidence that it can significantly reduce muscle temperature, in turn decreasing performance. Mohr et al. (2004), observed that muscle temperature dropped by approximately 2.1º C during a 15-minute passive intermission during a half-time period in a professional football game. The study associated this thermal decline with a 3.9% decrease in sprint performance during halftime. Another study echoed these findings, where they found that a passive intermission in activity led to a 1.5º C reduction in core temperature and a 2.0º C reduction in thigh muscle temperature, resulting in diminished repeated sprint performance and slower muscle contraction speeds post-intermission (Russell et al., 2018). This was also supported by Sargeant, (1987), who found that even a 1º C reduction in muscle temperature led to a significant drop in leg extension force and short-term power output. Taken together, these studies show the effect of passive rest during an intermission in activity and the effect on muscle and core temperatures.

To counteract the effects of passive rest, a range of RWU strategies has been proposed to maintain or restore body temperature and neuromuscular readiness during intermissions. These include short-duration, high-intensity exercise bouts (Yanaoka et al., 2018, 2021), moderate-intensity activity (Koutsouridis et al., 2024), and passive heat maintenance strategies such as heated garments or insulated clothing (Russell et al., 2018). Across the literature, passive rest has been associated with performance declines typically ranging from approximately 2-5% in sprint and explosive tasks (Koutsouridis et al., 2024; Mohr et al., 2004; Russell et al., 2018; Sargeant, 1987). In contrast, the implementation of RWU interventions generally limits these reductions to ~0-2% of baseline performance and, in some cases, provides a small improvement in performance. Active RWU protocols incorporating dynamic movement or short exercise bouts have commonly demonstrated improvements in repeated-sprint ability, jump performance, and agility performance of approximately 1-6% compared with passive rest conditions (Edholm et al., 2015; Koutsouridis et al., 2024; Mohr et al., 2004; Russell et al., 2018; Yanaoka et al., 2021). Passive heat-maintenance strategies have likewise been shown to minimise temperature loss and partially preserve sprint and power output, typically observed after passive rest (~2–3%). Although typically with slightly smaller performance benefit than active strategies (Russell et al., 2018).

The effectiveness of these interventions depends on their capacity to sustain core and muscle temperature, enhance muscle activation, and preserve neuromuscular readiness for subsequent competition (Koutsouridis et al., 2024; Russell et al., 2018; Yanaoka et al., 2018, 2021). However, despite this growing evidence across sprint, jump and agility tasks, relatively few studies have examined RWU effectiveness in ballistic upper-limb sporting actions such as throwing.

**Table** *1*. Summary of RWU studies strategies on Temperature

| Author(s) & Year | Study Design | Participants | Intervention (RWU Strategy) | Key Findings (Temperature-Specific) | Implications for RWU |
|---|---|---|---|---|---|
| Sargeant, 1987 | Laboratory study | Healthy adults | Control: room temp passive rest, Experimental: leg immersion in water baths at 44, 18, 12 °C | Cooling the muscles led to reductions in maximal force and power output, with greater reductions at lower muscle temperatures and higher contraction velocities. In this study, decreases in muscle temperature of 4–7°C resulted in reductions in peak power of 12–21% | Establishes direct temperature, force relationship, supporting rationale for RWU. |
| Mohr et al., 2004 | Experimental field study | Professional soccer players | Passive rest (15 min), RWU: running and other exercises at a moderate intensity (average heart rate 135 beats min  or 70% of the peak heart rate reached during the game) | Muscle temperature declined by ~2 °C during passive rest during half-time*, but in a RWU condition they did not find a significant decrease in muscle temperature prior to the second half. This was accompanied by significant reductions  in sprint and high-intensity running performance (2.47±0.3%)* which was shown to be attenuated by RWU. Temperature change was correlated with performance decline $. | Shows how muscle temperature loss during inactive periods impairs sprint performance, but this can be attenuated by a active RWU at moderate intensity. |
| Abade et al., 2017 | Acute crossover experimental study | Football players (team sport athletes) | Control (passive rest), Plyometrics, COD, Eccentric exercise | No RWU reduced sprint and CMJ performance*. Plyometric and COD RWU attenuated this decline and improved or maintained performance*, likely via PAP and increased neural activation. Eccentric RWU reduced sprint and CMJ performance*, likely due to acute fatigue and muscle damage. Arm swing jump was minimally affected. Ballistic and COD-based RWU were most effective. | Demonstrates that passive rest reduces sprint and CMJ performance, while active RWU (plyometrics and COD) attenuates these losses via PAP and improves explosive output. Eccentric RWU may impair performance due to acute fatigue, with overall RWU effectiveness dependent |

| Author(s) & Year | Study Design | Participants | Intervention (RWU Strategy) | Key Findings (Temperature-Specific) | Implications for RWU |
|---|---|---|---|---|---|
| | | | | | on intensity and force-orientation specificity. |
| Russell et al., 2018 | Experimental study | Competitive soccer athletes | Control: No heat maintenance, Passive: Survival jacket, Active: 7 min RWU, Combined: Survival jacket + RWU | Core temperature decline was significantly attenuated by heat maintenance^, as was PPO^, and repeated sprint ability (best, mean, and total) was significantly faster in both the active, passive and combined interventions compared to control^. Both peak power output and core temperature declined over half-time in the control condition, with all interventions attenuating these reductions, particularly in the Combined trial. | Demonstrates the impact of passive rest, with, without heat maintenance strategies, active RWU strategies and the combination on core temperature, PPO and sprint ability. |
| Yanaoka et al., 2021 | Controlled trial | Trained male athletes | Control: Passive rest, RWU: High-intensity cycling: 90% VO$_2$max, 1 min | RWU attenuated the decline in gastrointestinal (core) temperature ^ and preserved repeated sprint performance compared with passive rest ($p = 0.002$–$0.012$ for block comparisons, $\Delta$ sprint $p = 0.001$, $d = 1.89$ *). Maintenance of internal temperature was associated with sustained sprint output. No significant differences were observed for MVC. | Demonstrates high-intensity RWU's ability to restore or maintain internal temperature. |
| Koutsouridis et al., 2024 | Randomized crossover | Youth soccer players | Control: Passive rest, RWU: low-intensity cycling at 40% VO$_2$max for 3 min | RWU attenuated declines in physiological and performance measures after passive rest. CON showed large reductions in HR^, body temperature^, CMJ^, and MAT*, whereas RWU40 showed less percentage difference to pre-test and minimized the losses. RWU40 also resulted in slightly higher RPE compared to CON*. | Shows RWU minimizes temperature loss and preserves neuromuscular performance. |

N.B. Statistical values are reported where explicitly provided in the original manuscripts; symbols denote significance levels and associations relevant to the present review. * = $p < .05$, \$ = correlation coefficient ($r \approx 0.60$), ^ = $p < .001$, % = $p = 0.005$, ES = effect size (Cohen's d or Hedges' g, as reported), PPO = Peak Power Output, CMJ = countermovement jump (lower-limb explosive power), DJ = drop jump (reactive lower-limb power, stretch-shortening cycle), COD = change-of-direction speed, RWU = re-warm-up, $VO_2max$ = maximal oxygen uptake, HRmax = maximal heart rate, Values reported as mean ± SD unless otherwise noted

## 2.5 Effects of RWU Strategies on Explosive Performance

In the context of this thesis, explosive performance refers to short-duration, high-intensity movements requiring rapid force production, including sprint performance, COD and counter-movement jump (CMJ) performance. The literature consistently demonstrates that passive half-time periods result in significant impairments in explosive tasks, with sprint performance declining by approximately 2.5% CMJ performance decreasing by ~5%, and COD performance reducing by ~3% (Fashioni et al., 2020; Koutsouridis et al., 2024; Mohr et al., 2004). This represents a performance decrement of ~2-6%, across explosive performance measures such as sprinting, jumping and COD. But studies have demonstrated that RWU protocols across a variety of intensities and modalities can preserve or enhance explosive performance, likely through the maintenance of neuromuscular activation, and mechanisms related to stretch-shortening cycle efficiency, and muscle-tendon stiffness (Edholm et al., 2015; Flórez-Gil et al., 2025; Koutsouridis et al., 2024; Ltifi et al., 2023; Matsentides et al., 2023b; Russell et al., 2018; Yanaoka et al., 2018; Zois et al., 2013). Across nine studies involving approximately 150–200 athletes, the RWU literature focused on ballistic performance, is predominantly based on male participants from team and field-based sports, particularly soccer, with additional evidence drawn from youth, collegiate, and trained athletic populations. Overall, the evidence base is heavily skewed toward explosive and intermittent lower body sport contexts, with limited representation of upper body contexts. More recently, interest has shifted toward alternative RWU modalities that provide sufficient mechanical and neuromuscular stimulus at a relatively low metabolic cost. Within this context, eccentric cycling has shown that it enables high mechanical force production and muscle tension while limiting cardiovascular and metabolic strain (Beaven et al., 2014; Blazevich & Babault, 2019).

### 2.5.1 Jump Performance

Four studies investigating RWU effect on CMJ demonstrate that RWU interventions effectively preserve or enhance vertical jump performance following passive rest. This reflects the maintenance of vertical force production and rate of force development, which underpin a range of explosive sporting tasks such as sprinting, COD and sport-specific metrics. Low to moderate-intensity RWU protocols appear effective in attenuating reductions in short-term power output. Koutsouridis et al. (2024) demonstrated that a 3-minute cycling RWU limited the decline in CMJ height to -1.72%, compared with a -5.1% reduction following passive rest. This may suggest that even low-intensity, short-duration activity can meaningfully protect stretch-shortening cycle performance. Higher-intensity strength-based RWUs, designed to elicit post-activation potentiation (PAP) or post-activation performance enhancement (PAPE), can produce substantial improvements in explosive output. Zois et al. (2013) demonstrated that a 5RM leg-press RWU improved the flight-time to contraction-time ratio by ~9–10% and increased relative maximal rate of force development by 16–29%, which may reflect enhanced explosive force production. Plyometric RWU protocols have also demonstrated effects on jump performance. Flórez-Gil et al. (2025) and Abade et al. (2017) reported improvements following a plyometric RWU, demonstrating that CMJ reductions were smaller compared with the control condition. Specifically, Flórez-Gil et al., found plyometric RWU maintained CMJ and DJ performance post-test (ES = 0.08–0.11, $p > 0.2$), whereas the control condition showed significant declines (ES = −0.56 to −0.68, $p < 0.001$ *). Abade et al., also found similar findings. These findings indicate that jump-based RWU strategies are more effective at preserving lower-limb explosive performance than passive rest.

### 2.5.2 Sprint Performance

Sprint performance also appears highly responsive to RWU interventions. Five studies from the search analysed the effects of RWU on sprinting or repeated sprint performance. Moderate-intensity cycling RWU have been shown to improve short-distance sprint performance without inducing excessive fatigue. Koutsouridis et al. (2024) observed that moderate-intensity cycling RWU resulted in a 3.9% improvement in 20m sprint performance ($p<0.05$) without increasing fatigue. This may suggest that moderate-intensity activity strikes a favourable balance between physiological activation and minimal metabolic cost. Yanaoka et al. (2018) demonstrated that a 3-minute low-intensity cycling RWU showed enhancement of electromyographic activity and improved repeated-sprint performance, with a large effect reported for mean sprint work (power output multiplied by the duration of the sprint (5 seconds)) (partial $\eta^2 = 0.384$). Neuromuscular activity was also enhanced (partial $\eta^2 = 0.336$), indicating that even brief RWU can meaningfully restore neuromuscular function and repeated sprint capacity after an intermission.

Zois et al. (2013) also echoed the positive effects of RWU on repeated-sprint performance, showing increases in peak velocity (+4%), mean velocity (+3%), and acceleration (+18%) after a 5RM leg-press RWU compared to passive rest. These findings may reflect enhanced neuromuscular readiness and force production during successive high-intensity efforts. These findings highlight the capacity of heavier loading in enhancing neural drive and increasing power output, although such strategies may not be suitable for all athletes or competitive contexts due to fatigue considerations.

### 2.5.3 COD Performance

Change of Direction (COD) ability is critical for multidirectional sports like basketball, soccer, rugby, and field hockey (Sheppard & Young, 2006). COD actions require rapid deceleration, efficient braking and explosive acceleration in a new direction, capacities that depend on neuromuscular readiness, eccentric strength, muscle temperature, and joint mobility (Onodera, 2025; Sheppard & Young, 2006). Because COD actions are short, powerful, and highly reactive, they are sensitive to decreases in temperature and muscle activation that occur during passive breaks in competition (Sheppard & Young, 2006b). Given the established effects of muscle temperature and stiffness on force production, explained in Section 2.4, maintaining COD performance following rest is strongly dependent on effective RWU strategies.

There are minimal studies analysing in depth about COD and RWU (n = 2), but they suggest that RWU interventions are effective for preserving or enhancing COD performance after passive rest. Koutsouridis et al. (2024) reported that completing a 3-minute low-intensity aerobic cycling RWU at 40% VO2max limited performance decline on the Modified Agility T-Test to only 0.48% compared with a 3.13% decline observed during passive rest. Dynamic RWU strategies also appear beneficial. found that dynamic stretching preserved agility performance following rest, which may be related to improvements in ROM and tissue compliance that help maintain movement quality. Plyometric RWU and COD-based RWU strategies have been associated with small to moderate, but meaningful improvements in multidirectional performance. Matsentides et al. (2023) observed a 6.4% increase in

COD speed after plyometric RWU protocol (Hedges' g ≈ 0.18–0.46). This suggests that short bouts of explosive work may enhance neuromuscular function and improve multidirectional performance. Similarly, Ltifi et al. (2023) reported maintained agility scores following dynamic WU, reinforcing the value of mobility and activation components during intermission periods. Combined, these findings reinforce the inclusion of stretch-shortening cycle activities within RWU, where the rapid coupling of eccentric and concentric muscle actions may enhance neuromuscular readiness and facilitate improvements in COD performance.

Collectively, the evidence suggests that COD performance is highly responsive to RWU strategies. Because COD tasks rely on coordinated contributions from temperature, neural readiness, stiffness regulation, and joint mobility, athletes are more susceptible to performance declines during breaks than in linear sprinting. RWU interventions appear effective in preventing these deficits, supporting the rapid braking and acceleration abilities required for optimal COD performance.

### 2.5.4 Gaps in Current Literature

Despite the growing evidence supporting the effectiveness of RWU strategies for preserving lower-limb explosive performance, several limitations remain within the current literature. Most RWU research has focused on lower-body outcomes such as sprinting, jumping, and COD ability where there is relatively consistent evidence that short-duration, low to moderate intensity RWU protocols can attenuate performance decrements following passive rest. Although the underlying mechanisms driving these improvements, especially those related to stretch shortening cycle function and neuromuscular readiness, are still mostly inferred rather than directly measured across studies. There is a notable lack of research examining RWU effects in upper-body or ballistic sporting actions such as throwing, striking or overhead sports. These movements involve distinct neuromuscular demands, including rapid upper limb force production, high angular velocities and complex kinetic chain sequencing, which may respond differently to RWU strategies compared to lower limb tasks. Therefore, it remains unclear whether findings from lower-limb dominant studies can be directly applied to overhead athletes. This gap is particularly relevant given the prevalence of passive intermissions in throwing-based sports, where athletes must re-attain optimal performance following periods of inactivity.

**Table** *2*. Re-Warm-Up Effects on Power

| Author(s) & Year | Study Design | Participants | Intervention (RWU Strategy) | Key Findings | Implications for RWU |
|---|---|---|---|---|---|
| Zois et al., 2013 | Crossover experimental design | Male athletes | High-intensity 5RM leg press RWU | The flight-time to contraction-time ratio increased by 9–10% (ES ≈ 0.5–0.7, p < .05). Relative maximal rate of force development increased by 16–29% (ES ≈ 0.6–0.7, p < .05). Repeated sprint peak velocity increased by 4%, mean velocity increased by 3%, and acceleration increased by 18% compared to passive rest. | High-intensity RWU can acutely enhance explosive power, supporting its use before performance. |
| Edholm et al., 2015 | Soccer performance trial | Elite youth soccer players | Moderate jogging (~70% HRmax) | Sprint performance decreased by approximately 3% after the first half in both conditions. Following half-time, the control condition showed a further 2.6% decline (1.98 ± 0.06 s), whereas performance in the RWU condition remained stable (1.94 ± 0.05 s). Countermovement jump performance decreased by 7.6% in the control condition compared to a smaller reduction of 3.1% in the RWU condition. | Explosive RWU enhances sport-specific power and agility tasks. |
| Yanaoka et al., 2018 | Controlled laboratory trial | Male sprinters | Control: passive rest, RWU: Low, moderate-intensity cycling RWU | RWU enhanced repeated sprint performance and EMG activation vs control *. Moderate RWU preserved muscle temperature. | Brief aerobic RWU restores neuromuscular readiness and supports high-intensity repeat efforts |
| Fashioni et al., 2020 | Within-subjects repeated-measures design | 10 male soccer players | 15-min half-time period: CON = passive rest; RWU = 12-min passive rest + 3-min practical RWU (dynamic | RWU improved performance vs control: 20 m sprint (+1.2%, d = 0.24), CMJ (+3.6%, d = 0.25), SJ (+1.0%, d = 0.06). Effects were small, greatest in CMJ and sprint acceleration. | RWU provides small but consistent performance benefits over passive rest, particularly for sprint acceleration and CMJ performance, |

| Author(s) & Year | Study Design | Participants | Intervention (RWU Strategy) | Key Findings | Implications for RWU |
|---|---|---|---|---|---|
| | | | movements/sprints within a soccer-specific context) | | supporting its use as a performance maintenance strategy rather than a large ergogenic aid. |
| Matsentides et al., 2023 | Randomized controlled trial | Adolescent athletes | Plyometric RWU | COD improved 6.4% vs control (g ≈ 0.18–0.46 *). Ball velocity increased 4.7 ± 3.8% (g = 0.459; p = 0.014 *). No CMJ change (p > .05). | Indicates plyometric RWU enhances explosive movement skills relevant to sport |
| Koutsouridis et al., 2024 | Randomized crossover | Male team-sport athletes | Passive rest; low-intensity cycling (~40% $VO_2$max); moderate-intensity cycling (~70% HRmax) | CMJ decline attenuated (−1.72% RWU vs −5.1% passive rest *). Sprint-derived power and agility decline limited (0.48% RWU vs 3.13% passive rest *). Moderate RWU showed larger effects (ES ≈ 0.72 *) vs low RWU (ES ≈ 0.42 *). | Moderate RWU best preserves power; low RWU provides smaller benefits. |
| Flórez-Gil et al., 2025 | Randomized crossover | Youth soccer players | Plyometric RWU (jumps, bounds) vs control | CMJ & DJ maintained post-test (ES = 0.08–0.11, p > 0.2). Control declined (ES = −0.56 to −0.68, p < 0.001 *). COD maintained vs control (p > 0.05). | Shows plyometric RWU can restore neuromuscular activation and maintain jump performance |

N.B. Statistical values are reported where explicitly provided in the original manuscripts; symbols show significance levels and associations relevant to the present review. * = p < .05, $ = correlation coefficient (r ≈ 0.60), ^ = p < .001, % = p = 0.005, ES = effect size (Cohen's d or Hedges' g, as reported), CMJ = countermovement jump (lower-limb explosive power), DJ = drop jump (reactive lower-limb power, stretch-shortening cycle), COD = change-of-direction speed, RWU = re-warm-up, $VO_2$max = maximal oxygen uptake, HRmax = maximal heart rate, Values reported as mean ± SD unless otherwise noted.

Koutsouridis et al., 2024: Low (~40% $VO_2max$, ~50% HRmax) and moderate (~70% $VO_2max$, ~75% HRmax) intensity. Yanaoka et al., 2018: Low (~30% $VO_2max$) and moderate-intensity (~60% $VO_2max$)

## 2.6 Effects of WU on ROM

ROM plays a critical role in athletic performance, particularly in movements requiring joint mobility, elastic energy utilisation, and large movement amplitudes such as sprinting, jumping, throwing, and change of direction. Optimal ROM enhances movement efficiency by reducing stiffness, improving stride length, and allowing athletes to achieve biomechanically advantageous positions (Stewart & Sleivert, 1998). Active WU routines have been shown to produce an acute increase in joint ROM, potentially through increases in muscle and body temperature that reduce passive musculotendinous stiffness and increase stretch tolerance (Busch et al., 2021). Stewart & Sleivert (1998) demonstrated that a 15-minute active aerobic WU significantly increased hip extension and ankle dorsiflexion ROM ($p<.05$) compared with no WU , while also elevating heart rate and body temperature. Similarly, O'Sullivan et al. (2009), found that passive knee extension ROM increased significantly following an active WU ($p<.001$), with additional gains observed after static stretching ($p=.04$), whereas dynamic stretching yielded smaller effects. Busch et al. (2021) compared the effects of dynamic stretching and tubing exercises on the acute ROM of the shoulder in collegiate baseball athletes with glenohumeral internal rotation deficit (GIRD). This study reported significant increases in IR, ER and total ROM for up to 60 minutes after the intervention ($p<.001$), but not significant between condition effects were found. These studies indicate that active movement can acutely enhance functional joint mobility. Extending this concept to RWU contexts, limited evidence has directly examined whether active movement following passive rest can preserve joint function and performance.

### 2.6.1 Gaps in Current Literature

These WU mechanisms provide a logical basis for understanding RWU strategies, because RWU also elevates muscle temperature, increases blood flow, and stimulates neuromuscular activation following passive rest; it should theoretically preserve or even enhance ROM in a similar way to pre-exercise WU. However, despite its relevance for maintaining functional mobility in sports, there is currently limited research directly investigating the effects of RWU on joint ROM, representing a notable gap in the literature and highlighting the need for studies that explicitly measure ROM responses following RWU protocols. Integrating direct ROM assessments into future RWU research would clarify whether

RWU can mitigate rest-induced declines in functional flexibility and contribute to sustained performance in athletes.

## 2.7 Effects of Warm-Up and Re-Warm-Up on Perceived Readiness.

Perceived readiness refers to an athlete's subjective measure of physical preparedness to compete and perform in their chosen environment (Weinberg & Gould, 2023). The literature generally supports the notion that WU has a positive effect on perceived readiness to perform in sports, but in the RWU context, it has yet to be researched in-depth, despite its influence on movement execution and neuromuscular engagement (Bishop, 2003; Ochoa et al., 2024). While no studies examining the effects of RWU interventions on perceived readiness to perform were identified, studies on standard WU interventions provide some insight. Yanci et al. (2019) studied the effects of different WU durations on "readiness to play" in team sport athletes. The study reported significant improvements in self-reported readiness scores following all WU durations, suggesting that psychological preparedness can be achieved with minimal time investment. Additional studies examining the psychological effects of RWU strategies are limited, but suggest that active movement following passive rest may help maintain athletes' perceived readiness to perform. Romaratezabala et al. (2018) reported that handball players maintained perceived readiness scores following both shorter (17 minutes) and longer (34 minutes) WU protocols, indicating that psychological preparedness may be preserved even when WU duration varies. However, improvements in readiness did not always coincide with improved physical performance, highlighting the importance of assessing subjective and objective outcomes together (McGowan et al., 2015).

Beyond physiological preparation, WU may also influence psychological readiness by increasing athletes' emotional arousal to prepare for subsequent performance (Bishop, 2003). Qualitative research with elite wrestlers demonstrated that athletes perceive pre-competition WU as both performance-enhancing and psychologically preparatory. In some cases, athletes described feeling lethargic or unfocused prior to warming up, but WU helped them feel more energised, focused, and mentally engaged before competition (Gencer, 2021). Although this research was conducted in a pre-competition WU context rather than specifically examining RWU strategies, the findings suggest that active preparation periods may play a similar role in restoring psychological readiness following passive rest periods. As RWU protocols are typically implemented after periods of inactivity during competition, they may help re-activate motivational and attentional processes that contribute to perceived readiness to perform.

The relationship between WU intensity and perceived readiness has also been explored using progressive protocols. Tillaar et al. (2025) examined perceived readiness during a structured sprint WU consisting of eight 50m runs with progressively increasing intensity. Readiness increased significantly with each increment in effort and showed strong positive correlations with percentage of maximal effort (r = .72-.80). Readiness also demonstrated moderate to good test-retest reliability (ICC≈ 0.71), supporting its use as a repeatable subjective metric. WU induced hormonal responses may influence perceived readiness, but Cook et al. (2024) did not measure this association directly. The parallel between observed hormonal changes and psychological states described in the broader literature (Cook & Crewther, 2012; Crewther et al., 2011) provides a theoretical basis for this hypothesis.

### 2.7.1 Physiological Mechanisms Linking Psychological Readiness to Performance

Physiological biomarkers may correspond with subjective readiness, although the evidence is still emerging. Recent work Cook et al. (2024) showed changes in salivary testosterone, cortisol and testosterone-to-cortisol ratio following a land-based WU prior to a surfing session, with hormone levels generally higher after active WU compared with control conditions. While this study did not specifically test statistical associations between these hormonal changes and self-reported readiness, the observed hormone responses align with a broader literature linking testosterone and cortisol dynamics with psychological states such as arousal and competitive readiness in sports contexts (Cook & Crewther, 2012; Crewther et al., 2011). It remains speculative whether WU induced hormonal responses directly influence perceived readiness, as Cook et al. (2024) did not measure this association. The parallel between observed hormonal changes and psychological states described in the broader literature (Cook & Crewther, 2012; Crewther et al., 2011) provides a theoretical basis for this hypothesis, but direct evidence is currently lacking.

### 2.7.2 Practical Implications and Gaps in the Literature

When taken together, the literature reflects that perceived readiness is highly responsive to WU interventions, even when protocols are brief or time-efficient (McGowan et al., 2015; Yanci et al., 2019). Improvements in readiness can occur independently of physical performance changes, highlighting the importance of assessing both subjective and objective outcomes (Flórez-Gil et al., 2025; Romaratezabala et al., 2018).  For applied practitioners, perceived readiness offers a rapid, low-cost method of monitoring athlete preparedness during training and competition (Zois et al., 2013).

Evidence indicates that structured WU activities of varying durations (8-25 minutes) can significantly improve perceived readiness and subjective preparedness for performance (Yanci et al., 2019). WU that progressively increases intensity have also been shown to elevate perceived readiness and exertion while demonstrating good reliability of readiness measurements (van den Tillaar et al., 2025). Similarly, active RWU strategies combined with health maintenance may improve hormonal responses and performance scores compared with passive rest (Cook et al., 2024). These findings suggest that RWU routines should incorporate progressive, sport-specific movements that elevate heart rate and reinforce athlete confidence prior to performance. Monitoring perceived readiness through simple Likert-scale ratings may also provide practitioners with a practical tool for assessing athlete preparedness and adjusting RWU strategies accordingly.

## 2.8 Conclusion

The current literature demonstrates that RWU interventions play an important role in preserving and/or enhancing aspects of athletic performance following passive rest periods or intermissions (McGowan et al., 2015; Mohr et al., 2004). Physiologically, RWU strategies help maintain core and muscle temperature, sustain neuromuscular activation, and optimise enzymatic and metabolic function (Abade et al., 2017). These facets of physiological changes collectively support explosive movements, sprinting, and COD performance. Evidence also shows that RWU interventions can preserve or enhance ROM, prevent declines in joint mobility, and maintain tendon and muscle stiffness necessary for efficient power production (Flórez-Gil et al., 2025; McGowan et al., 2015).

RWU does not solely impact physical outcomes, with emerging evidence suggesting that psychological factors such as perceived readiness may also be influenced by traditional WU (McGowan et al., 2015; Yanci et al., 2019). Although direct RWU specific evidence in this area remains limited, mechanisms linked to WU could be utilized in the RWU context also, but this needs to be further studied (Flórez-Gil et al., 2025; Romaratezabala et al., 2018). Studies show that brief time-efficient interventions are effective and may further support confidence, focus, and neuromuscular engagement during subsequent performance.

### 2.8.1 Practical Implications

A variety of RWU strategies have been used, including low-intensity cycling, high-intensity resistance, plyometric exercises, and sport-specific dynamic activities (Flórez-Gil et al., 2025; Koutsouridis et al., 2024; Matsentides et al., 2023b; Zois et al., 2013). Although different approaches have been explored, all approaches aim to maintain muscle and core temperature, neuromuscular activation, and mechanical readiness, thus minimising performance declines after a passive rest. When maintaining muscle and core temperature, evidence suggests that moderate-intensity aerobic activity (≈60–70% HRmax) for approximately 3-7 minutes can effectively mitigate declines in muscle temperature and subsequent performance decrements (Mohr et al., 2004; Russell et al., 2018). Short high-intensity RWU (e.g., ~90% $VO_2$max for ~1 minute) may also be effective when time is limited. This is because they can rapidly elevate internal temperature and preserve performance (Yanaoka et al., 2021). When movement is restricted, passive heat maintenance strategies, such as insulated garments, may help minimise reductions in core temperature and power output (Russell et al., 2018).

In order to preserve explosive performance, RWU should incorporate dynamic activity combined with brief high-intensity or explosive contractions. Cycling at ~40–70% $VO_2$max for 2–5 minutes can mitigate reductions in power output, while high-intensity resistance and plyometric exercises enhance neuromuscular activation through PAPE mechanisms (Blazevich & Babault, 2019; Koutsouridis et al., 2024; Zois et al., 2013). Plyometric drills, including jumps and bounds, can be effective for maintaining sprint, agility, and COD performance (Flórez-Gil et al., 2025). These can be implemented using 1–3 sets of 3–6 near-maximal repetitions with adequate recovery to limit fatigue.

Maintaining ROM is also critical, with dynamic mobility exercises preferred over prolonged static stretching (Ltifi et al., 2023). Although this information is from a WU context, the mechanisms should closely mimic RWU, although this needs to be further explored. Movement-based activities performed through functional ROM support flexibility while preserving neuromuscular performance. Practically, 2–5 minutes of dynamic mobility combined with light aerobic activity can mitigate ROM reductions during intermissions.

Finally, subjective perceived readiness offers a practical, low-cost method of monitoring athlete preparedness. As a self-reported measure of physical readiness, it may provide insight into underlying neuromuscular and physiological states, supporting the individualisation and optimisation of RWU strategies in applied settings (Romaratezabala et al., 2018; Yanci et al., 2019).

As a whole, these findings indicate that RWU is an effective and practical strategy for minimising performance decreases caused by passive rest, while simultaneously supporting psychophysiological readiness (McGowan et al., 2015). The effectiveness of RWU is context-dependent, with optimal outcomes likely achieved when protocols are aligned with the specific physiological and neuromuscular demands of the sport, including targeted activation of relevant muscle groups. Integrating sport-specific RWU protocols that reflect these demands may therefore enhance both objective performance and subjective readiness, while also reducing injury risk and improving consistency (McGowan et al., 2015; Yanci et al., 2019). This evidence provides a clear rationale for the inclusion of RWU strategies in training and competition settings, and further supports the relevance of combining both physical and psychological metrics, such as PRS.

Despite growing support for RWU strategies, much of the current evidence is short-term, sport-specific, and predominantly conducted in male team-sport athletes, which may limit generalisability across competitive levels and movement demands.

# Chapter 3: Effects of an Eccentric Motorised Cycling Re-Warm-Up Protocol on Throwing Performance in Trained Male Baseball Athletes

## 3.0 Prelude

It is clear that while RWU strategies have been widely investigated in lower-body or whole-body contexts, the application to upper-body tasks such as overhead throwing remains underexplored. As observed in Chapter 2, the existing literature shows key physiological and psychological mechanisms where RWU may influence performance. However, the magnitude to which these mechanisms translate to throwing tasks, such as velocity, is not well established. Additionally, the effects of RWU on ROM and psychological factors, such as perceived readiness, are not well established. This gap is particularly relevant in sports such as baseball, where athletes regularly experience intermissions and must re-attain optimal performance levels in a time-constrained environment. Accordingly, the following study looks to expand the current RWU knowledge into an upper-body context by examining the effectiveness of EMC as a novel RWU application. By comparing EMC with a plyoball intervention and a passive control condition, this study aims to provide a further understanding of both the physiological and psychological responses to throwing performance following intermissions.

## 3.1 Abstract

RWU strategies are used to mitigate decreases in performance following intermissions in sport, although the effectiveness of upper-body RWU methods for overhead throwing remains unclear. This study investigated whether EMC enhances post-intermission throwing performance compared to plyoball and a passive control condition. Shoulder ROM and perceived readiness (PRS) was also investigated to understand physiological and psychological factors involved in performance following RWU. Thirteen participants completed three randomised conditions of control, plyoball (weighted balls) and EMC (eccentric motorised cycling for the upper extremities). Following a standardised intermission, shoulder ROM and PRS were measured, after which participants performed five maximal intent throws. The velocity of each throw (km/h), shoulder ROM and PRS were recorded as dependent variables. A repeated-measures ANOVA showed no significant main effect of condition on throwing velocity ($p = .150$, $\eta p^2 = .158$); however, EMC demonstrated the smallest velocity decline ($-1.20\%$, $d = 0.39$) and differed significantly from the plyoball condition (mean difference = 1.83

km/h, p = .045, d = 0.54). No significant differences in shoulder ROM were observed. A moderate negative trend between ER and velocity was found in the control condition (r = −.525). Perceived readiness differed significantly across conditions ($\chi^2(2) = 7.581$, p = .023), with EMC producing the highest median scores (Mdn = 4.0), and a moderate positive trend between PRS and velocity change was observed in the plyoball condition ($\rho = .482$). EMC shows potential as an effective RWU strategy to maintain velocity and enhance perceived readiness after over passive rest following brief intermissions. Further research with larger sample sizes is, however, required to answer this question.

## 3.2 Introduction

Baseball is a high-intensity intermittent sport characterised by periods of explosive movements occurring with extended durations of passive rest. Within this structure, games are organised such that each team alternates between offensive and defensive roles within an inning. Consequently, pitchers, with very few exceptions, experience prolonged periods of passive rest while their team is on offence (*Warmup Pitches | Glossary*, n.d.). These intermittent stoppages are further reinforced by standardised commercial breaks and pitching transitions between half-innings (Smith, 2019). During these intervals, pitchers are generally limited to passive recovery, with minimal opportunity to engage in preparatory activities, potentially contributing to fluctuations in performance upon returning to play.

The extent of the exercises may be limited to resistance bands, plyo balls or light throwing and a few pitches on the mound to maintain or restore optimal throwing readiness before returning to the game if an extended inning occurs (*Warmup Pitches | Glossary*, n.d). Analysis conducted for this thesis on recent MLB-wide data suggests that the velocity of the first fastball (four-seam, two seam, or cutter) of a new inning is lower on average than fastballs thrown later within the same inning across all starting pitchers in the Major League Baseball (2024 season; first innings excluded) (Baseball Savant, 2025). Specifically, the first fastball thrown after a break between innings is approximately 0.86 mph slower on average than subsequent fastballs thrown by a starting pitcher within that inning (Baseball Savant, 2025). This suggests that starting pitchers show a short-term reduction in immediate post-break velocity. This likely reflects a short-term decline in neuromuscular readiness or incomplete

RWU. Although this difference is small in magnitude, it is practically meaningful, as even a 1 mph reduction in fastball velocity has been associated with approximately a 0.040 increase in opponent batting average, highlighting the performance sensitivity to small velocity decrements (Baseball Savant, 2025).

Warm-ups have consistently been found to improve subsequent performance; however, passive intermission and breaks during competition have been shown to decrease performance by lowering body temperature (Koutsouridis et al., 2024; Mohr et al., 2004; Yanaoka et al., 2018). An essential component to returning to play after an intermission is actively engaging muscles under controlled strain to induce greater muscle activation, increase core temperature, and optimise blood flow. This contributes to enhanced muscle function after an intermission (Koutsouridis et al., 2024; Russell et al., 2018). Exploring RWU strategies, particularly during these passive intervals, is essential to mitigate performance losses and injury risks, ensuring athletes maintain optimal readiness throughout the competition.

Plyoballs have been used in overhead throwing athletes as a sport-specific training tool to enhance throwing performance through either overload or underload conditions, depending on whether the ball is heavier or lighter than a regulation baseball. This has been shown to enhance throwing velocity, with studies reporting improvements ranging approximately 3-11% (Escamilla et al., 2000). However, these adaptations are not consistent across all studies, with studies suggesting that although muscle activation patterns may be altered, these changes do not always translate to immediate improvements in maximal throwing performance (O'Connell et al., 2022; Shin & Choi, 2018).

Eccentric muscle actions showcase a unique contraction mode characterised by the active lengthening of the muscle that is under load. This enables the production of high forces with relatively low metabolic and cardiovascular demand compared to concentric and isometric contractions (Abbott et al., 1952; Bigland-Ritchie & Woods, 1976). This high force, low energy cost relationship is underpinned by mechanical factors such as increased force per cross-bridge and contributions from passive elastic elements such as titin (Herzog, 2014). Neuromuscular features are also accounted for, including altered motor unit recruitment and enhanced synchronisation (Enoka, 1996). Eccentric contractions are also critical for controlling and decelerating high-velocity movements, making them highly relevant to dynamic sporting tasks such as throwing (Frost, 2016). In an acute context such as a RWU, these properties are especially advantageous. Eccentric exercise has been proposed to provide a neuromuscular stimulus that enhances motor unit activation, stiffness regulation, and readiness for force production (Herzog, 2014). Eccentric exercise might achieve these things without imposing undue metabolic fatigue or cardiovascular strain, therefore making it well-suited to situations where athletes must re-activate musculature following short periods of inactivity. When athletes are appropriately exposed to eccentric low-volume eccentric loading, it may serve as an efficient priming strategy, aligning with post-activation performance enhancement mechanisms while minimising the risk of fatigue-related performance decrements.

Overhead throwing athletes may be able to utilise EMC as a RWU intervention. Unlike traditional eccentric exercises or free-weight resistance training, which often require external loading, setup time, and higher levels of coordination, EMC enables a controlled whole-limb eccentric loading through a motor-driven system (Elmer, Danvind, et al., 2013). EMC also allows workload and cadence to be externally prescribed, reducing technical and coordination demands on the athlete (Elmer, Marshall, et al., 2013). This may be advantageous in time-constrained environments, where athletes require efficient preparatory strategies with minimal coordination demands (Bishop, 2003; McGowan et al., 2015). According to Bishop (2003), the intensity of a WU should not negatively impact the subsequent performance, and he defines this intensity level as approximately 60% of VO2 max. Eccentric contractions generate greater force than concentric contractions, while energy consumption is lower, therefore making them suitable for keeping the physiological intensity low and neuromuscular activity high for the athlete who is re-warming up (Hody et al., 2019; Lindstedt et al., 2001). Supporting this, $VO_2$ during EMC has been found to be significantly lower than during concentric arm cycling at the same workload, with very large reductions at 40%, 60%, and 80% peak power output (ES = 3.62 to 4.16)(Beaven et al., 2014). EMC is useful for exercising the elbow, trunk, and shoulder musculature while minimising the strain on the metabolic and cardiorespiratory systems and perceived exertion. Collectively, this makes it a viable option to be used as a RWU tool for pitchers during intermissions between defensive innings.

Shoulder ROM is an important consideration in overhead throwing performance, together with neuromuscular and temperature-related factors (Aso & Kagaya, 2023; Paul et al., 2025). Acute changes in ROM can occur after both WU and throwing, influencing joint stiffness and movement efficiency (Case et al., 2015). Shoulder external and internal rotation (IR) are essential for optimal force production and energy transfer during the throwing motion, although studies have shown that ROM may influence the mechanical constraints of the throwing motion, but may not be the primary determinant of performance outcomes (Cross et al., 2023; Hurd & Kaufman, 2012). However, excessive or insufficient ROM may disrupt this balance, potentially impacting performance or increasing injury risk (Myers et al., 2022). Thus, examining changes in ROM alongside throwing velocity may provide further insights into the mechanisms underpinning performance changes following RWU.

To complement the objective performance measures, psychological responses to the RWU interventions were also considered. The inclusion of both subjective and objective measures provides a more comprehensive assessment of athlete preparedness, capturing not only physiological performance outcomes but also the athlete's internal perception of readiness. Perceived readiness reflects an athlete's confidence, emotional response, and perceived capability to perform sport-specific tasks following training or injury-related interventions (Saw et al., 2016). It is most commonly assessed using validated instruments such as the ACL-return to Sport after Injury (ACL-RSI) scale (Webster et al., 2008). Although these measures are primarily used within return-to-sport decision-making contexts, psychological state has been shown to influence motor performance and movement execution, with factors such as attention, self-regulation, and confidence (Ardern et al., 2013; Lochbaum et al., 2023). Emerging evidence indicates that although subjective readiness measures may not directly correlate with physical performance indicators, their sensitivity to changes in loads supports their inclusion alongside objective neuromuscular (Saw et al., 2016). This integrated approach allows for a more holistic evaluation of EMC, capturing both physiological and psychological responses to RWU interventions in overhead throwing.

Warm-up strategies are known to enhance neuromuscular performance, especially in explosive movements, through mechanisms such as increased muscle temperature and activation (Bishop, 2003; McGowan et al., 2015). However, subjective measures of readiness do not consistently correlate with physiological performance indicators; however, they demonstrate greater sensitivity to changes in training load and may provide insight into athlete state (Saw et al., 2016). This approach allows for a more holistic evaluation of the efficacy of EMC by integrating both subjective PRS and objective throwing performance following intermissions.

The ability to RWU effectively to mitigate this loss of velocity from passive rest throughout a pitching outing is crucial to success (Baseball Savant, 2025). Despite the growing interest in RWU strategies, there remains a dearth of empirical evidence informing scientists and practitioners on the effectiveness of EMC as a RWU intervention (Elmer et al., 2013). Thus, this study aims to explore the effects of RWU strategies on baseball throwing velocity, shoulder ROM and perceived readiness to throw.

## 3.2 Methods

### 3.2.1 Study Design

This study used a within-subject repeated measures crossover experimental design aimed to investigate the effects of EMC on throwing velocity, ROM and subjective readiness to throw to understand the efficacy of this protocol as a RWU in trained individuals. A random cross-over design was utilised, where the participants performed an EMC intervention, a weighted ball intervention, or passive rest (control). After each protocol, the participants retested their shoulder external rotation ER: IR ROM, and were asked to rate their readiness to throw (1-5), then 5 WU throws were completed, followed by 5 maximum intent recorded throws (km/h). The dependent variables, including max throwing velocity (km/h), difference from maximum velocity (km/h), shoulder IR: ER (degrees), and PRS (1-5), were examined. The protocols consisted of a 1-minute upper-body RWU session for the EMC condition, and five submaximal throws with a weighted ball (plyoball; a small, typically under- or overweight training ball used to enhance arm speed, strength, and neuromuscular activation) for the plyoball condition, with both interventions designed to activate the upper body.

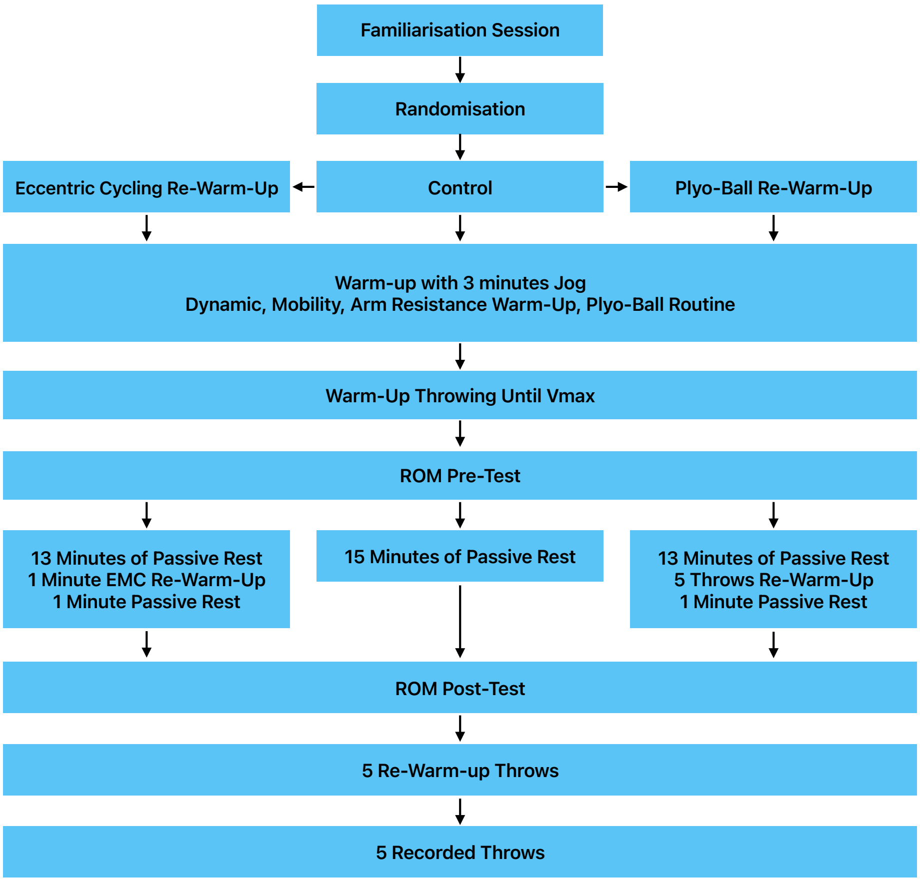

**Figure** 2. Experimental design scheme

### 3.2.2 Participants

Thirteen male participants volunteered to participate in this study (16-28 years old). Before testing, the study procedures and risks were explained verbally, and written informed consent was obtained from all participants. Inclusion criteria for the study were trained individuals (who have played baseball for at least 4 years), aged 16 to 30 years, injury-free for the past six months, and currently participating in baseball, throwing at least twice a week. Participants were excluded if they had a current injury or history of orthopaedic or arthritic conditions affecting their back, elbow, shoulder or lower extremities.

### 3.2.3 Ethics Statement

Ethics approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC: 25/181), granted 22 July 2025.

### 3.2.4 Procedures

Participants completed two familiarisation sessions, during which they received instruction on proper technique and form to ensure familiarisation with the EMC exercise. Each participant then completed three experimental testing sessions: (1) EMC intervention, (2) weighted ball (plyoball) condition, and (3) control (passive rest only). The order of conditions was randomised for each participant to minimise potential order effects. A minimum of 48 hours separated each testing session.

Upon arrival at each session, participants completed a standardised WU consisting of 2 minutes of jogging, followed by dynamic stretching, mobility exercises (targeting the thoracic spine, hips, quadriceps, and hamstrings), arm-specific stretches, resistance band exercises (Jaeger Sports, n.d.), and a plyoball WU (Gielen, 2017). The resistance band protocol included flies, and IR and ER exercises, while the plyoball WU consisted of reverse throws (2000g plyoball), pivot picks (1000g plyoball), rocker drills (150g plyoball), walk-ins (150g plyoball) performed in that order. Each variation of resistance band and plyoball WU consisted of 8 reps. Following the WU, participants engaged in progressive throwing of a standard baseball (Brett BR200 standard nine-inch five-ounce baseball) with a partner until they felt prepared to throw at maximal intensity. Participants then performed maximal effort throws into a net (Vmax). Immediately following Vmax assessment, participants’ shoulder ROM was assessed and they began a passive rest period. Shoulder ROM was assessed using a smartphone goniometer application.

When participants completed the WU, maximal throwing measurement, ROM testing, and passive rest, they proceeded to the next protocol. They were assigned to the following session. Participants in the EMC and plyoball conditions underwent 13 minutes of passive rest, while the control condition involved 15 minutes of passive rest to reflect game-like conditions. Following the rest period, the respective intervention was applied in the EMC and plyoball conditions, while the control group continued with passive rest. Subsequently, all participants underwent a second ROM assessment. Participants then completed five submaximal WU throws to replicate in-game pre-inning preparation. This was followed by five maximal-effort throws, with velocity recorded for analysis.

All testing was conducted either on a baseball field or within an indoor training facility on a flat surface. Participants were instructed to wear appropriate baseball attire, including shorts or baseball pants, and cleats or turf shoes. Data collection took place during the season and was standardised with a minimum of 48 hours prior or post games or practice.

#### 3.2.4.1 Eccentric Motorised Cycling Protocol (EMC)

Participants performing the EMC condition engaged in a 1-minute EMC RWU protocol after 13 minutes of passive rest. The intervention protocols were conducted on a custom-made eccentric cycling machine. The eccentric cycling device features a sturdy metal base, which provides a solid foundation. Attached to this base is a motor connected to the pedals. The underside of the base is equipped with spikes, ensuring stability and preventing any unwanted movement during use. The cadence for the eccentric cycling was set at 30 revolutions per minute (rpm). The motor drives the pedals in a backward direction, requiring participants to actively resist the pedal movement to achieve the desired eccentric effect. The participants were required to resist the pedals of the machine while maintaining a high plank position, but if this became too difficult, they were allowed to modify this to a kneeling position to complete the movement.

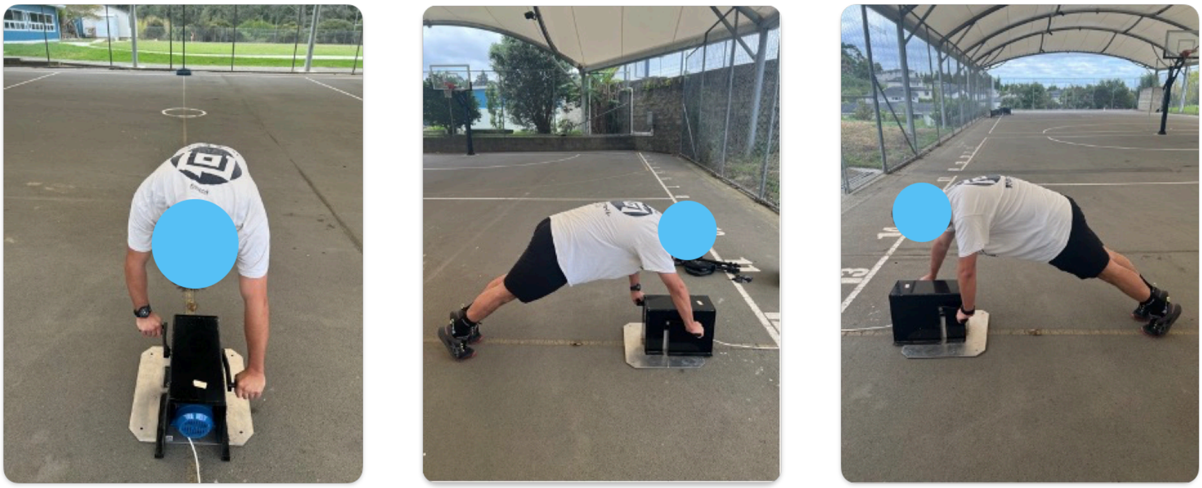

**Figure** 3. Eccentric Motorised Cycling position, The subject is required to maintain this position while resisting the moving pedals in an anti-clockwise motion

### 3.2.4.2 Weighted Plyo-ball Protocol

Participants performing the weighted ball RWU engaged in 5 sub-maximal throws with a 150 g Swings Plyoball (https://www.drivelinebaseball.com/product/driveline-plyocare-balls-sets-plus/?srsltid=AfmBOor8xQdkIWhud0fxbe-tCyEzfd83632QblYs9OG95h0FAyVAP5cm). The participants had the freedom to choose how they threw the ball to RWU, but were limited to 5 throws. This action was chosen as weighted-ball throwing has been shown to acutely influence throwing velocity and arm speed, particularly with lighter implements (Fleisig et al., 2017). It may enhance performance through mechanisms consistent with post-activation performance enhancement and the specificity of WU (Bishop, 2003; Blazevich & Babault, 2019).

**Figure** *4***.** Plyoballs used in the plyo conditions, weights are as follows: Black: 2000g, Blue: 1000g, Red: 150g

### 3.2.4.3 Control Protocol

The control condition involved 15 minutes of passive rest, during which participants remained seated and avoided any upper-body activity, before resuming throwing. This protocol was intended to replicate the passive nature of in-game intermissions and serve as a baseline comparison to the active RWU interventions.

## 3.2.5 Performance Tests

Performance tests were undertaken by the participants throughout this protocol, including ROM IR:ER, PRS, and velocity difference for five throws.

### 3.2.5.1 Difference in Vmax and Post-intermission Velocity

To evaluate the effectiveness of the RWU, the change in velocity was assessed by comparing the first five throws performed immediately after the RWU throws post-intervention to baseline peak velocity recorded prior to the passive rest or RWU condition. The velocity of each of the throws was recorded using a radar device (Stalker ATS II radar gun, Applied Concepts Inc., Plano, TX, USA) positioned behind the throwing area. These throws were performed under standardised conditions, including a consistent target distance of five metres, a fixed rest interval of 10 seconds between attempts, and on a flat, non-slip surface. All participants used a Brett BR200 standard nine-inch five-ounce baseball and received consistent instruction and encouragement. Each throw was then compared to the athlete's maximum throwing velocity (Vmax), defined as the highest velocity achieved during the baseline maximal throwing test earlier in the session. The velocity difference between each throw and Vmax was calculated. This allows for assessment of how quickly athletes are able to return to peak throwing performance following the RWU.

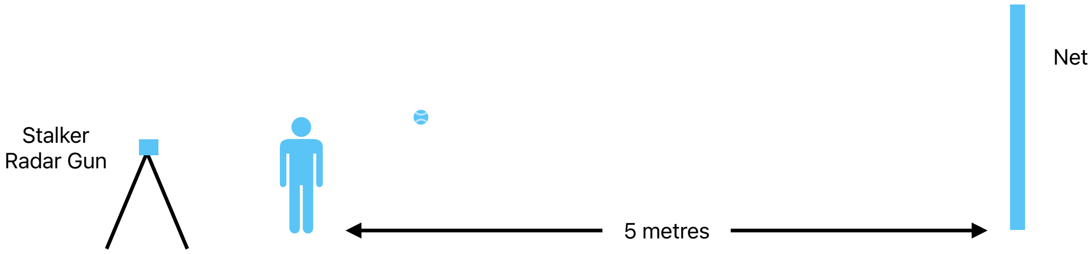

**Figure 5.** Diagram showing velocity testing set-up

**Figure 6.** Set-up from behind radar gun showing data collection view

### 3.2.5.2 Shoulder IR:ER ROM

Shoulder IR and ER were measured before intermission and after RWU protocols were completed. Participants were told to lie down on their back ensuring that their head, upper back, and hips were all in contact with the ground. For IR participants started in a 90 degree “L” position and pushed their palm toward the floor as far as they could without moving any other part of their body. For the ER test, the participants were told to lie down in the same manner but push the back of their hand toward the ground. An electrical goniometer (AngleMeter on AppleStore, version 4.7.2) application for an iPhone 13 Pro Max (Apple Inc., Cupertino, CA, USA) was used to measure the IR and ER for each test. For these measurements, the phone was placed on the inside of their forearm to measure ER and outside of their forearm to measure IR (Park et al., 2022).

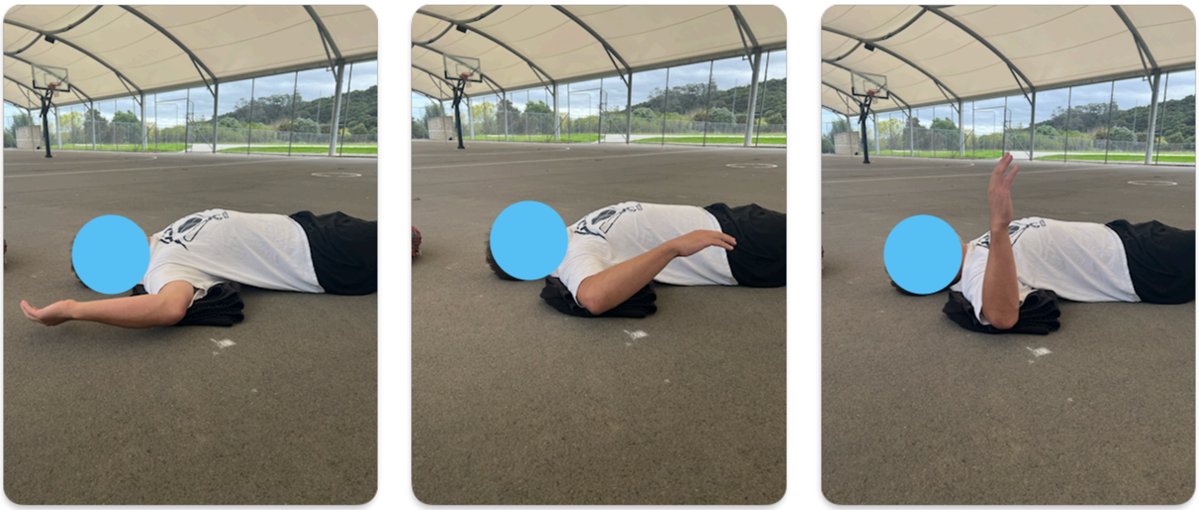

**Figure** *7*. ROM Testing, participant in a supine position with shoulder abducted to 90°, Elbow at 90°. Towel under their elbow to align the elbow with the glenohumeral joint.

### 3.2.5.3 Perceived Readiness Scale

Subjective readiness was measured using the perceived readiness scale (PRS), which is a 5-point scale to understand the subjective readiness for participants to throw at maximum intent. The PRS was administered after the intermission and before the participant started their second set of throwing. The scale will be as follows; 1: Not Ready (feeling cold, fatigued unable to throw at high intensity, 2: Low readiness (Some fatigue, below average throwing capability, and reduced explosiveness), 3: Moderate readiness (Neutral, neither fatigued or fully prepared, capable of moderate effort), 4: High readiness

(Well-prepared, minimal fatigue, able to throw at near maximal effort), 5: Fully ready (Completely fresh, fully prepared to throw at maximum effort without limitations).

## 3.3 Data Analysis and Statistics

Statistical analyses were performed using IBM SPSS Statistics v33.1. Descriptive statistics (mean ± standard deviation (SD), median, interquartile range (IQR), and range where appropriate) were calculated for all dependent variables.

Prior to analysis, data were screened for missing values, outliers, and assumption violations. Outliers were assessed using boxplots and the interquartile range method (extreme threshold: $Q3 + 3 \times IQR$) at the within-participant level. The five post-throws were examined for each condition, for every participant separately, given the substantial between-subject variability in throwing velocity that would interfere with individual-level outliers. Across all condition datasets, one extreme outlier was identified and removed from the analysis. After this data point was removed, normality of continuous variables was evaluated using Shapiro–Wilk tests, which showed that pre and post-throwing velocities were normally distributed across conditions ($p>.05$). Change scores were normally distributed in the EMC ($W = .983$, $p = .992$) and plyoball ($W = .957$, $p = .703$) conditions. However, the control condition change scores violated normality ($W = .718$, $p = .001$) due to one participant who showed a large performance decrement in the control condition (-19.16 km/h). These data points were retained, given evidence that repeated-measures ANOVA is generally robust to moderate violations of normality assumptions with relatively small sample sizes, especially with consistent results across conditions and homogeneous variances (Levene $F = 0.072$, $p = .930$), supporting the use of parametric tests (Field, 2018; Norman, 2010). Homogeneity of variance and sphericity were assessed using Levene’s test for post-intervention velocity means and change scores. For repeated-measures analyses, sphericity was tested using Mauchly’s test, and where violations occurred, Greenhouse–Geisser corrections were applied.

To examine the effect of intervention condition (EMC, plyoball, and control) on changes in throwing velocity, a one-way repeated-measures analysis of variance (ANOVA) was conducted. Where significant main effects were observed, Bonferroni-adjusted pairwise comparisons were performed to identify specific differences between conditions. Effect sizes were reported as partial eta squared ($\eta p^2$) to quantify the magnitude of effects and were interpreted as small (≥ .01), medium (≥ .06), or large (≥ .14).

Changes in shoulder ROM, including IR, ER, and total ROM, were analysed using paired samples t-tests to compare differences between conditions. These analyses were selected to assess short-term changes in joint mobility following each intervention.

Differences in PRS between conditions were analysed using a Friedman test due to the ordinal nature and non-normal distribution of the data. Where significant main effects were identified, post-hoc pairwise comparisons were conducted using Wilcoxon signed-rank tests with Bonferroni-adjusted alpha levels to control for Type I error.

Associations between changes in shoulder ROM and throwing velocity were assessed using Pearson product–moment correlation coefficients. Relationships between PRS and post-intervention throwing velocity were analysed using Spearman's rank-order correlations due to the ordinal nature of PRS data. Correlation strength was interpreted as trivial (< .10), small (.10–.29), moderate (.30–.49), or large (≥ .50), providing context for the practical significance of observed relationships.

All statistical tests were two-tailed, and statistical significance was set at $\alpha = .05$ unless otherwise adjusted for multiple comparisons. Given the number of statistical tests performed, results should be interpreted with consideration of the potential for Type I error.

## 3.4 Results

### 3.4.1 Throwing Velocity by Condition

Data screening identified one outlier in the dataset. Participant 2, control throw 3 (134.6 km/h) deviated 11.3 km/h from the participant's mean post-intervention control velocity, and exceeded the extreme outlier threshold (Q3 + 3*IQR) by 9.0km/h (see figure 8). No other extreme outliers were identified across any participant or condition after screening of all post-intervention throws. This was likely a recording error and was excluded from the following analyses.

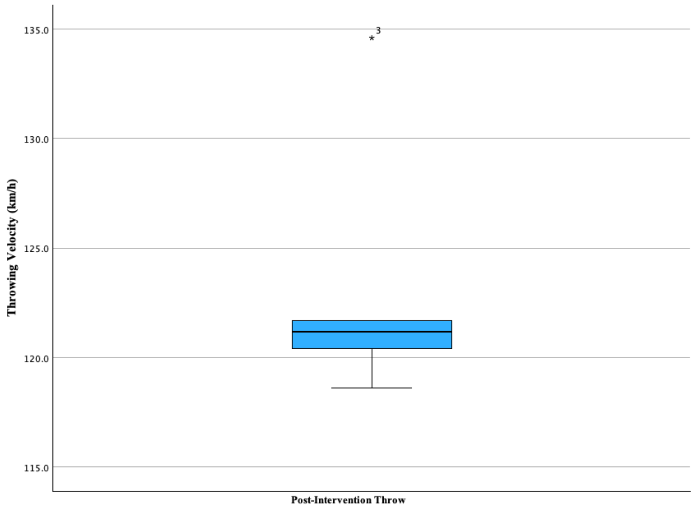

**Figure** *8***.** Box and whisker plot of Participant 2’s post-intervention throwing velocities in the control condition (n=5). The asterisk indicates throw 3 (134.6 km/h) as an extreme outlier. This exceeds the extreme outlier threshold (Q3 + 3×IQR = 125.6 km/h) by 9.0

Mauchly’s test indicated that the assumption of sphericity was violated (W = .448, p = .012), therefore, degrees of freedom were corrected using the Greenhouse–Geisser estimate (ε = .644). As indicated in Figure 8, one throw was identified as an extreme outlier and removed from the subsequent analysis. A repeated-measures ANOVA revealed no statistically significant main effect of condition on changes in throwing velocity, F(1.289, 15.466) = 2.255, p = .150, $\eta p^2$ = .158 (see figure boxplot). As observed in Figure 9, the smallest reduction in velocity occurred in the EMC condition (M = −2.98 ± 3.61 km/h; 95% CI: −5.16 to −0.80), followed by the plyoball condition (M = −4.81 ± 2.46 km/h; 95% CI: −6.30 to −3.33), with the greatest reduction observed in the control condition (M = −5.54 ± 4.55 km/h; 95% CI: −8.29 to −2.79). This pattern reflects progressively larger decreases in velocity from EMC to plyoball to control.

Bonferroni-adjusted pairwise comparisons identified a statistically significant difference between the EMC and plyoball conditions (mean difference = 1.83 km/h; 95% CI: 0.04 to 3.62; p = .045), while no other comparisons reached significance. The EMC vs control conditions were absent of a significant difference, despite showing the largest descriptive separation, which is likely attributed to the small sample size or substantially elevated variance in the control condition (SD = 4.55 km/h), rendering statistical tests unable to pick up significance. The variance in the data set was caused by one participant who demonstrated an unusually large performance decrement (−19.16 km/h), which lowered statistical power for this comparison. Although the main effect of condition was not statistically significant, a large effect size and consistent descriptive pattern indicated progressively smaller reductions in velocity from control to plyoball to EMC.

**Table 3.** Post-intervention throwing velocity outcomes by condition (n=13)

| **Condition** | **Pre (mean ± SD)** | **Peak post (mean ± SD)** | **Change % (95% CI)** | **d** | **EMC vs CON mean diff ± SE (d)** | **PLY vs CON mean diff ± SE (d)** | **EMC vs PLY mean diff ± SE (d)** |
|---|---|---|---|---|---|---|---|
| Control | 120.28 ± 11.40 | 116.23 ± 11.13** | −3.33<br>(−5.53 to −1.13) | −0.92 | 2.55 ± 1.51<br>*d = 0.53, p = .351* | 0.73 ± 1.38<br>*d = 0.24, p = 1.000* | 1.83 ± 0.65<br>*d = 0.54, p = .045** |
| EMC | 119.28 ± 12.12 | 117.85 ± 11.71 | −1.20<br>(-3.07 to +0.67) | −0.39 | | | |
| Plyoball | 120.85 ± 12.60 | 117.56 ± 12.27*** | −2.72<br>(−3.80 to −1.65) | −1.53 | | | |

N.B. All velocities in km/h. Values are mean ± SD. ** p = .006, *** p < .001 vs pre (paired t-test); EMC p = .188 (ns). Change % = (peak post − pre) / pre × 100. d = Cohen's d (within-condition: pre vs peak post; between-condition: difference score SD). Between-condition pairwise comparisons from repeated-measures ANOVA with Bonferroni correction; F(1.289, 15.466) = 2.255, p = .150, $\eta p^2$ = .158 (Greenhouse–Geisser corrected). * p < .05 (Bonferroni-adjusted). CON = control; PLY = plyoball.

The plyoball condition produced a statistically significant, large within-condition decline in peak velocity. The control condition showed a significant, large decline in peak velocity, and the EMC showed the smallest decline, which was non-significant.

### 3.4.2 Throwing Velocity by Throw

Mauchly's test indicated that the assumption of sphericity was not violated for throw-to-throw velocity variability (W = .884, p = .508). A repeated-measures ANOVA revealed no statistically significant effect of condition on variability, F(2, 24) = 0.012, p = .988, ηp² = .001. Descriptive statistics indicated that the variability was almost identical across conditions. Vmax across throws control (1.50 ± 0.44 km/h, 95% CI [1.24, 1.77]), EMC (1.46 ± 0.89 km/h, 95% CI [0.93, 2.00]), and plyoball (1.47 ± 0.69 km/h, 95% CI [1.03, 1.89]). No pairwise comparisons reached significance, indicating that throw-to-throw variability was comparable across all three conditions. Throwing velocity across successive throws is presented (see figure line graph), demonstrating consistently lower velocities in the control condition compared to the EMC and plyoball condition.

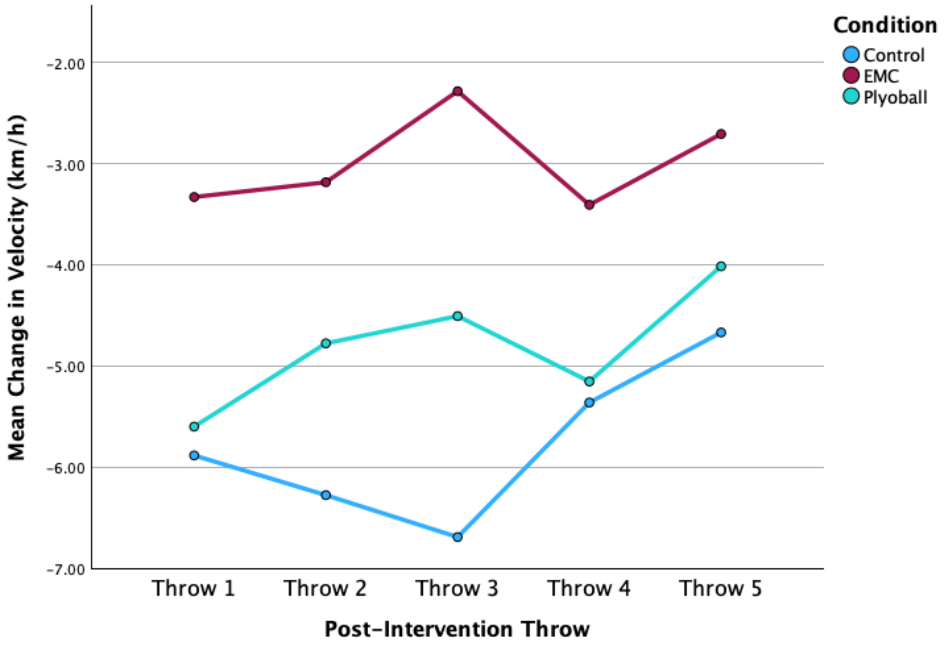

**Figure** 9. Mean change in throwing velocity (km/h) from pre-intervention across five post-intervention throws by condition (n = 13). Negative values indicate velocity reduction relative to pre-intervention Vmax. EMC = eccentric motorised cycling

### 3.4.3 ROM By Condition

In the plyoball condition, IR increased (Δ = +4.85 ± 17.22°), but showed minimal change following the EMC condition (Δ = +0.23 ± 13.80°), and decreased in the control condition (Δ = −3.62 ± 15.55°). Observed changes for ER are as follows: plyoball Δ = +3.62°, EMC Δ = −1.92°, and control Δ =

−1.85° Paired samples t-tests revealed no significant differences in IR, ER, or total ROM between conditions (all p > .05). The repeated measures ANOVA's on ROM change scores showed no statistically significant effect of condition on IR (F(2, 24) = 0.866, p = .433, ηp² = .067, ER (F(2, 24) = 0.887, p = .425, ηp² = .069), or Total ROM (F(2, 24) = 0.902, p = .419, ηp² = .070). Mauchly's test indicated that sphericity was not violated for any ROM outcome (IR: W = .692, p = .132; ER: W = .799, p = .292; Total: W = .899, p = .558), so no corrections were made.

### 3.4.4 ROM Correlation to Velocity

Pearson correlation analyses were conducted to examine the relationship between changes in shoulder ROM and changes in throwing velocity across conditions. Given that altered ROM has been previously suggested to influence throwing performance, this analysis was conducted as an exploratory analysis (Manzi et al., 2022). No significant correlations were observed for ER or total ROM in any condition (Control: ER r = −.347, p = .245; Total r = −.459, p = .115; EMC: ER r = −.038, p = .902; Total r = −.049, p = .874; Plyoball: ER r = −.386, p = .193; Total r = −.454, p = .119). These findings suggest that changes in shoulder ROM were not meaningfully associated with changes in throwing velocity following any of the three interventions."

**Table** *4***.** Difference scores for perceived readiness scale (PRS) by condition (n = 13)

| Comparison | Median | IQR | Mean ± SD | Range |
|---|---|---|---|---|
| **EMC – Control** | 1.0 | 2.0 | 0.77 ± 1.01 | −1 to 2 |
| **EMC – Plyoball** | 1.0 | 1.0 | 1.15 ± 1.46 | −2 to 3 |
| **Plyoball – Control** | −1.0 | 2.0 | −0.38 ± 1.12 | −2 to 1 |

N.B. Difference scores calculated as pairwise condition comparisons (e.g. EMC – Control = EMC PRS score minus Control PRS score). Friedman test: χ²(2) = 7.581, p = .023. Post-hoc Wilcoxon signed-rank tests with Bonferroni correction (α = .0167): EMC vs Control Z = −2.226, p = .026; EMC vs Plyoball Z = −2.232, p = .026; Plyoball vs Control Z = −1.232, p = .218. No pairwise comparisons reached adjusted significance.

Median scores from the descriptive statistics for PRS showed that median scores were the highest following the EMC condition (Mdn = 4.0, IQR = 0.0, M = 4.08 ± 0.64), compared control (Mdn = 3.0, IQR = 1.0, M = 3.31 ± 0.75) and plyoball (Mdn = 3.0, IQR = 1.0, M = 2.92 ± 1.12). Difference scores between conditions are presented in Table 4. A Friedman test revealed a significant overall difference in PRS between conditions, $\chi^2(2) = 7.581$, p = .023. Post-hoc Wilcoxon signed-rank tests with Bonferroni correction ($\alpha = .0167$) indicated no pairwise differences reached statistical significance, although median PRS scores were descriptively highest following the EMC intervention. The correction reducing statistical power in a small sample may have caused this, as both EMC vs control (Z = −2.226, p = .026) and EMC vs plyoball (Z = −2.232, p = .026) were close to the adjusted threshold. No meaningful difference was observed between plyoball and control conditions (Z = −1.232, p = .218).

### 3.4.5 PRS and Post-Intervention Change in Throwing Velocity

Spearman's rank-order correlations were conducted to examine the association between PRS and post-intervention throwing velocity within each condition. No significant associations were observed in the EMC ($\rho = 0.101$, p = .742 or Control conditions ($\rho = -0.245$, p = .420), or plyoball ($\rho = .482$, p = .095), although descriptive trends suggested a weak positive relationship for EMC and control (see in table 5).

**Table** 5. Spearman rank-order correlations between PRS and mean velocity change by condition (n = 13)

| **Condition** | **Spearman ρ** | **p-value** | **Interpretation** |
|---|---|---|---|
| **Control** | −.245 | .420 | Weak negative, not significant |
| **EMC** | .101 | .742 | Negligible positive, not significant |
| **Plyoball** | .482 | .095 | Moderate positive trend, not significant |

N.B. Spearman's rank-order correlations between perceived readiness scale (PRS) and mean post-intervention velocity change score within each condition. All correlations non-significant (all p > .05).

Figure 10 shows the distribution of velocity change scored by PRS rating across all three conditions. A descriptive trend is shown where participants who reported lower perceived readiness showed a median velocity decrease compared to those reporting full readiness (PRS 5). This may suggest that subjective readiness may partially reflect the degree of velocity loss that is experienced. Though this trend is not consistent across all PRS values, for example, PRS 3 showed a slightly larger median decrease than those rating PRS 2. The PRS 4 group also displayed an unusually large decrease and the widest variability (SD = 5.27 km/h). Although there seems to be a descriptive trend showing in the figure, the wide variability within PRS groups limits the interpretability of this descriptive trend, and is consistent with the results observed in the Spearman correlations shown within individual conditions.

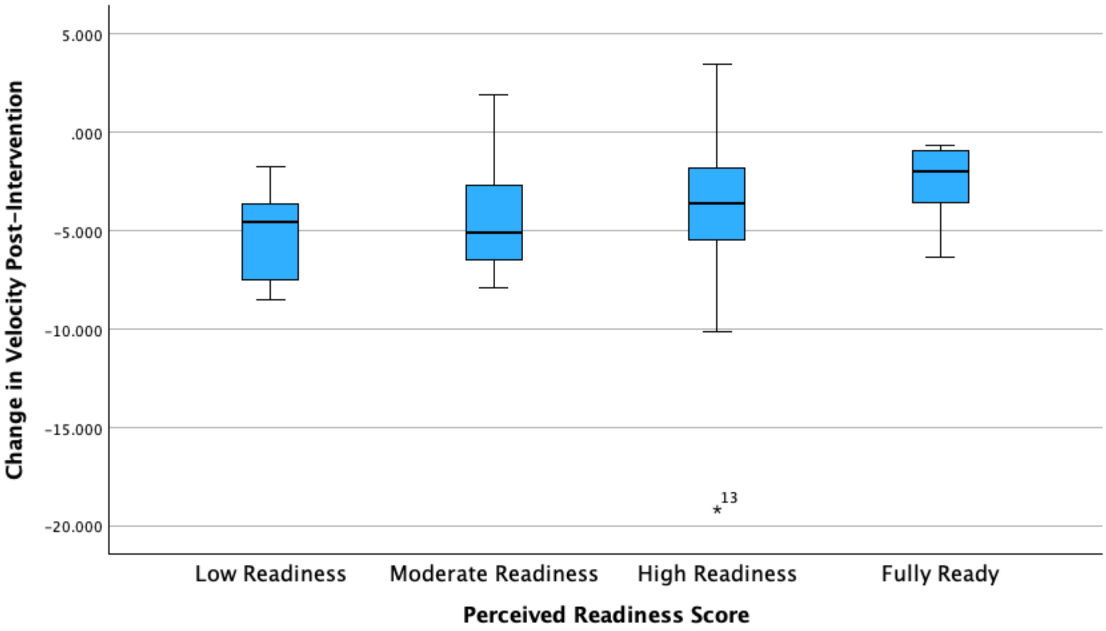

**Figure** *10*. Box and whisker if mean change in throwing velocity (km/h) by perceived readiness scale (PRS), across all conditions (n=39). Negative values indicate reduction.

## 3.5 Discussion

RWU strategies have been explored in recent literature as a way to mitigate performance decreases after intermissions. This study examined the effects of RWU on several baseball-related performance metrics, including throwing velocity, shoulder ROM and PRS. The interventions in this study included a baseball-specific weighted implement, a non-specific upper-body eccentric cycling protocol, and passive rest. Comparing the changes of these performance variables within condition (pre- vs post-intermission + RWU) and between conditions (magnitude of change from pre to post between the different protocols) was intended to elucidate the effectiveness of different protocols on post-intermission throwing velocity, ROM, and PRS. However, the overall findings were that statistically, there was insufficient evidence to confirm a definitive advantage of one intervention over another for velocity and ROM, and PRS. However, moderate to large effect sizes and consistent directional trends were shown across conditions, which particularly favoured the EMC intervention. From an applied perspective, these trends suggest that even small improvements in velocity maintenance or perceived readiness may be meaningful in competitive environments, where small gains can influence performance outcomes.

Although the repeated-measures ANOVA did not reveal a statistically significant main effect of condition on throwing velocity ($p=.150$), the presence of a large effect size ($\eta p^2 = .158$) and consistent descriptive trends suggest a practically meaningful pattern. Specifically, the control condition experienced the largest decrease in throwing velocity following the intermission, while the plyoball condition demonstrated a smaller reduction, and the EMC condition had the smallest loss in post-intermission throwing velocity. Although the overall main effect of condition was not statistically significant, the effect size was large ($\eta p^2 = .158$), suggesting meaningful practical differences between conditions. This response pattern indicates that both active interventions may help attenuate velocity loss compared to no RWU, with EMC providing a marginally better response. The trend observed in the EMC condition may be partly due to the physiological properties of eccentric actions. Eccentric contractions are capable of generating greater force at lower metabolic cost compared to concentric contractions, and are also proposed to enhance motor unit activation and musculotendinous stiffness while limiting cardiovascular and metabolic fatigue (Enoka, 1996; Herzog, 2014; Hody et al., 2019). These properties may allow EMC to provide meaningful neuromuscular stimulus that primes the shoulder muscles for high velocity throwing, without excessive fatigue. These findings align with the broader RWU literature, which shows that RWU strategies play an important role in preserving and potentially enhancing aspects of athletic performance following passive intermissions (Edholm et al., 2015; Koutsouridis et al., 2024; Yanaoka et al., 2018).

### 3.5.1 Throw by Condition

The largest decrease in velocity was observed in the control condition (M = −5.54 ± 4.55 km/h; 95% CI: −8.29 to −2.79), with less decreases in the plyoball condition (M = −4.81 ± 2.46 km/h; 95% CI: −6.30 to −3.33), and the EMC condition (M = −2.98 ± 3.61 km/h; 95% CI: −5.16 to −0.80). Although the overall main effect of condition did not reach statistical significance F(1.289, 15.466) = 2.255, p = .150), the large effect size ($\eta p^2 = .158$) could show a practically meaningful difference, which, in order to detect the significance, the sample size was too small (n=13). Something to note, although, was that the Bonferroni-adjusted pairwise comparisons identified a significant difference between EMC and plyoball conditions, while EMC and control was close but did not reach significance (mean difference EMC vs Plyoball= 1.83 km/h, p = .045, EMC vs Control 2.55 km/h, p = .351). This was likely because of the high variance in the control condition driven by one participant who showed an unusually large performance decrement (-19.16 km/h), which increased the standard error of the mean difference, reducing statistical power and preventing the comparison from reaching significance even though there was a large descriptive gap. This value was kept in the analysis as it did not align with a recording error, as all five post-intervention throws for this participant were internally consistent (range 100.3 – 105.1 km/h), showing a genuine but unusually large acute performance decrease rather than a data issue. This is different from the removed outlier as the outlier was deemed extreme as it was outside of the extreme outlier threshold (Q3 + 3×IQR = 125.6 km/h). Contrary to the outlier, the data that was retained is consistent with the principle that genuine biological variability should be kept in the analysis even where it contributes to non-significant findings. Within-condition paired t-tests also supported this pattern, with the control (p = .006, d = 0.92) and plyoball (p < .001, d = 1.53) conditions showing statistically significant pre to post declines in peak velocity, while the EMC condition did not (p = .188, d = 0.39). This could suggest that the EMC intervention better minimised the reduction in throwing velocity associated with between-inning intermissions. Something to note is that the non-significant within-condition decline in the EMC condition should not be taken as evidence that EMC produced no change in throwing velocity. The lack of statistical significance does not confirm the null hypothesis. With a small sample size (n=13) and a moderate effect size (d=0.39), it was likely that the study had a lack of power to detect a true within-condition effect in the EMC condition if one exists (Cohen, 1988; Field, 2018). The direction of change was consistent with the other conditions, all showing reductions, but the magnitude was the smallest in EMC, which is practically meaningful regardless of statistical significance.

The performance decrements following the passive intermission shown in this study closely align with wider literature (Koutsouridis et al., 2024; Matsentides et al., 2023; Mohr, 2004; Yanaoka et al., 2018). The control condition for the current study produced a 3.33% reduction in throwing velocity, which is similar to the magnitude of the ~2.47% decline in sprint performance after a 15-minute passive rest reported by Mohr et al. (2004), the 2.6% post half-time sprint decline in the control condition reported by Edholm et al. (2015), and the 3.13% sprint derived power decrease reported by Koutsouridis et al. (2024). This demonstrates similar performance decrements under inactivity. The attenuation of velocity loss shown in the EMC condition relative to control (2.35%) is similar to the magnitude of performance preservation reported in the wider RWU literature. Edholm et al. (2015) reported that sprint performance remained stable compared to a 2.6% decline under passive rest. Koutsouridis et al. (2024) echoed these findings showing that RWU minimised CMJ decline (-1.72% vs -5.1%) and COD time (-0.48% vs -3.13%) compared to passive rest, with moderate intensity RWU producing larger effects than low intensity RWU (ES ≈ 0.72 vs 0.42). Although the current study examined throwing velocity rather than sprinting or jumping performance, the direction and magnitude of changes observed across the conditions are consistent with previous RWU research. These performance decrements have been attributed to decreases in core and muscle temperature in the wider literature, such as Mohr et al. (2004) showing that after a 15-minute passive rest a ~2°C reduction in muscle temperature was observed under inactivity, resulting in decreased performance. Similarly, Yanaoka et al. (2021) reported that gastrointestinal temperature during half-time decreased from 38.9°C to 37.7°C in the control condition, reporting a 3.08% decrease, whereas the RWU condition only decreased from 38.6°C to 38.0°C, showing a smaller 1.55% decrease. This minimisation of temperature loss was accompanied by maintenance of sprint performance by 2.4-3.6% during the later stages of intermittent exercise. Additionally, variability in individual responses and the relatively small sample size may have limited the ability to detect statistically significant effects. The contrast with Abade et al. (2017), who found that eccentric RWU decreases sprint and CMJ performance, most likely reflects the difference in exercise volume and intensity. The low-volume and low-intensity EMC protocol used in the present study seeks to avoid acute fatigue and muscle damage associated with higher-load eccentric exercise (Hody et al., 2019). This may explain the more favourable velocity trends in the current study.

The only statistically significant between-condition difference in the present study was between EMC and plyoball (mean difference = 1.83 km/h, p = .045, d = 0.54). This suggests that despite both interventions attenuating velocity loss, relative to passive rest, the EMC intervention produced a statistically meaningful greater maintenance of velocity. As a sustained activity, EMC likely produced its primary benefit through muscular activation, which may have attenuated temperature decline, hence minimising the decrease in performance (Mohr et al., 2004; Yanaoka et al., 2018). The plyoball intervention was selected based on the idea of movement specificity to prime neuromuscular coordination and stretch-shortening cycle function relevant to the subsequent task. However, the thermogenic benefits of the stretch-shortening qualities of plyoball exercise may be minimised by the mechanical demands on tendons during throwing movements. Tendons have minimal blood flow with limited capacity for heat exchange. This means that metabolic heat that is generated during plyoball throwing may not transfer as efficiently to the surrounding musculature in comparison to actions that directly target the muscle (Kjaer, 2004; Tempfer & Traweger, 2015). In comparison, EMC targets the muscle, and while the metabolic cost may be lower due to the eccentric muscle actions, the sustained direct muscular stimulus may better maintain muscle temperature over the duration of the intermission (Barreto, 2021; Mohr et al., 2004). In addition to this, the lesser impact of plyoball on performance may be attributed to the volume of plyoball intervention allowed the participants to perform. Participants only completed five throws as part of their standardised RWU, which may have been insufficient to elicit a meaningful response, reflecting the dose-dependent nature of throwing. Studies have shown that the acute effects of weighted ball throwing are inconsistent, with some evidence of improvements and others showing no benefit (Jermyn et al., 2021; O'Connell et al., 2022). Acute PAPE effects from overweight implement throws have been reported under controlled conditions, but the effects are variable and appear dependent on implement weight, volume, and recovery duration (Jermyn et al., 2021). The more consistent velocity improvements associated with weighted ball use are from chronic adaptations requiring repeated exposure over an extended training period rather than a reliable acute effect (Bowman et al., 2023). This may explain the limited response shown in the five-throw plyoball protocol in the present study. Thus, five throws may have been partially sufficient to maintain movement coordination and attenuate some temperature-related performance loss, but the stimulus may have been insufficient to maximise neuromuscular readiness for high-velocity throwing, which followed. In contrast, the EMC intervention provided a sustained stimulus, which may have more effectively primed the neuromuscular system and increased muscle temperature for the throwing task. The volume of plyoball RWU protocol should be increased and analysed in future research to see if the performance benefits could be comparable to EMC.

Another possible explanation for the observed trends is that RWU interventions influenced neuromuscular function that supported performance expressions in some individuals. This neuromuscular support, however, was not consistent enough to produce a statistically detectable group effect. In comparison, passive rest may reduce this ability, limiting the athlete's ability to express maximal performance, which may be particularly important for overhead throwing. Efficient coordination and rapid force transmission through the kinetic chain are essential to throwing (Fleisig et al., 2017). Throwing also relies heavily on proximal to distal sequencing for velocity production, which may reduce the extent to which eccentric-caused potentiation is shown in throwing velocity (Fleisig et al., 2017). These findings provide an understanding of the differences observed between RWU interventions, especially the more favourable trends associated with EMC, but its transferability to upper-body ballistic tasks may be more variable. This provides the background for understanding why both EMC and plyoball interventions demonstrated some capacity to attenuate velocity loss, but with inconsistent effects across individuals.

### 3.5.2 ROM by Condition and Relationship with Velocity

No significant differences in shoulder ROM were observed between conditions ($p > .05$) in the present study. IR increased following the plyoball condition ($\Delta = +4.85 \pm 17.22°$), with ER also increasing (Δ = +3.62°), yielding a combined total ROM change of approximately +8.47°. These findings suggest that neither RWU intervention meaningfully altered shoulder ROM in the short-term following a brief intermission. Enhanced musculotendinous stiffness and potentiation from eccentric exercise may support the preservation of ballistic tasks, the temperature demands of ROM adaptation may operate through a different mechanisms. In previous literature, it has been shown that acute exercise interventions, especially those involving dynamic or concentric muscle actions, can increase ROM, often connected to elevated muscle temperature and reduced passive stiffness (Bishop, 2003). Although eccentric exercise has also been suggested to acutely increase ROM, it has been shown to have lower metabolic cost compared to concentric or plyometric actions, and may not elevate muscle temperature to the same degree (Aune et al., 2019; Lindstedt et al., 2001). These factors may help explain the minimal ROM changes shown in the EMC condition, as insufficient increases in muscle temperature may limit acute changes in tissue extensibility. Although it is difficult to definitively conclude this, as the study did not measure muscle temperature to explain this phenomenon. In contrast, the slightly greater increases observed in the  may reflect the coordinative demands of throwing rather than just the thermal effects. High velocity throwing involved extreme ranges of shoulder motion, especially in ER during the arm-cocking phase. This may cause an acute stretching effect on the soft tissues and contribute to the temporary increases in ROM independent of temperature changes (Case et al., 2015; Fleisig et al., 2017). However, as discussed in the velocity findings, the plyoball condition was limited to five throws, which may have been insufficient to show meaningful changes in ROM. Another aspect to take into consideration was that due to the design of the study, there was a possibility that the pre-test for ROM may also have been exposed to the throwing-related stretching effect from the WU throws. This may also be contributing to the wide variability of the dataset and the lack of meaningful results. Consequently, the modest ROM increases observed following the plyoball intervention may reflect the acute mechanical stretching effects rather than a thermal-caused increase in tissue compliance. This, although cannot be confirmed in this study, as it did not measure muscle temperature directly.

Although there were no significant between-condition differences in ROM, a moderate negative relationship was observed between changes in ER and throwing velocity in the control condition ($r = -.525$, $p = .065$). Although this finding should be taken with caution, due to the small sample size, the direction of the trend is worth noting. This suggested that increases in ROM were associated with decreases in performance when no RWU strategy was performed. This does not agree with previous literature linking increased external ROM with enhanced throwing performance in overhead athletes, especially in the context of chronic adaptations (Manzi et al., 2022). This difference may be explained by the distinction between chronic and acute changes of ROM. Chronic increases are associated with structural adaptations such as sarcomerogenesis, whereas acute increases may reflect temporary reductions in passive stiffness or neuromuscular control (Behm & Chaouachi, 2011; Peviani et al., 2018). From a neuromechanical perspective, ideas such as optimal feedback control suggest that the central nervous system may interpret this state of acute increased ROM as reduced joint stability, leading to a protective downregulation of motor output (Scott, 2004; Todorov & Jordan, 2002). This relationship was not seen in the EMC or plyoball conditions. This may suggest that these interventions could help restore the neuromuscular conditions necessary to effectively utilise available ROM following a brief intermission. These findings from this study reinforce that ROM alone does not determine performance capability, but rather, its collaboration with a functionally prepared neuromuscular system is crucial. This finding should be interpreted with caution due to the small sample size and multiple comparisons.

### 3.5.3 PRS and Relationship with Post-Intervention Change in Throwing Velocity

The present study identified an overall significant effect of condition on PRS, $\chi^2(2) = 7.581$, $p = .023$, with higher scores shown in the EMC intervention compared to plyoball and control conditions. The median difference scores indicated small positive differences between EMC and both plyoball and control, while minimal differences were observed between plyoball and control. Post-hoc comparisons, although, did not reach statistical significance, likely because of inter-individual variability, as reflected by wide ranges and interquartile ranges across conditions. The relationship between PRS and throwing velocity was also investigated, showing a moderate positive trend between

PRS and throwing velocity in the plyoball intervention ($\rho = .482$, $p = .095$). This suggested that higher PRS may be associated with greater performance output in the plyoball intervention, though this did not reach statistical significance. This information should be interpreted with caution given the smaller sample size and the possibility that a relationship exists, but was undetected due to the insufficient statistical power. Although statistical conclusions cannot be drawn, the directional patterns across conditions are worth noting as an exploratory analysis. Previous research examining subjective readiness and performance suggests that perceptual measures reflect an athlete's functional state and are associated with performance outcomes. Studies have reported a significant positive relationship between readiness and actual sprint effort during a structured WU, which show that readiness is closely aligned with physiological output rather than being just purely subjective (R. V. D. Tillaar et al., 2025). The trends shown in the present findings are tentatively consistent with previous literature, but the current study was not able to confirm this relationship statistically. A possible explanation is that lower PRS reflects an internal assessment of insufficient neuromuscular readiness or increased perceived risk. This may be resulting in a subconscious downregulation of motor output consistent with protective motor behaviour frameworks (Lochbaum et al., 2023; Todorov & Jordan, 2002). The EMC condition may have provided a more consistent enhancement of neuromuscular readiness across participants, therefore reducing variability. The plyoball condition may have elicited more individualised responses, allowing for the trend between PRS and performance to emerge. This interpretation is tentatively supported by the variability observed in PRS difference scores across conditions. The absence of an RWU intervention may have resulted in a mismatch between perceived and actual readiness, limiting the performance regardless of subjective perception. Although these findings are exploratory and should be interpreted cautiously, they could suggest that perceived readiness may be a meaningful contributor to performance. This indicates that RWU interventions may influence not only physiological preparedness but also the athlete's perception of readiness, which may interact to determine performance outcomes. Future research with larger samples should examine descriptively higher PRS scores after EMC to identify if it translates to statistically significant differences.

### 3.5.4 Limitations and Future Research Considerations and Directions

Several limitations should be addressed and the study should be interpreted having these in mind. The relatively small sample size may have reduced statistical power and increased the likelihood of Type II error, potentially taking away from meaningful effects. The variability in individual responses to the interventions influenced by a variety of factors, including training history and familiarity, which may have contributed to the variation in performance outcomes. The study also failed to record physiological measurements, such as muscle or core temperature, which also limits the ability to confirm the mechanisms proposed to explain the observed trends. Another factor to highlight was the fact that the plyoball intervention may not have provided sufficient volume or intensity of stimulus to elicit a meaningful acute potentiation effect, especially when compared to structured weighted ball training protocols. Although the study was designed to mimic a realistic intermission, the lack of control over external and contextual factors could potentially limit the generalisability of the findings. Future research should aim to build on these findings by using a larger sample size to improve statistical power and allow for more robust comparisons between conditions. The inclusion of direct physiological and neuromuscular measures, such as muscle or core temperature or electromyography, would provide better insight into the mechanisms explaining RWU effectiveness. Further research into plyoball RWU strategies would also be meaningful. Especially, examining the effects of increased value, varied loading and different intensities to determine whether a stronger acute stimulus can enhance performance outcomes. Promising trends observed in the EMC condition should prompt future studies to explore the application of eccentric-based RWU interventions across different populations and sporting contexts. Finally, continued examination of the relationship between perceived readiness and objective performance may help to better understand how perception and physiology can interact to influence performance following intermission.

## 3.6 Conclusion

The main findings of this study were that EMC showed potential as a RWU strategy to mitigate performance loss in baseball throwing following a brief intermission alongside plyoball compared to control conditions. Although the overall effect of the condition was not statistically significant, a significant pairwise difference in EMC and plyoball conditions suggests that EMC may be a more effective strategy for preserving performance. Contrary to expectation no differences were observed in shoulder ROM across conditions, and changes to ROM were not associated with throwing velocity. Although a moderate, non-significant negative trend was seen between shoulder ER and throwing velocity in the control condition. This suggests that in the absence of a RWU intervention, increased external ROM may be detrimental to throwing velocity post-intermission. This, however, was not present in the intervention groups, indicating that EMC and plyoball conditions may have an effect of regulating this effect. PRS showed variability across conditions, where EMC condition had participants scoring the highest median score, while no other pairwise differences reached a statistically significant result. No statistically significant results were seen, but this information should be taken cautiously due to the low sample size. These results may support the notion that performance is not determined by isolated physical characteristics, but by the integration of mechanical and perceptual factors within a prepared neuromuscular system. Increases in ROM with corresponding improvements in perceived readiness may enable athletes to more effectively express their physical capacity during high-velocity tasks.

Overall, this study shows findings that suggest that EMC as a RWU strategy, although not indicating that it improves performance metrics, shows promise in maintaining throwing velocity and PRS after an intermission. This study provides novel insight into the usage of EMC as a RWU application in overhead athletes and further highlights the need for further research with an increased sample size to understand its mechanisms and effectiveness.

# Chapter 4: Summary, Practical Applications and Future Research

## 4.1 Summary

The present thesis aimed to investigate the effectiveness of EMC as an RWU strategy for overhead throwing athletes following a brief intermission, with comparison to plyoball throwing and a passive control condition. The study additionally examined PRS and its relationship with subsequent throwing velocity.

The literature review highlighted that the RWU strategies are indeed effective in mitigating performance declines following passive rest. This was primarily through the maintenance of muscle and core temperature, neuromuscular activation, and mechanical readiness. The evidence points to the fact that both aerobic and high-intensity or explosive activities can support the preservation of power, sprint, and COD performance. Additionally, dynamic mobility exercise may also help maintain ROM. Emerging research indicates that RWU may positively influence psychological factors such as perceived readiness to perform, although this area remains very underexplored. Together, these findings emphasise that RWU is effective in mitigating performance declines due to intermissions, but the effectiveness may be dependent on the specific demands of the sport and the characteristics of the intervention, while also highlighting a lack of research in sport-specific and overhead-throwing contexts.

Although the experimental chapter did not reveal a statistically significant main effect of condition on throwing velocity, the combination of a large effect size, significant pairwise differences and consistent descriptive trends suggests that EMC may offer a practically meaningful advantage for maintaining throwing velocity following a brief intermission. No significant differences in shoulder ROM were observed between conditions, and no meaningful relationships were found between total ROM and throwing velocity. However, a significant negative correlation between ER and velocity in the control condition suggests that, in the absence of RWU, increases in ROM may be associated with reduced performance. PRS differed significantly across conditions, with EMC producing the highest scores, followed by plyoball and control conditions. While no pairwise differences reached statistical significance, these trends suggest that there is still potential for future research in this area. A moderate positive trend between PRS and velocity was observed in the plyoball condition, indicating that perceived readiness may influence performance in certain contexts.

Overall, these findings suggest that EMC may be an effective strategy for maintaining throwing velocity and enhanced perceived readiness after short intermissions, although further research is required to confirm these effects with larger sample sizes.

## 4.2 Practical Applications

The findings in this study could influence future research and practical applications for coaches and practitioners and overhead athletes, particularly in sports such as baseball, where repeated short intermissions are common.

Firstly, given that the control condition resulted in the greatest decline in performance, practitioners should avoid complete passive rest during intermissions where possible. Incorporating a structured RWU intervention may help mitigate performance declines associated with neuromuscular cooling. Through this study, we can see that the descriptive trends show that EMC could be a viable option to assist practitioners and athletes in preparing for resumed competition after an intermission.

Secondly, while plyoball RWU demonstrated some benefit, EMC also showed velocity maintenance and higher PRS. This may suggest that EMC may provide a more controlled neuromuscular stimulus, potentially offering advantages in managing fatigue and maintaining neuromuscular function. The findings relating to PRS highlight the importance of subjective measures in athlete preparation. Practitioners may consider integrating simple readiness scales to monitor athlete preparedness. Due to there being no meaningful changes in ROM, the performance benefits of EMC are unlikely to be driven by acute changes in joint mobility. Instead, mechanisms such as neuromuscular activation, muscle temperature maintenance, or musculotendinous stiffness may underpin the observed effects. This reinforces the importance of targeting neuromuscular readiness rather than solely focusing on flexibility during RWU routines.

## 4.3 Study Limitations

This thesis provided some insight into the effects of EMC as a part of RWU; limitations existed in both the experimental chapter and the literature review. In the broader thesis, the literature review was not conducted using a systematic approach, which was primarily due to the lack of research specifically investigating EMC within RWU contexts. While a narrative approach allowed the study to take a more flexible exploration of related concepts, it increases the risk of selection bias and may limit the comprehensiveness and reproducibility of the review. The literature also displayed a wide variability in methodological design, including differences in participant populations, RWU protocols, outcome measures and study design, making direct comparisons challenging and limiting the ability to draw definitive conclusions regarding the effectiveness of specific RWU strategies. The theoretical foundation underpinning this, the experimental design, should be interpreted with some caution because of these factors.

The primary limitation of the experimental study portion of this thesis was the small sample size, which reduced statistical power and increased the likelihood of Type II error. This limits the ability to detect true differences between the conditions and may partially explain the lack of statistically significant findings despite the presence of moderate to large effect sizes. The small sample may also reduce the generalisability of the findings to broader athletic populations.

The timing of the ROM assessments relative to the throwing bouts was also a limitation of the present study. Pre-intervention ROM was assessed following the initial throwing measurements, whereas post-intervention ROM was measured prior to the second bout of throwing. Since dynamic activity such as throwing has been shown to acutely increase ROM, these timepoints represent different physiological states. Direct comparisons between pre- and post-intervention ROM may be overshadowed by the effects of throwing, making it difficult to solely isolate the impact of the intervention.

Another limitation that should be mentioned was environmental variability. The study collected data in both outdoor and indoor environments due to the weather. The data was collected primarily outdoors to more closely simulate a common baseball environment, but adverse weather forced data collection to be moved indoors occasionally. Although the testing environment was as similar as possible, there may have been some disparity regarding temperature and wind. When data collection was conducted outdoors without control of measurement of conditions such as temperature, wind, or precipitation, these factors may have influenced physiological readiness and performance outcomes. This may have introduced uncontrolled variability in the results due to the absence of recorded environmental data, which limited the ability to contextualise these potential effects.

Practical constraints related to equipment further implicated the study. The limited access to power sources restricted the flexibility of the testing set-up, and the reliance on a generator introduced background noise that may have disrupted participant focus, but posed as a significant barrier to participants signing up to the study. An attempted portable power solution was unsuccessful, as the battery that was purchased was unable to support the EMC device. These factors combined reduced the ability to establish a consistent and controlled testing environment.

The timing of the data collection for this study also posed a significant challenge in the present study. Data collection took place during the Christmas period and within the competitive season, which limited participant availability and contributed to a smaller sample size. This may have also introduced selection bias, as those available during this period may not be representative of the broader athletic population. Coordinating testing sessions around training and competition also complicated data collection. This made it difficult to ensure that participants were consistently assessed in a well-recovered state without interfering with performance demands. Consequently, some sessions may have been conducted under varying levels of fatigue, contributing additional variability to performance outcomes.

## 4.4 Future Research Directions

Future research should aim to address these limitations by improving experimental control and study design. The recruitment of larger samples outside peak holiday and competitive periods would enhance statistical power, reduce selection bias, and improve generalisability. Also, conducting testing in controlled environments, such as indoors or at least incorporating environmental monitoring, would allow for more accurate interpretation of performance outcomes. It should also ensure consistency in measurement timing, such as assessing ROM at the same time points relative to throwing, to allow for more accurate comparisons. Further investigation into EMC should focus on refining duration and timing within RWU contexts. Finally, future studies should examine the interaction between fatigue, PRS and performance, as well as explore the effectiveness of eccentric-based RWU strategies across environmental conditions and competitive settings. The continuation of this study would contribute to a more comprehensive and applied understanding of RWU in sport.

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# APPENDICES

## Appendix 1: Ethics Approval, Auckland University of Technology Ethics Committee

22 July 2025

Matt Brughelli
Faculty of Health and Environmental Sciences

Dear Matt

Re Ethics Application: **25/181 Eccentric Motorised Cycling as a Rewarm-Up Strategy for Baseball Pitchers**

Thank you for your responses to AUTEC's conditions.

Your ethics application has been approved for three years until 22 July 2028.

**Standard Conditions of Approval**

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

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

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

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

The AUTEC Secretariat
**Auckland University of Technology Ethics Committee**

Cc: Yuukischool1188@gmail.com; aaron.uthoff@aut.ac.nz

## Appendix 2: Consent Form

## Appendix 3: Parental consent form

# Consent Form

For use when laboratory or field testing is involved.

***Project title**: Eccentric Motorised Cycling as a Rewarm-Up Strategy for Male Baseball Pitchers*

***Project Supervisor**: Dr Matt Brughelli, Dr Aaron Ulthoff*

***Researcher:** Yuuki Takahashi*

○ I have read and understood the information provided about this research project in the Information Sheet dated 10/07/2025

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that participating in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged.

○ I understand that if I withdraw from the study, I will be offered the choice between having any data identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removing my data may not be possible.

○ I am not suffering from any current injury, illness, or disorder that may impair my ability to perform the required task.

○ I agree to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

○ I agree to answer questions and provide physical effort to the best of my ability throughout testing.

Participant's signature.......................................................................................................................

Participant's name: .......................................................................................................................

Participant's Contact Details (if appropriate):

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Date:

***Approved by the Auckland University of Technology Ethics Committee on 22 July 2025, AUTEC Reference number 25/181***

*Note: The Participant should retain a copy of this*

# Parent/Guardian Consent Form

***Project title**:* Eccentric Motorised Cycling as a Rewarm-Up Strategy for Male Baseball Pitchers

***Project Supervisor**:* Dr Matt Brughelli, Dr Aaron Ulthoff

***Researcher:*** Yuuki Takahashi

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 10/07/2025.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.
- ○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw my child/children and/or myself from the study at any time without being disadvantaged in any way.
- ○ I understand that if I withdraw my child/children and/or myself from the study then I will be offered the choice between having any data that is identifiable as belonging to my child/children and/or myself removed or allowing it to continue to be used. However, once the findings have been produced, removal of our data may not be possible.
- ○ I agree to my child/children taking part in this research.
- ○ I understand that my child is able to refuse to give assent to take part in this research.
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Child/children's name/s : ……………………………………………………………………………………

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Parent/Guardian's signature: …………………………………………………………………………………………

Parent/Guardian's name: ………………………………………………………………………………………………

Parent/Guardian's Contact Details (if appropriate):

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Date:

***Approved by the Auckland University of Technology Ethics Committee on 22 July 2025, AUTEC Reference number 25/181***

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

# Appendix 4: Information Sheet

## Participant Information Sheet

**Date Information Sheet Produced:**

10/07/2025

**Project Title**

Eccentric Motorised Cycling as a Rewarm-Up Strategy for Male Baseball Pitchers

**An Invitation**

My name is Yuuki Takahashi, and I am a master's student at Auckland University of Technology. I am conducting research alongside Associate Professor Matt Brughelli and Senior Lecturer Aaron Uthoff. Our study investigates the effects of upper-body eccentric cycling for shoulder activation on throwing velocity in baseball pitchers returning from a short break, such as between innings. We aim to determine the effects of eccentric cycling on throwing velocity and perceived readiness in baseball pitchers.

It is solely your choice as to whether you participate in this study or not. If you decide you no longer want to participate, you can withdraw yourself or any information you have provided for this study at any time prior to the completion of data collection. You will not be disadvantaged in any way. When you sign and date the consent form, you indicate your permission to participate in this study. Signing the consent form indicates that you have read and understood this information sheet, freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT.

**What is the purpose of this research?**

The purpose of this study is to investigate the effects of eccentric motorized cycling (EMC) as a shoulder activation method on throwing velocity and perceived readiness in overhead-throwing athletes following a brief intermission, such as between innings.

Historically, pitching velocity has been observed to decrease on the first pitch of a new inning. This drop in velocity may negatively impact performance by reducing pitch effectiveness over the course of a game. Maintaining velocity after an intermission is crucial for optimising in-game performance and sustaining competitive advantage.

Range of motion has also shown to change after intermission and can have an impact on injury risk, therefore we will also measure range of motion throughout testing.

We will also examine how subjective readiness scores (PRS) compare between re-warm-up protocols to better understand the relationship between perceived and actual performance.

The findings of this research may be used for academic publications and presentations and will contribute to the development of evidence-based warm-up and re-warm-up strategies for overhead-throwing athletes.

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

You have been identified as a potential participant for this research because you are a male baseball pitcher aged 16 to 28 with at least two years of experience and are either currently or previously representing New Zealand at a competitive level. You must also have no known medical conditions, be able to complete questionnaires and give informed consent. Also, individuals who have not experienced any major injuries in the last 6 months. This study focuses on examining the effects of eccentric cycling as a shoulder activation method on throwing velocity following a brief intermission, such as between innings.

### How do I agree to participate in this research?

If you agree to participate in this research, email me at nfy8648@autuni.ac.nz, to express your interest. You will be asked to report to the AUT-Millennium SPRINZ laboratory space, where you will be given written information about the testing procedure. Before signing the consent form, you will be given an opportunity to ask me any questions about the research study. Following this opportunity for questions or queries, you will be required to sign and date the consent form.

Participation in this research is your choice, and whether you participate will neither advantage nor disadvantage you. You can withdraw from the study at any time. Suppose you decide to withdraw from the study. In that case, you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, removing your data may not be possible once the findings have been produced.

### What will happen in this research?

Once you have decided to participate in the study, you will complete two familiarization sessions at the AUT Millennium Sports Hall or at a chosen public park. These sessions will ensure you understand the proper technique and form for the eccentric motorized cycling (EMC) exercise.

The study testing procedures are as follows:

Following familiarization, you will complete three testing sessions at either the AUT Millennium sports hall, or a chosen public park. This location will be kept consistent during the testing sessions to ensure a decreased chance of unwanted variability. One session with the EMC rewarm-up, one with a plyoball re-warm-up, and one with passive rest as the control condition. The order of these sessions will be randomised to prevent order effects.

Each session will begin with a standard warm-up that includes light jogging, arm stretches, resistance band exercises, and throwing with Plyo balls. After warming up, you will throw until you reach your top consistent velocity, measured with a radar gun.

Once you reach this velocity, you will take a 15-minute break to simulate the time between innings. Before throwing again, you will either rest (control session) or complete a 1-minute cycling warm-up after 13 minutes (EMC session), or complete a plyoball re-warm-up after 13 minutes (plyoball session). Just before resuming throwing, you will rate how ready you feel to throw using a simple 1-5 scale.

Range of motion will also be tested after the full warm-up, before the interventions, and after the interventions to understand the effect of the interventions on range of motion.

Participants will first complete 5 warm-up throws, which will be recorded but not used in the primary analysis. These will be followed by 5 test throws, which will constitute the dataset for analysis.

### What are the discomforts and risks?

#### What discomforts or risks might I experience?

During the testing sessions, you will be asked to perform a warm-up, throw at maximum effort, and complete a short cycling warm-up in one of the sessions. Because of this, you may feel temporary muscle fatigue or mild discomfort, especially in your throwing arm and shoulders. After the session, it is possible to experience slight muscle soreness for a day or two, similar to what you might feel after a regular throwing session.

#### How will these discomforts and risks be managed?

To minimise the risk of soreness, you will complete two familiarisation sessions before testing to help your body adjust to the cycling warm-up. If you feel any discomfort at any point during testing, you are encouraged to let the researcher know immediately so they can assist you.

### What are the benefits?

As a participant in this study, you will gain practical experience with an eccentric cycling warm-up, which may help improve shoulder activation and maintain throwing velocity after a break. Additionally, you will receive insights into how different warm-up methods impact your throwing performance, including how an intermission can impact your throwing velocity. By understanding how your body responds to eccentric cycling compared to traditional warm-up methods, you may discover new strategies to optimise your throwing preparation and overall performance.

**What compensation is available for injury or negligence?**

In the unlikely event of a physical injury because of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

**How will my privacy be protected?**

Although the researchers collecting the data will be aware of the participants' identities due to the nature of the study, we will ensure participant privacy and confidentiality by employing coded identifiers throughout the research process. Immediately after data collection, all participants' names will be removed from the dataset to maintain their confidentiality. The information of the participants will only be accessible to the researchers involved, and all results will be stored in a password-protected Excel spreadsheet. Any publications resulting from the study will not contain any identifiable details of the participants.

**What are the costs of participating in this research?**

Besides your time and effort, you will not have a financial cost to participate in this study. You must attend two 30-minute practice sessions before the testing session to become familiar with the movements. The three testing sessions will take approximately 45 minutes each to complete. The testing sessions will be separated by 72 hours. In total, the participant will report to the testing site 5 times. You will also be compensated for your time with $15 fuel voucher to thank you for your time.

**What opportunity do I have to consider this invitation?**

We would appreciate it if you could let us know within **two weeks** whether you would be available to participate in the study. After consideration, you may withdraw your participation at any time.

**Will I receive feedback on the results of this research?**

Yes, if requested, we can provide a comparison between each exercise protocol. If indicated on the consent form, after the completion of the study, a summary of the research will be sent out to you. Whether you share this information with a health professional or others is your choice.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Matt Brughelli, matt.brughelli@aut.ac.nz, 09 921 9999 x7025 or 027 221 7777.

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

**Whom do I contact for further information about this research?**

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

## *Researcher Contact Details:*

Yuuki Takahashi

Email: nfy8648@autuni.ac.nz

## *Project Supervisor Contact Details:*

Dr Matt Brughelli, Sports Performance Research Institute New Zealand (SPRINZ), School of Sport and Recreation, Faculty of Health and Environmental Sciences, AUT University, Private Bag 92006, Auckland 1020, matt.brughelli@aut.ac.nz, 09 921 9999 x7025 or 027 221 7777.

***Approved by the Auckland University of Technology Ethics Committee on 22 July 2025, AUTEC Reference number 25/181***