INFLUENCE OF POST-ACTIVATION PERFORMANCE ENHANCEMENT ON LOWER LIMB MUSCLES AFTER CONDITIONING ACTIVITIES AMONGST SELECTED EXERCISE PARTICIPANTS: RANDOMIZED CONTROLLED TRIAL

by

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Abstract

Design: A repeated measures mixed-design ANOVA was used to evaluate the effects of two different tempos of conditioning activities using the back squat exercise on countermovement jump performance in untrained young adults. **Methods:** Fifty-four healthy untrained participants completed two experimental sessions and one control session across three separate days. Each ~ 32-minute session began with a standardized warm-up, followed by a baseline countermovement jump (CMJ). After baseline, participants performed their assigned protocol: for the dynamic muscle action condition (DMAC), 3 sets of 10 repetitions (reps) at 60% one repetition maximum (1RM) with tempo <1/0/<1/0 seconds; for the traditional muscle action condition (TMAC), 3 sets of 5 reps at 60% 1RM with tempo 2/0/2/0 seconds; and for the control condition (CON) [no conditioning activity (CA)]. A post-CMJ was recorded immediately after each protocol. **Results:** A total of 162 trials were collected, but 150 valid trials were included after 12 trials were excluded due to ForceDecks errors affecting 4 participants' data. Using repeated measures mixed-design ANOVA with Greenhouse-Geisser correction, take-off peak force (TPF) did not differ across conditions, $F(1.48, 70.80) = 0.045$, $p = .913$ and TPF also did not change across time points. Males outperformed females in all conditions and at both time points $p < .001$. Concentric impulse (CI) showed no main effect of condition, but there was a condition × sex interaction with males outperforming females in all three conditions, $p < .001$. A condition × time interaction: post-CI improved compared to pre-CI for DMAC, while CON post-CI worsened compared to baseline CMJ. Peak power (PP) showed no main effect of condition or time, yet a significant three-way interaction driven by sex emerged, with males outperforming females across conditions and time points, $p < .001$. Jump height (JH) showed a significant condition × time interaction. Post-JH stayed the same as pre-JH for both CAs, but CON post-JH dropped significantly compared to TMAC post-JH, $p = .020$, and compared to CON pre-JH, $p = .003$. **Conclusions:** Slow tempo did not significantly improve participants' CI, however, fast tempo increased participants' CI, and CON decreased participants' CI. Post-JH performance dropped drastically in CON, while both slow and fast tempo conditions only helped participants maintain post-JH performance.

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Dedication

This thesis is dedicated to all the research participants who took part in this study. Your time, effort, and consistent commitment were invaluable to the success of this work. Thank you for making this research possible.

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Table 3.1 Baseline measurements

Table 3.1. depicts the results of fifty participants' baseline measurements. N = number of participants, BMI = body mass index, FFM = fat free mass, FM = fat mass, 1RM = one repetition maximum, cm = centimeter, kg = kilogram, kg/m^2 = kilogram per meter square.

Table 3.2 Data in mean and standard deviation

Table 3.2. is a tabular representation of data in mean and standard deviation. $\bar{X}$ = Mean, SD = standard deviation, n = number of participants, TPF = take-off peak force, CI = concentric impulse, PP = peak power, and JH = jump height.

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Abbreviations and Meanings

2/0/2/0 – 2 = 2 seconds eccentric and concentric, 0 = no pause

<1/0/<1/0 – <1 = as fast as possible eccentric and concentric, 0 = no pause

CONI = Concentrically loaded Isometric

CA = Conditioning Activities

CON = Control Condition

CI = Concentric Impulse

CI = Confidence Interval

CMJ = Countermovement Jump

DMAC – Dynamic Muscle Action Condition

ECCI – Eccentrically loaded Isometric

EMG – Electromyographic

ISOMS – Isometric

ISOTS – Isotonic

IMTP – Isometric Mid-thigh Pull

JH = Jump Height

MVC – Maximum Voluntary Contraction

MVIC – Maximal Voluntary Isometric Contraction

PAP – Post-activation Potential

PAPE – Post-activation Performance Enhancement

PP = Peak Powe

RFD – Rate of Force Development

RLC – Regulatory Light Chain

SJ – Squat Jump

TMAC – Traditional Muscle Action Condition

TPF = Takeoff Peak Force

Chapter 1 – Research Model

1.1. Introduction

Post-activation performance enhancement (PAPE), as described by a plethora of studies, is a phenomenon that helps exercise participants to improve performance (see Appendix I). Accordingly, related studies (see Appendix I) have found that such improvement can be due to a group of muscles having undergone certain muscle tension as a result of a conditioning activity (CA). Furthermore, enhancing performance in voluntary activities after a maximal or submaximal muscle contraction (i.e., a conditioning activity [CA]) is attributed to PAPE (Cuenca-Fernández et al., 2017; Seitz & Haff, 2016); the use of such strategies has been shown to be effective in sports and/or movement performance that involve dynamic muscle actions including, sprinting, throwing, and jumping (Seitz & Haff, 2016; Wilson et al., 2013).

Additionally, it was demonstrated that a variety of movement tempos can be employed during resistance training to promote muscle hypertrophy, according to data from earlier studies (Schoenfeld et al., 2015). Moreover, PAPE was posited by Fu et al. (2023) to suggest the enhancement of maximum voluntary strength, power or speed either dynamic or static, after a CA. These enhancements contribute to improved strength and power in jumping and sprinting exercises (Blazevich & Babault, 2019; Prieske et al., 2020). Notably, hypertrophy and strength are two prevalent long-term objectives of resistance training, influenced by the adjustment or modification of several factors such as load, volume, exercise sequence, exercise choice, and rest intervals between sets, among others (Grgic et al., 2017; Nunes et al., 2021; Schoenfeld et al., 2016; Schoenfeld et al., 2017). Nonetheless, a frequently overlooked training element that is crucial for attaining these objectives is the movement tempo of certain repetitions (Wilk et al., 2021).

Prior studies have examined various movement tempos, weights, and repetition counts, demonstrating that modifications to these factors impact physiological reactions such hormone and blood lactate levels (Rogatzki et al., 2014; Tanimoto & Ishii, 2006; Watanabe et al., 2014; Wilk et al., 2018). Consequently, it may be assumed that modification of movement tempos may impact females differently, these disparities in CMJ performance may be as a result of muscle structure and neuromuscular activation patterns (Komi, 1984; Mangine et al., 2014). Behm et al. (2025) noted that a missing ingredient in many sport science papers is the under-representation of females in the study groups as well as their contributions as research authors. Therefore, recommended that more research is needed to highlight possible sex differences. A previous study reported males to have faster movements through the full range of motion and accelerations, and faster rates of electromyography (EMG) rise (Ives et al., 1993). They postulated that the females were more neutrally constrained (rapid EMG activation of the triceps brachii) resulting in limits in the braking process.

Another study reported that maximal voluntary strength (torque) of the tibialis anterior accounted for sex differences in voluntary rate of torque development (Inglis et al., 2017). They also suggested that over just three testing days, a greater rate of increase in EMG with a significant reduction in electromechanical delay may reveal that females might incorporate a different motor unit activity pattern than males at contraction onset. Further, Behm et al. (2025) emphasized that there were peripheral (muscle) evoked sex differences, with females experiencing longer evoked electromechanical delay but no differences in voluntary electromechanical delay.

However, one of the earliest studies to compare untrained males and females, reported that relative strength was similar between sexes after 10 weeks of intensive resistance training when expressed relative to body weight (Wilmore et al., 1974). Other earlier studies reported that motor unit activation capacity was similar between males and females (Belanger & McComas, 1981; Young, 1984). Further, one study compared motor unit numbers in the biceps brachii and vastus medialis and reported no sex differences (Miller et al., 1993). The same research group also reported no differences in motor unit activation during elbow flexion or knee extension between sexes (Miller et al., 1993). Additionally, studies of single fibers report similar force per cross-sectional area and contractile velocity in type I and type II fibers across sexes (Trappe et al., 2003). However, it is also possible that untrained females may also begin with a lower baseline level of fitness compared to untrained males (Shephard, 2000). Similarly, researchers believe that a key consideration in comparing the responses in males and females is that pre-training levels of muscle size and strength are generally greater in males, independent of training status (Alway et al., 1989; Janssen et al., 2000; Roth et al., 2001). Despite existing research, the major sex differences across neuromuscular, muscular, and hormonal domains in response to resistance training have not yet been consolidated in a single review (Alway et al., 1989; Janssen et al., 2000; Roth et al., 2001).

Additionally, across most studies, males demonstrate greater increases in absolute strength compared to females (Daniels et at., 1982; Dias et al., 2005; Rutherford & Jones, 1986). Nevertheless, several studies find that relative improvements in muscle strength and hypertrophy are similar for males and females (Abe et at., 2000; Häkkinen et al., 1998; Hostler et al., 2001; Hunter, 1985; Hurlbut et al., 2002; Jozsi et al., 1999; Kosek et al., 2006; Roth et al., 2001; Salvador et al., 2009; Staron et al., 1994; Weiss et al., 1988), while other studies reported that females exhibit greater relative strength gains than males (Carlsson et al., 2017; Cureton et al., 1988; Hubal et al., 2005; Ivey et al., 2000; Jozsi et al., 1999; Kell, 2011; Martin Ginis et al., 2005; O'Hagan et al., 1995; Peterson et al., 2011; Ribeiro et al., 2014; Stock & Thompson, 2014). Notably, Hubal et al. (2005) observed higher relative strength improvements in females than in males in one of the largest investigations of sex differences to date.

Collectively, there are limited sex differences in skeletal muscle properties between males and females (Roberts et al., 2020). Similarly, the effects of CA were not significantly different between males and females (Wilson, 2013). However, if data from both sexes are collapsed, and their responses differ, a real effect can be missed. Likewise, if only one sex was included in the study, the potential sex-based differences cannot be analyzed. Therefore, including both males and females allows us to test for potential sex-specific responses (Piñero et al., 2025), rather than assuming transferability from male-only samples. This may help improve external validity and address a noted gap in PAPE research.

Another key factor in PAPE is warm-up. In research, it is critical to control for as many confounding variables as possible therefore, to determine whether PAPE enhances performance, muscle temperature must be controlled, as it can independently improve performance (Asmussen & BØJe, 1945). Similarly, Macintosh et al. (2012) highlighted that performance enhancements following conditioning activities are often attributed to warm-up protocols. However, it is not clear whether these effects are due to acute neuromuscular alterations from the conditioning activity or merely reflect the effects of a general warm-up therefore, the researchers suggested that a standard warm-up may be compared with a modified (experimental) procedure (Macintosh et al., 2012). Ultimately, a common limitation in literature is the absence of, or insufficient, warm-up prior to the conditioning activity (Hamada et al., 2000), thus restricting the generalizability and external validity of the findings (Mina et al., 2019). Consequently, this study protocol simulates Low et al. (2019) and Masel & Maciejczyk (2022).

In addition to other factors previously examined in relation to PAPE, some studies explored the anabolic process after altering certain factors during exercise. It was opined that since the anabolic process is an intricate process, altering one factor (tempo, for example) can have a direct or indirect impact on other factors that are similarly important to anabolic processes (load, number of repetitions performed, TUT, fatigue etc.) (Wilk, Tufano, et al., 2020). Overall, the number of repetitions completed in a single set is impacted by abrupt changes in movement tempo (Sakamoto & Sinclair, 2006).

Similarly, the maximum number of repetitions that may be performed with a slower movement tempo is less than that of a faster tempo when calculating training volume using sets*repetitions with the same load and activity (Sakamoto & Sinclair, 2006; Wilk et al., 2018; Wilk et al., 2019; Wilk et al., 2020). Wilk et al. (2021) posited that intentional slow tempo can be strategically employed when the load is sufficiently light to maintain control, and fatigue does not impair one's capacity to regulate movement velocity, while an unintentional slow tempo may arise during resistance training, primarily due to a heavy load or the onset of exhaustion, resulting in prolonged movement length throughout repetitions (Mookerjee & Ratamess, 1999). Therefore, there is a limit to how much deliberate control over the movement tempo is feasible (Suchomel et al., 2019a; Suchomel et al., 2019b), strength is a limiting factor during concentric motions, but it may be somewhat controlled during eccentric actions, where loads even higher than 100% of 1RM can be controlled (Wilk et al., 2021).

Additionally, Morrissey et al. (1998) compared fast (1/0/1/0) and slow (2/0/2/0) movement tempos and reported that the fast tempo led to greater performance improvements.

Likewise, Munn et al. (2005) found that 6 weeks of fast-tempo (1/0/1/0) training produced larger strength increases than slow-tempo (2/0/2/0) training in untrained individuals.

1.2. Review of Literature

1.2.1. Maximum Voluntary Contraction (MVC)

The enhancement of MVC has been identified by many studies to enhance jumping performance (Baudry & Duchateau, 2007; Hamada et al., 2000; Vandervoort et al., 1983). A submaximal voluntary contraction or MVC in skeletal muscle has been found to increase twitch torque which is an increased peak force generated by the skeletal muscles (Miyamoto et al., 2011). Furthermore, Gullich & Schmidtbleicher (1996) also observed remarkable increases in jump height after 3 to 5 sets of 5-second isometric MVC of leg press. Meanwhile, other studies have shown that plyometric training improves isometric maximum voluntary contraction (MVC) strength (Cornu et al., 1997; Kyröläinen et al., 2004; Spurrs et al., 2003). Further, studies have shown that enhanced agonistic muscle activation after plyometric exercise leads to increases in the plantar flexors' isometric MVC strength (Kubo et al., 2007; Kyröläinen et al., 2004).

Interestingly, enhancing performance in voluntary activities after a maximal or submaximal muscle contraction (i.e., a conditioning activity [CA]) is attributed to PAPE (Cuenca-Fernández et al., 2017; Seitz & Haff, 2016); the use of such strategies has been shown to be effective in sports and/or movement performance that involve dynamic muscle actions including, sprinting, throwing, and jumping (Seitz & Haff, 2016; Wilson et al., 2013). Similarly, PAPE was posited by Fu et al. (2023) to suggest the enhancement of maximum voluntary strength, power or speed either dynamic or static, after a CA. These enhancements contribute to improved strength and power in jumping and sprinting exercises (Blazevich & Babault, 2019;

Prieske et al., 2020). According to González-Alonso et al. (2000), the time course of the peak rise in temperature following a vigorous activity session appears to coincide with the time course where PAPE should exhibit its peak effect, which is approximately 5–10 minutes after the CA.

Ultimately, Tsoukos et al. (2016) found that twelve minutes after the warm-up, three 3-second isometric contractions at 50–90% of the maximum voluntary isometric contraction (MVIC) in the 140-knee flexion squat exercise significantly increased CMJ height (Tsoukos et al., 2016).

1.2.2. Eccentric and Concentric Contraction of the Muscles

Many studies have investigated the effects of PAPE using dynamic actions (concentric and eccentric contractions) like stretch-shortening cycle to compare with isometric muscle contractions and researchers are still working on this (Esformes et al., 2011). As a result, Vargas-Molina et al. (2021) compared the acute effects of applying an isometric activation protocol and an isotonic dynamic one on the CMJ performance after one and two sets of the back squat exercise. The study found that PAPE response was achieved after a single set of the selected exercise in both conditions, likewise, a significant increase in vertical jump performance were observed in both isometric (ISOMS) (2.8%) and isotonic (ISOTS) (2.3%) conditions (Vargas-Molina et al., 2021).

Garner et al. (2008) investigated how different loading combinations affect the electromyographic (EMG) amplitude in order to induce isometric muscle contractions. According to the study, there are no variations in the EMG amplitudes linked to isometric contractions where the muscle is trying to resist lengthening (eccentrically loaded isometric - ECCI) as opposed to isometric contractions where the muscle is trying to shorten (concentrically loaded isometric - CONI). The results of the study show that isometric contractions loaded in an eccentric or concentric manner produce equal EMG amplitudes when used in research settings thus, permit direct comparison between research because it was discovered that the isometric muscle contractions when loaded eccentrically and concentrically were similar (Garner et al., 2008).

Notwithstanding, understanding that fatigue may influence research outcomes may help reduce its impact (Kay et al., 2000). This indicates that in order to achieve a potentiating effect larger than exhaustion following a CA, a proper rest period must be given which will boost performance beyond what would be anticipated from traditional training methods (Enoka & Stuart, 1992). Further, existing research indicates that the type, intensity, and duration of contractions may have an impact on how fatigue develops (Enoka & Stuart, 1992; Tesch et al., 1990).

1.2.3. Conditioning Activity (CA)

PAPE, as investigated, has been suggested to indicate the enhancement of maximal voluntary (dynamic or isometric) strength, power, or speed after a conditioning muscle action (Fu et al., 2023). This neuromuscular phenomenon enhancing voluntary muscle performance is effective after a CA in, generally, at a time window between 3 – 10 minutes (Cuenca-Fernández et al., 2017; Cuenca-Fernández et al., 2019; Cuenca-Fernández et al., 2020; Cuenca-Fernández et al., 2023), and most importantly, it contributes remarkably to PAPE and practical applications in athletic performance enhancement (Fu et al., 2023).

Accordingly, considering the importance of CA as a determinant of PAPE, Vasconcelos et al. (2023) stratified studies that employed a non-specific warm-up before CA from those that used CA in lieu of warm-up. Neither the presence nor the absence of a non-specific warm-up exercise before CA played a moderator role in the PAPE effects thus, CA is considered a key factor for the effect of PAPE (Boullosa et al., 2018).

1.2.4. Take-off Peak Force (TPF), Concentric Impulse (CI), Peak Power (PP) and Jump Height (JH)

By using dimensional reduction strategies to discover force-time measures, practitioners can concentrate on the most pertinent metrics that include distinct information, thereby producing the best training adaptations throughout successive training blocks (Merrigan et al., 2022). Similarly, by defining groups of variables based upon contributions to performance variability, positional differences in strategy can be discovered to inform the establishment of valuable performance characteristics (James et al., 2021; Jiménez-Reyes et al., 2017).

Accordingly, peak power was defined as the maximum immediate power obtainable before takeoff (Amonette et al., 2023) Additionally, Merrigan et al. (2022) noted that several overlapping variables such as peak power, contribute similarly to the explained variance of CMJ performances. Further, given that jump height is derived from impulse momentum, differences in jump height will be strongly associated with peak velocity and power (Linthorne, 2021). Likewise, regarding the impulse–momentum concept, mechanical impulse dictates the velocity of the body's center of mass at the final point of a push-off (i.e., take-off velocity) and, consequently, the jump height (JH) (Kirby et al., 2011; Knudson, 2009; Mohr & Krustrup, 2013 Nedelec et al., 2014).

Notwithstanding, it is currently unclear which metrics are most crucial to track the variables that are most closely associated with jump height, and it makes sense to monitor parameters like concentric impulse and peak power or velocity (Merrigan et al., 2022). Hughes et al. (2022) noted that discrete characteristics (e.g., jump height, peak power), the timing of distinctive events (e.g., start of braking phase, start of concentric phase), or waveform shape (e.g., unimodal, bimodal) are commonly taken into account in analyses. Similarly, the variable of interest in identifying factors that contribute to jump timing efficiency is the time to take-off (TTO). At take-off, maximizing center of mass velocity is equivalent to maximizing net impulse, usually by minimizing eccentric time and/or increasing mean concentric force (Laffaye et al., 2014). Thus, to optimize impulse, take-off force, and the resulting vertical center of mass displacement (i.e., jump height), the CMJ requires the best possible coordination and timing of force output (Merrigan et al., 2022c).

Importantly, Attia et al. (2017) describes JH as the measurement of flight time (FT) or vertical response force. Chiu & Dæhlin (2020) defines JH as the difference in the body's center of mass's vertical position between standing and the height of the jump. For many sports, JH performance is one of the key functional factors (Ziv & Lidor, 2010). Consequently, athletes' abilities to jump quickly and high determine whether a certain sporting action (e.g. jumping events) is successful or unsuccessful (McNitt-Gray, 1991; Reiser et al., 2006; Van Hooren et al., 2017).

Ultimately, more research is necessary across the sports sector to inform practitioners of variables that are related to performances in their sport (James et al., 2021).

1.2.5. Countermovement Jump (CMJ)

The CMJ is one of the most commonly used tests to evaluate neuromuscular performance in athletes (Van Hooren & Zolotarjova, 2017). A CMJ is an explosive jump that accelerates the center of mass vertically to leave the ground by first moving downward and then upward (Amasay & Suprak, 2022). It is widely used as a basic test that reveals the neuromuscular and stretch-shortening cycle (SSC) capacities of the lower extremities (Pérez-Castilla et al., 2021). It has been proposed that the difference between movement performance with and without CMJ is caused by the performance-enhancing effect of the SSC (McGuigan et al., 2006); however, there may be other factors providing the performance-enhancing benefits which will be further explored in the following section.

CMJ is performed in a way where the individual starts while in a standing position and then takes a downward movement which is instantly followed by an upward movement, which leads to the take-off (Van Hooren & Zolotarjova, 2017). Subsequently, during the downward movement in CMJ, the average angular velocities of the ankle, knee, and hip joint are about 0°, 133–199°, and 216° per second respectively (Bobbert et al., 1996; Finni, Ikegawa, et al., 2001; Kurokawa et al., 2003). Further, Van Hooren & Zolotarjova (2017) noted that the height attained, or power exerted during a CMJ is higher than that of the one produced during squat jump (SJ). Exploring the mechanism behind CMJ further, Van Hooren & Zolotarjova (2017) noted that the stretch-shortening cycle is commonly defined as a muscle stretch followed by a shortening phase. They further stated the muscle's stretching and shortening components are not differentiated, which might result in inaccurate readings. For instance, it is frequently believed that when the CMJ descends, the fascicles of the leg muscles undergo an eccentric activity, or active lengthening. The fascicles do stretch during the descending phase of a CMJ, according to some research, although this lengthening is generally passive and mostly affects monoarticular muscles (Finni et al., 2000; Finni, Ikegawa, et al., 2001; Finni, Ikegaw, et al., 2001; Van Hooren & Zolotarjova, 2017).

Furthermore, other studies (Finni et al., 2001; Kurokawa et al., 2003) demonstrated shortening of fascicles, while others suggest an isometric action of the contractile element during the downward phase of a CMJ (Kopper et al., 2013; Kopper et al., 2014). Therefore, it was postulated that there is usually no active lengthening (i.e., eccentric action) of the fascicles during the downward movement of the CMJ although, the fascicles may passively lengthen only during slowly executed, submaximal, and large-amplitude (i.e., deep countermovement). CMJs dissipate energy; on the other hand, at quicker, maximal effort, and small-amplitude jumps, the muscles remain isometrically or concentrically contracted (Kopper et al., 2013; Kopper et al., 2014; Roberts & Konow, 2013). Accordingly, Kopper et al. (2014) & Kurokawa et al. (2003) added that muscle fibers do not necessarily lengthen during the downward phase of the countermovement.

As regards measurement and duration, the CMJ as measured from the start of the downward movement until take-off ranges from 500 to 1,000 milliseconds (Van Hooren & Bosch, 2016). Thus, a decrease in the duration of active state may lead to an increase in the utilization of elastic energy [this is defined as the energy preserved and re-used during joint flexion and extension respectively] (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978; Vanrenterghem et al., 2008) during the CMJ (Arakawa et al., 2010). Conclusively, CMJ has been shown to be appropriate for assessment of the PAPE effect following a back squat CA (Gołaś et al., 2016; Krzysztofik et al., 2020). This is because it provides an assessment of the capability to quickly produce force in SSC movements (Van Hooren & Zolotarjova, 2017), hence why it is suitable for the present proposed study. Accordingly, it is thought that residual force enhancement, as a result of SSC, also occurs during a CMJ, and it could therefore partially explain the superior acute performance during a CMJ.

1.2.6. Statement of the problem and objective

It has been speculated that intentionally slowing the movement tempo decreases lifting momentum, boosting muscular activity that may favorably modulate intracellular anabolic signaling, and increase the hypertrophic response (Schoenfeld et al., 2015). In addition, there is also evidence that intentionally slowing down the movement tempo of a single repetition can raise muscle activation for a certain number of repetitions (Burd et al., 2012; Wilk et al., 2020). Thus, altering the movement tempo may have a beneficial or adverse impact on skeletal muscle growth, contingent on numerous other interrelated factors (Wilk et al., 2021).

Further, some studies have demonstrated that, in contrast to faster tempos, slower tempos result in a lesser load lifted during 1RM tests (Headley et al., 2011; Wilk, Gepfert, et al., 2020). Wilk, Golas, et al. (2020), suggested that reduced tempos intensify the intensity of effort for a specified load, and that the intensity of effort will vary when the same load is utilized during training at differing tempos (based on a volitional tempo one-repetition maximum test) (Wilk et al., 2021). Therefore, the impact of movement tempo on strength may be associated with the type of exercise (Wilk et al., 2021). The purpose of this study was to investigate how TMAC and DMAC conditioning activities influence PAPE effects on countermovement jump height in untrained individuals. A secondary purpose was to examine mechanistic outcomes including CI, PP, and TPF, which were examined to elucidate potential mechanisms underlying the post-activation performance enhancement phenomenon. Previous research has identified concentric impulse (Kubota et al., 2026), peak power, and takeoff peak force (Rong et al., 2025) as indicators of jump height performance. Further, while PAPE has been well-documented in trained athletes and CA following multiple weeks training (Bottaro et al., 2007; Keeler et al., 2001; Morrissey et al., 1998; Munn et al., 2005; Neils et al., 2005; Westcott et al., 2001), it remains unclear whether untrained individuals with limited training experience, acute CA training and reduced training loads can also benefit from the neuromuscular performance. Thus, the present study sought to address this gap. Additionally, the current study used intentionally slow and fast tempos against a control condition, with the back squat exercise to explore the influence of tempos on performance. The most used exercise in PAPE research is the back squat (Krčmár et al., 2021; Mina et al., 2019; Popp Marin et al., 2021; Wyland et al., 2015).

1.2.7. Research Hypotheses

The study had the following hypotheses:

1. There will be a significant difference in JH, CI, PP, and TPF among the three conditions from pre- to post-assessment with the dynamic conditioning exercise condition performing the best of all three conditions.
2. There will be a significant difference in JH, CI, PP, and TPF between male and female participants with the male participants performing better than the female participants in the three conditions.

Chapter 2 – Methods

This study utilized a repeated measures mixed-design ANOVA in which participants were randomly assigned to one of six sequences (ABC, ACB, BAC, BCA, CAB, or CBA), which indicated the order in which they performed the three conditions. These conditions were A=TMAC, B=DMAC, and C=CON. Permuted block randomization was used to generate the allocation sequence. For each block of 6 participants, the six possible condition sequences were written on identical cards, placed in an opaque material, and thoroughly mixed. An independent person drew cards sequentially without replacement to determine the order within each block. This process was repeated to generate nine blocks for the total sample of 54 participants. In addition, block size was set at six, and allocation concealment was maintained during sequence generation. The person drawing cards did not view the sequence on each card until after it was drawn and placed face-down.

In addition, the drawn order was then entered into a password-protected Excel file by the principal investigator. The Excel file containing allocation data was inaccessible to participants, and participants were unaware of the coding scheme used for the different interventions. Participants were blinded to intervention allocation until immediately before administration of each condition. Due to the distinct nature of DMAC, TMAC, and CON, it was not possible to blind participants or the PI to the intervention once administered. All participants were blinded with the tempo interventions and completed four sessions over the course of thirteen days in a counterbalanced order.

Further, there were four dependent variables (CI, PP, TPF, and JH) used to assess participants' CMJ in the study. Vertical ground reaction force data were collected at 1000 Hz using dual portable ForceDecks (VALD FDLite, Australia). Body mass was determined from a 1-s quiet standing period prior to each jump and was used to establish a body mass offset. For each CMJ, four dependent variables were calculated from the force-time curve. Concentric Impulse was calculated as the time integral of net vertical force from the onset of propulsion to takeoff. That is, the total force applied over time during the upward propulsive phase. Peak Power was computed as the maximum value of the instantaneous product of net vertical force and center of mass velocity, where velocity was derived by integrating net force divided by body mass over time. Takeoff Peak Force was defined as the maximum net vertical force during the propulsive phase. That is, the highest force value obtained during the jump. Jump Height was calculated using the takeoff velocity method: $Jh = \frac{v_0^2}{2g} \times 100$, where JH is jump height in centimeters (cm), v_o is velocity at takeoff in meters per second, and g is acceleration due to gravity (9.81 meters per second squared) (VALD Performance, N.D; Cormack et al., 2008).

2.1. Experimental Approach to the Problem

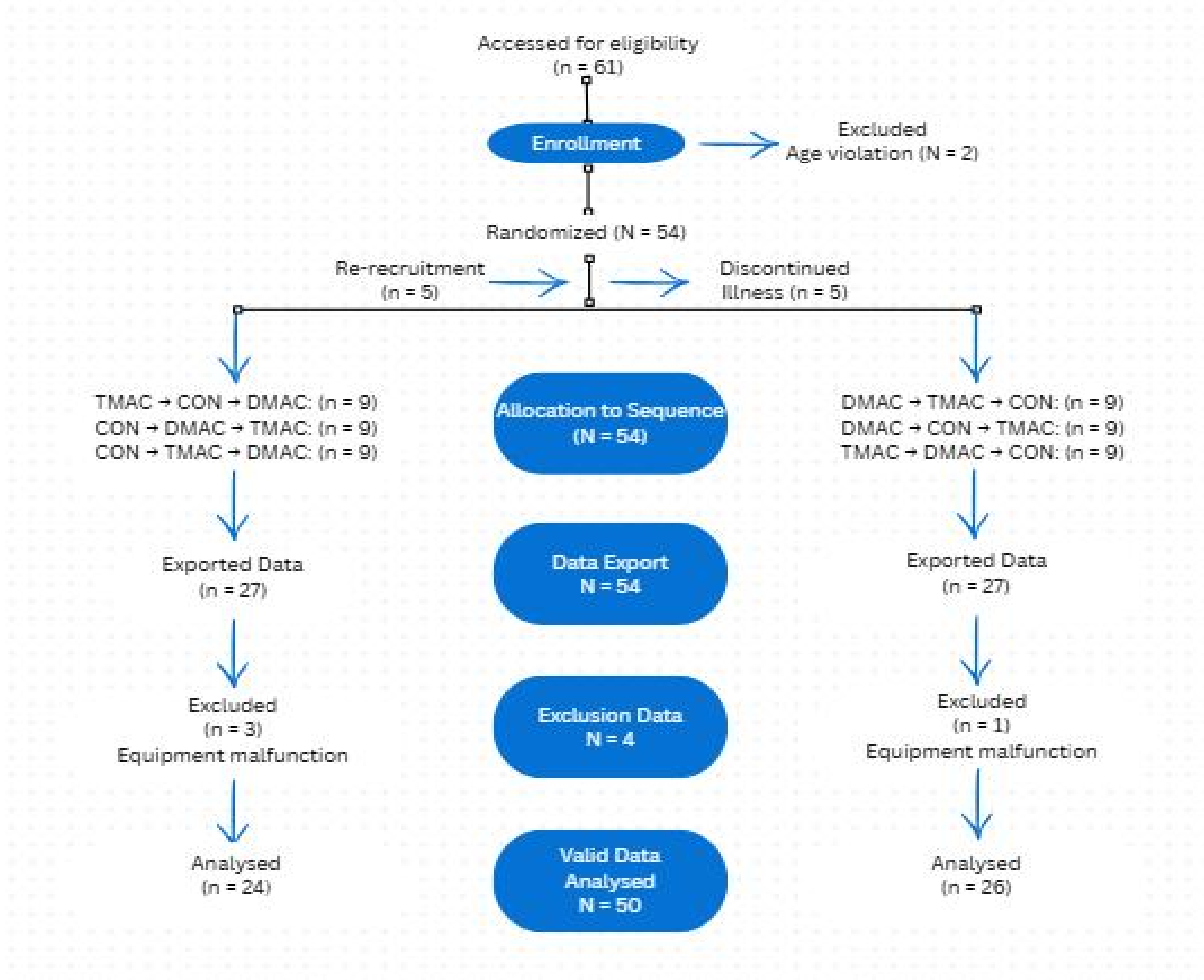
The protocol of this study simulates Warr et al. (2020), a study that explored the reliability of measurements during countermovement jump assessments. Each participant completed a total of four sessions separated by at least 72 hours (three days). The sessions were performed based on each participant's availability; however, each participant was tested for all sessions at the same time of the day as they came in for their first session. This was to eliminate time-of-day effect as a potential confounding variable. All the tests were completed at the High-Performance Training Centre, at the University of Manitoba. The participants were encouraged to attend the laboratory in their usual training clothes and wearing running shoes. The pretesting client guidelines (See Appendix IV) were sent to all participants prior to them attending their first session, which consisted of no eating or drinking within four hours of the test, no moderate or vigorous exercise within 12 hours of the test, void completely within 30 minutes of the test, abstain from alcohol consumption within 48 hours of the test, do not ingest diuretics, including caffeine, before the assessment, unless they are prescribed by a physician, and if you are in a stage of menstrual cycle during which you perceive you are retaining water, postpone testing.

Contrary to Warr et al. (2020), different testing protocols were conducted in all the sessions and involved 3 trials of hands-on-waist CMJ. Baseline measurements of age, sex, height, body mass, resting heart rate, resting blood pressure, body mass index, percentage body fat, fat mass, fat free mass, and one repetition maximum, were measured on the first session. In addition, participant ID's and order in which they perform the three conditions were randomly assigned to each participant. Each participant attended all 4 sessions and performed all the conditions.

2.2. Participants

Fifty-four (54) healthy untrained exercise participants aged 18-35 years (Please see Table 3.1. for baseline measurements) data was analyzed in the study. However, sixty-one (61) participants were recruited, two were subsequently excluded from the study due to violating age inclusion criteria: one was over the age limit, and one was under, while five participants discontinued the study due to illness unrelated to the study protocol. Consequently, five additional participants were recruited, randomized, and completed all three conditions (See Figure 2.1). Overall, the data from 50 participants was included in the final analysis. Four participants were excluded due to equipment malfunction during the testing. The recruitment periods took nine months. The sample size was based on a calculation using G*Power with an effect size of $\eta_p^2 = 0.043$ from a previous study (Masel & Maciejczyk, 2022), $\alpha = 0.05$, and $\beta = 0.10$. Other inclusion criteria required all participants to have at least two months of resistance training experience in order to prevent overuse injuries, the untrained population needs to have a fundamentally strong foundation, and plyometric exercises need to be cautiously applied (Leukel, Gollhofer, et al., 2008; Leukel, Taube, et al., 2008). This was confirmed through self-report during participant recruitment. Further, all participants that filled out the approved Get Active Questionnaire (GAQ) (See Appendix II) reported no injuries in the last six months before their participation in the study. Conversely, exclusion criteria included injuries in the last six months, participants younger than 18 or older than 35, and having less than two months of resistance training experience.

Additionally, the participants received a thorough written and verbal explanation of the research process in addition to a test demonstration (Warr et al., 2020). Likewise, the participants signed the approved informed consent form (See Appendix III) prior to coming in for their first session. The study, with study protocol number HE2025-0010, as well as other documents, were approved by the University of Manitoba's Research Ethics Board committee (See Appendices V & VI).



Participant Flow

Figure 2.1. depicts a within-subject crossover design. All participants received DMAC, TMAC, and CON in randomized order with a 3-day rest period between conditions. The data from 50 participants was included in the final analysis. Four participants were excluded due to equipment malfunction.

2.3. Procedures

2.3.1. Warm-up Protocol

The warm-up protocol was standardized and was performed at the beginning of each session (Warr et al., 2020). Warm-up exercises alter muscle temperature and activation, which affects performance in the following exercise bouts (Blazevich & Babault, 2019). The total duration of the warm-up was approximately 15 minutes (Warr et al., 2020), and it consisted of three phases. The first phase was a general warm-up to raise body temperature (Warr et al., 2020). Additionally, Vasconcelos et al. (2023) noted that since warm-up itself can influence performance, comparing CA to exercise without a preceding warm-up does not provide an adequate assessment of PAPE effects. Consequently, the warm-up session included five minutes of dynamic stretching (~60% of predicted maximal heart rate) (Bogdanis et al., 2014; Turki et al., 2011; Warr et al., 2020), the second was five minutes of cycling on a cycle ergometer (KEISER, Germany) (Lepak, 2007; Warr et al., 2020), at a heart rate of 60% of their age-predicted maximum heart rate (MHR) (Munro et al., 2017), measured with a heart rate transmitter (Polar H10, Malaysia) and wrist watch (Polar Electro OY, Finland), followed by approximately 5 minutes of self-paced drop jump, also at an intensity set at 60% of their age-predicted MHR with the same heart rate monitor used during cycle ergometer.

Further, participants were asked to rest when their heart rate exceeded 60% of their MHR and continue when it drops. Exercises such as drop jumps are deemed appropriate for warm-up session for PAPE studies (McGowan et al., 2015). Additionally, to reduce learning effects, Warr et al. (2020) suggested conducting at least one familiarization session prior to the initial testing session. Ultimately, static stretching activities were excluded based on prior suggestions that they may impair jump performance (Vetter, 2007).

2.3.2. Familiarization Session

The familiarization session consisted of three phases, including baseline and somatic measurements (Warr et al., 2020), familiarization of CMJ with drop jump exercise, and 1RM determination (Warr et al., 2020), on a Smith Machine (Warr et al., 2020).

2.3.3. Baseline and Somatic Measurements

In the first phase, during the baseline and somatic measurements, participants stood barefoot on the Bioelectrical Impedance Analysis machine and were told to uniformly distribute their body weight on the platform (Warr et al., 2020). A stadiometer (SECA, USA) was used to measure their heights (Warr et al., 2020), and the Bioelectrical Impedance Analysis machine (InBody 270, Korea) was used to measure body mass and body composition (body fat, fat free mass, fat mass, and BMI). Please see Table 3.1 for all baseline measurements.

2.3.4. Familiarization of CMJ with Drop Jump

The second phase of the familiarization session included drop jump since it mimics the assessment exercise, that is, CMJ. This was to help lower the incidence of injuries and improve physical performance (Pedley et al., 2017). In addition, the drop jump was used to improve performance and track participants' readiness for training (Markwick et al., 2015), as well as for injury-risk assessment (Noyes et al., 2005; Rathleff et al., 2014; Schmitz et al., 2014). Further, Behm et al. (2025) postulated that individuals who are not highly trained may receive larger magnitude training benefits in plyometrics training. In addition, according to Chen et al., (2013), drop jumps with a lower volume (e.g., within 10 repetitions) and a shorter recovery period (e.g., within two minutes) can have a good acute effect on CMJ performance.

Participants were asked to stand on the edge of a 12-inch-high box (UCS Strength & Speed, USA) with one of their feet raised above and outside the box. Then they were asked to drop with both feet into the squat position, then jump with both feet off the ground and land in the squat position. They were asked to continue this for approximately five minutes and may take rests in between especially when their heart rate goes above 60% of their age-predicted heart rate maximum.

The third phase of the familiarization session included 1RM determination on a Smith Machine. Participants performed a standardized warm-up and the subsequent 1-RM for the back squat resistance-exercise was assessed using standardized methods as used by the National Strength and Conditioning Association (NSCA) of the United States of America. All repetitions were performed using the Smith Machine (SQT 1), and participants were instructed to achieve 90 – 100 degrees at their knee joints in the eccentric phase of the movement. This is because peak patellofemoral joints experience peak forces at 90 to 100 degrees of knee flexion during the squat (Kotani & Hori, 2017). It is also noteworthy to mention that 1RM procedures for the study used volitional movement tempos.

Figure 2.2. is a visual representation of the 1RM determination and the study intervention on a Smith Machine with back squat exercise.

2.3.5. Counter-Movement Jump Measurements

The participants were instructed to put their feet shoulder-width apart (Cook et al., 2006), bend their knees to ~90 degrees, then jump as high as possible (Cormack et al., 2008), with their hands on their hips (akimbo), and land in the same posture (Tsoukos et al., 2016). There were three attempts given to the performance of the CMJ, with 30 seconds max of passive rest between performances, and the best performance in each instance was used to evaluate the data (O'Grady et al., 2021). The measurements were performed with ForceDeck platforms (VALD FDLite, Australia), and the platform has been found to give excellent reliability for countermovement jump (Collings et al., 2024), and participants received verbal comments to verify or adjust certain areas of their execution technique (Warr et al., 2020). Further, according to meta-analysis by Wilson et al. (2012), the duration of the PAPE effect can last up to 10 minutes.

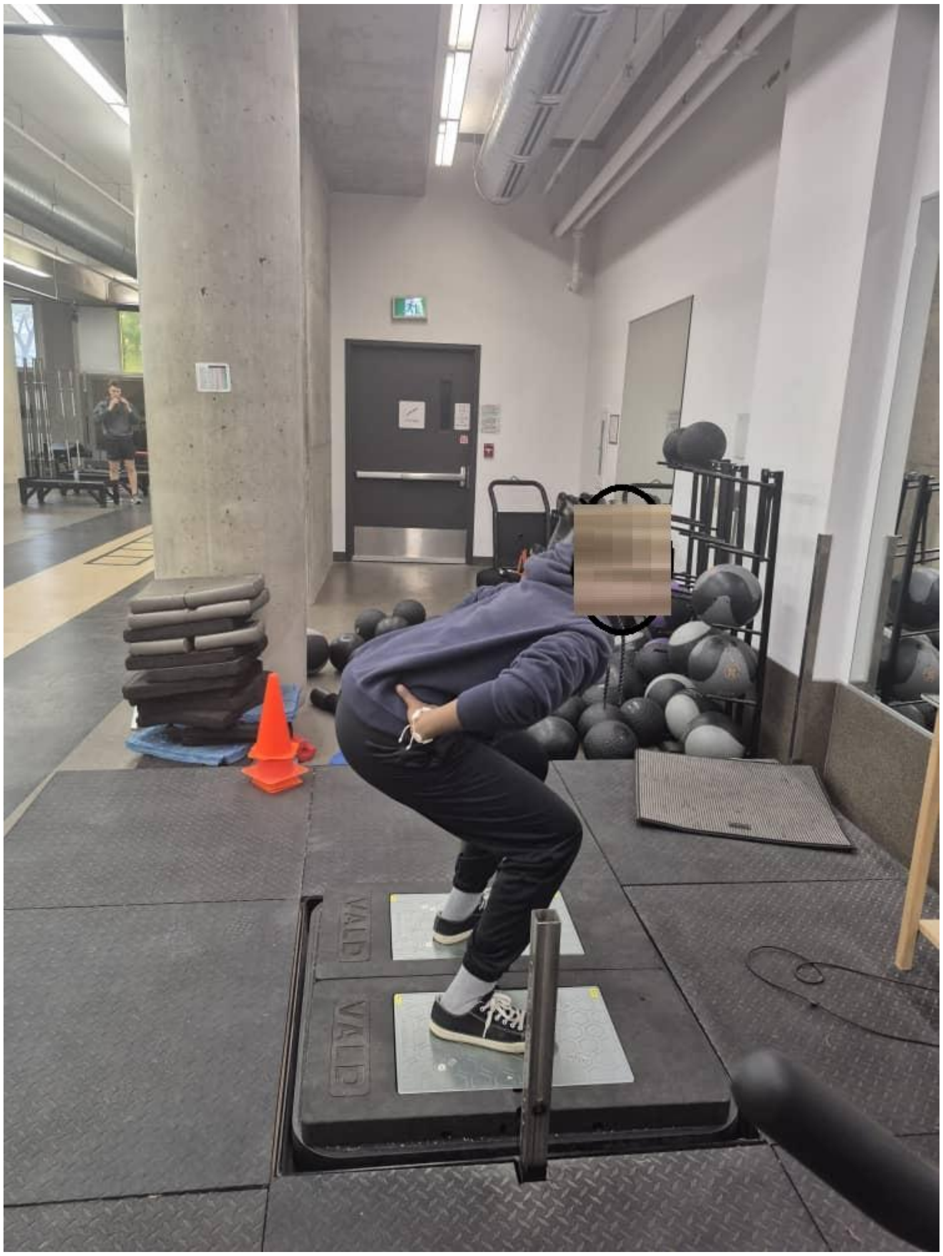
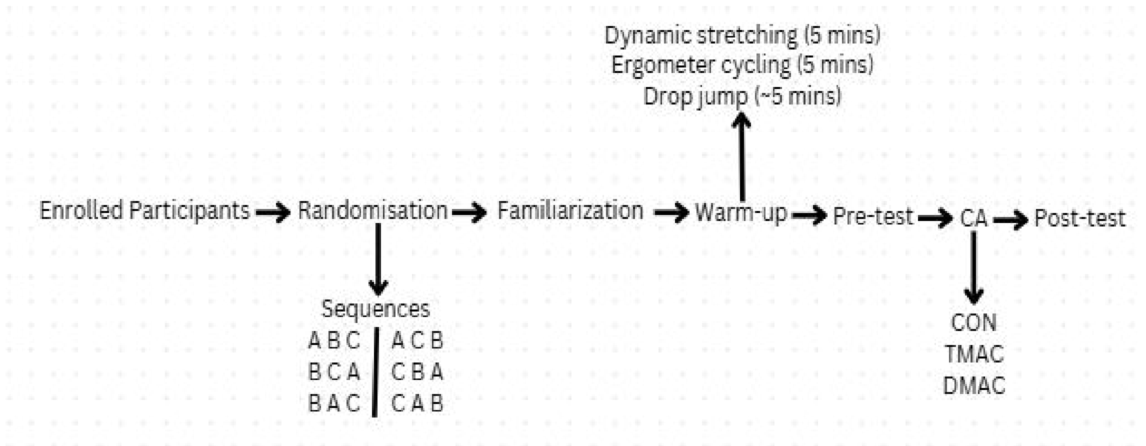


Figure 2.3. is a graphical illustration of the study participants performing a countermovement jump on the ForceDecks.

2.3.6. Experimental and Control Sessions

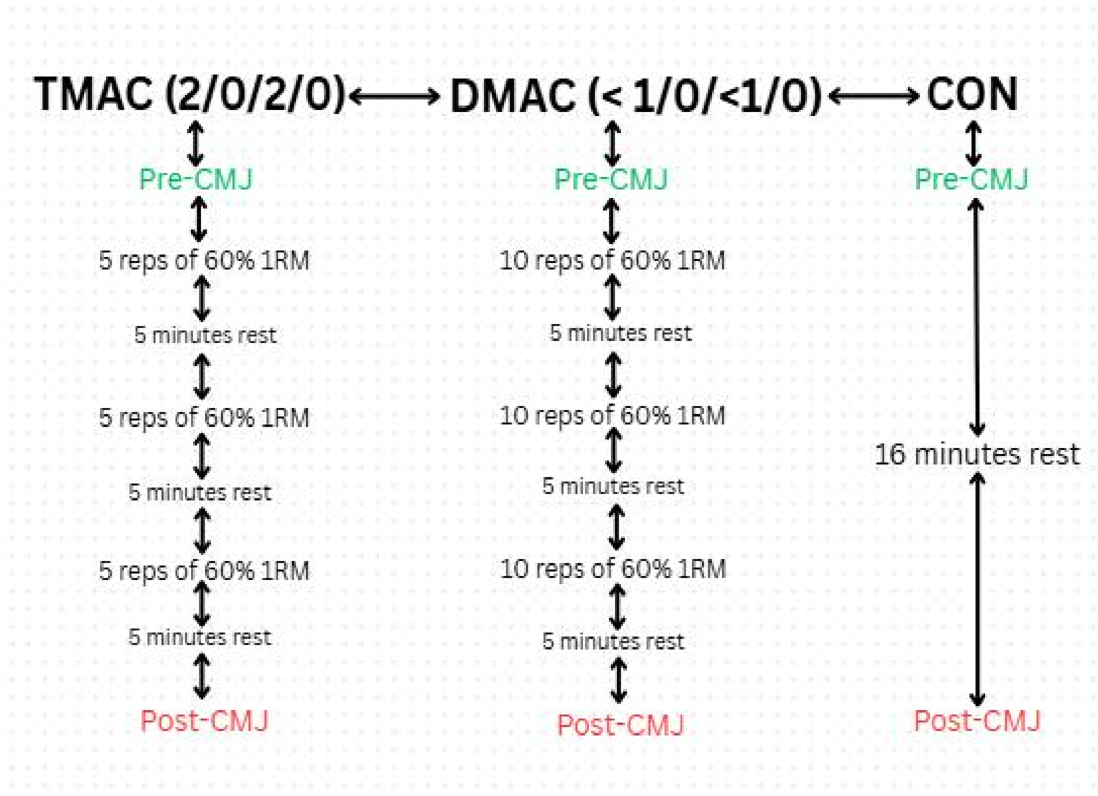
The participants performed two experimental sessions that took approximately 32 minutes and one control session that took the same time (32 minutes). Each session began with the standardized warm-up (as in familiarization session) and immediately after the warm-up, they performed baseline CMJ. After baseline CMJ, the participants performed three sets of 10 repetitions at 60 % of 1RM at tempo of <1/0/<1/0 for the DMAC, and three sets of 5 repetitions at 60 % of 1RM at tempo of 2/0/2/0 for the TMAC however, Wilk et al. (2021) acknowledged that different unintentional velocities may result from intent and fatigue. Regarding greatest strength improvements, novice to intermediate athletes are advised by the American College of Sports Medicine position stand "Progression Models in Resistance Training for Healthy Adults," (2009) to perform 8–12 repetitions with loads equal to 60–70% 1RM or 60–84% 1RM (Wilson et al., 2013). Further, for the TMAC, the metronome (SEIKO, DM51, China) was set to 30 bpm, allowing no pause between the eccentric and concentric phases (Moras et al., 2009). This closely follows Delorme (1945) and De Lorme et al. (1952) recommendations. Participants were tested before and after each of the conditions.

There were five minutes of recovery time between each set, and five minutes after the third set before the post-CMJ. Seitz & Haff (2016) recommend a duration of five to seven minutes for optimal benefit, or three to seven minutes in relation to vertical jump performance (Dobbs et al., 2019). Accordingly, Wilson et al. (2012) noted that PAPE effect can last for up to 10 minutes. During the control session (CON), they performed baseline jump (pre-CMJ) and waited 16 minutes doing nothing before taking their post-CMJ. A schematic overview of the protocol is provided in **Figure 2.1.** below.



Graphical Representation of Study Protocol

Figure 2.4. CA = conditioning activity, CON = control condition, TMAC = traditional muscle action condition. DMAC = dynamic muscle action condition, Sequences = counterbalanced order to control for order effects.



Intervention Procedure

Figure 2.5. depicts the schematic overview of the intervention procedure. 1RM = one repetition maximum, reps = repetitions, pre-CMJ = pre-countermovement jump, post-CMJ = post-countermovement jump, 2/0/2/0 (2 = 2 seconds eccentric and concentric, 0 = no pause), X/0/X/0 (X = as fast as possible, 0 = no pause).

2.3.7. Statistical Methods

A repeated measures mixed-design ANOVA was employed to test the research hypotheses of the study. The participants' data from the ForceDecks VALD system was accessed from an iPadOS Version 17.6.1 (10^{th} generation), and data was manually inputted in the Excel spreadsheet for analysis. All data is presented as mean and standard deviation (SD). The Shapiro–Wilk test showed that variables were normally distributed across all conditions, while Levene's test showed that the variances between groups are equal. Therefore, a 3 x 2 x 2 mixed-design ANOVA was conducted with condition (TMAC vs. DMAC vs. CON) and time (pre vs. post) as repeated measures within-subjects factors, and sex (males vs. females) as a between-subjects factor. Mauchly's test was used to assess sphericity, and where sphericity was violated, Greenhouse-Geisser corrected values were reported. Post-hoc analyses were performed using Bonferroni's post-hoc test where there were significant main or interaction effects. The IBM SPSS Statistics version 28.0.1.1 (15) was implemented for statistical calculations. Alpha was set at <0.05 for the primary outcome (Jump Height), while secondary outcomes were considered exploratory. Partial eta squared (η_p^2) was used to measure the effect sizes. Partial eta squared (η_p^2) is considered small at 0.01, medium at 0.06, and high at 0.14 (Richardson, 2011).

Chapter 3 – Results

A total of 162 testing sessions were conducted excluding the first sessions which were for the baseline measurements. However, 150 valid testing sessions were included in the analysis. This was because four of the participants' data was omitted due to error from the ForceDecks during the trials which led to erroneous results. Thus, their data was omitted from the analysis. Out of the 50 participants' data analyzed, 24 were males, while 26 were females. Furthermore, baseline characteristics between males (n = 24) and females (n = 26) were compared using an independent samples t-test. As shown in Table 3.1, there were no significant differences in baseline measurements between sexes, except for age (p = .030), with females older than males (see baseline measurements below).

Table 3.1. Baseline Measurements

Measurements	Males (n = 24)	Females (n = 26)	P – value (T-test)
Age	21.54±3.05	24±4.56	p = 0.030
Height (cm)	177.79±7.57	164.79±9.34	p = 0.339
Body mass (kg)	80.06±9.04	69.00±17.94	p = 0.121
BMI (kg/m²)	25.40±3.12	25.28±5.52	p = 0.146
FFM (kg)	65.92±8.05	49.25±11.24	p = 0.161
FM (kg)	13.09±7.71	20.72±11.41	p = 0.305
1RM (kg)	95.29±25.16	65.58±23.69	p = 0.737

Table 4.1. depicts the results of fifty participants' baseline measurements. N = number of participants, BMI = body mass index, FFM = fat free mass, FM = fat mass, 1RM = one repetition maximum, cm = centimeter, kg = kilogram, kg/m^2 = kilogram per meter square.

There was no significant condition × time × sex interaction for JH, $F(2, 96) = 2.01$, $p = .139$, $\eta_p^2 = .040$. However, a condition × time, interaction $F(2, 96) = 3.66$, $p = .030$, $\eta_p^2 = 0.071$, was found. A Bonferroni post hoc analysis showed that there was no significant difference between TMAC (31.14 ± 8.32 cm) vs. DMAC (30.75 ± 9.34 cm) (Please see Table 3.2, $p = .514$) and DMAC (30.75 ± 9.34 cm) vs. CON (30.69 ± 8.98 cm) (Please see Table 3.2, $p = .272$). However, CON post-JH (30.09 ± 8.79 cm) significantly decreased compared to pre-JH (31.29 ± 9.18 cm, $p = .003$) and there was a significant difference between TMAC post-JH (31.21 ± 8.35 cm) and CON post-JH (30.09 ± 8.79 cm) (Please see Table 3.2, $p = .020$). The condition × sex, $F(2, 96) = 0.97$, $p = .383$, $\eta_p^2 = .020$, time × sex, $F(1, 48) = 1.072$, $\eta_p^2 = .022$, interactions were not significant. In addition, there was no main effect of condition, $F(2, 96) = 0.72$, $p = .489$, $\eta_p^2 = .015$, time, $F(1, 48) = 2.43$, $p = .126$, $\eta_p^2 = .048$; however, there was a main effect of sex, (female: 25.55 ± 6.34 cm, male: 36.62 ± 7.60 cm), $F(1, 48) = 34.56$, $p < .001$, 95% CI, 7.284 cm to 14.856 cm, $\eta_p^2 = .419$, males demonstrated greater JH performance compared to females.

There was no significant condition × time × sex interaction for CI, $F(2, 96) = 2.71$, $p = .072$, $\eta_p^2 = .053$. However, a two-way interaction of condition × sex, $F(2, 96) = 3.85$, $p = .025$, $\eta_p^2 = .074$ was found, but this was only driven by a large sex-based effect, with males (211.36 ± 33.98 N/s) outperforming females (148.96 ± 39.98 N/s) across all conditions (Please see Table 3.1, $p < .001$). Similarly, a significant condition × time interaction was observed, $F(2, 96) = 4.16$, $p = .019$, $\eta_p^2 = .080$. A Bonferroni post hoc analysis showed that DMAC post-CI (179.90 ± 47.57 N/s) was better than baseline result (175.16 ± 48.28 N/s) ($p = .042$), while TMAC post-CI (181.66 ± 49.29 N/s) was not significantly different than baseline result (178.92 ± 45.99 N/s) ($p = .051$), CON (pre-CI: 179.92 ± 50.85; post-CI: 177.90 ± 49.34) also did not change significantly. There was no time × sex interaction, $F(1, 48) = .326$, $p = .571$, $\eta_p^2 = .007$ for CI. The condition,

$F(2, 91.99) = 1.13$, $p = .328$, $\eta_p^2 = .023$, and time, $F(1, 48) = 2.09$, $p = .155$, $\eta_p^2 = .042$, were not significant.

There was a significant condition × time × sex interaction for PP, $F(1.78, 85.51) = 3.670$, $p = .034$, $\eta_p^2 = .071$. A Bonferroni post hoc indicated that males (4102.49 ± 802.09 W) outperformed females (2728.37 ± 830.39 W) across conditions and time points (male pre = 4134.78 ± 804.38 W; female pre = 2736.60 ± 848.40 W; male post = 4070.19 ±799.81 W; female post = 2720.14 ± 812.38 W, $p < .001$). The condition × time, $F(1.78, 85.51) = 0.88$, $p = .408$, $\eta_p^2 = .018$, condition × sex, $F(1.70, 81.72) = 2.08$, $p = .130$, $\eta_p^2 = .042$, and time × sex, $F(1, 48) = 0.657$, $p = .422$, $\eta_p^2 = .013$ interactions were not significant. There was no main effect of condition (TMAC = 3387.79 ± 1026.31 W; DMAC = 3402.25 ± 1081.39 W; CON = 3373.8 ± 1090.93 W), $F(1.70, 81.72) = 0.16$, $p = .821$, $\eta_p^2 = .003$, nor time (pre = 3407.73 ± 1082.59 W; post = 3368.17 ± 1049.83 W), $F(1, 48) = 1.86$, $p = .179$, $\eta_p^2 = .037$; however, there was a main effect of sex (male, 4102.49 ± 802.09 W, female, 2728.37 ± 830.39 W), $F(1, 48) = 39.55$, $p <.001$, 95% CI, 934.813 W to 1813.415 W, $\eta_p^2 = .452$.

There was no significant condition × time × sex interaction for TPF, $F(2, 77.94) = .693$, $p = .474$, $\eta_p^2 = .014$. The condition × time, $F(1.62, 77.94) = 1.33$, $p = .268$, $\eta_p^2 = .027$, condition × sex, $F(1.48, 70.80) = .14$, $p = .807$, $\eta_p^2 = .003$, and time × sex. $F(1, 48) = .027$, $p = .870$, $\eta_p^2 =.001$, interactions were not significant. Similarly, there was no main effect of condition (TMAC: 1580.22 ± 364.23 N; DMAC: 1583.86 ± 393.08 N; CON: 1586.54 ± 373.85 N), $F(1.48, 70.80) = .05$, $p = .913$, $\eta_p^2 = .001$ or time (pre: 1587.33 ± 376.42 N; post: 1579.75 ± 377.68 N) $F(1, 48) = .93$, $p = .339$, $\eta_p^2 = .019$, but there was a main effect of sex (male 1771.17 ± 253.71 N; female:

1410.34 ± 392.53 N) $F(1, 48) = 16.18$, $p < .001$, 95% CI, 180.454 N to 541.213 N, $\eta_p^2 = .252$, with males outperforming females across conditions and time points.

Table 3.2. Dependent Variables Pre and Post Data in Mean and Standard Deviation

Variable	Time	TMAC		DMAC		CON	
		Female (n=26)(X̄±SD)	Male (n=24) (X̄±SD)	Female (n=26) (X̄±SD)	Male (n=24) (X̄±SD)	Female (n=26) (X̄±SD)	Male (n=24) (X̄±SD)
TPF	Pre	1401.92±366.06	1755.42±238.23	1408.04±408.07	1796.67±279.46	1434.27±401.32	1770.79±244.83
	Post	1415.31±378.23	1776.83±262.54	1401.54±421.17	1759.04±235.28	1400.96±380.32	1768.29±261.93
*CI	Pre	152.73±41.82	207.29±31.47	142.12±35.38	210.96±32.17	148.27±42.46	214.21±34.50
*	Post	153.04±42.43	212.67±35.92	149.31±36.76	213.04±33.88	148.27±41.01	210.00±35.94
PP	Pre	2821.81±862.54	4008.42±737.99	2680.62±857.34	4203.33±864.35	2707.38±825.33	4192.58±810.77
	Post	2742.58±823.78	4079.29±816.84	2775.85±823.70	4061.54±750.03	2642.00±789.66	4069.75±832.57
*JH	Pre	26.131 ±5.84	36.421±7.18	24.892±7.53	37.275±8.13	25.831±6.47	37.212±7.98
*	Post	26.092±5.85	36.754±7.06	25.527±6.21	36.221±7.63	24.808±6.13	35.817±7.61

Table 3.2. is a tabular representation of data in mean and standard deviation. X̄ = Mean, SD = standard deviation, n = number of participants, TPF = take-off peak force, CI = concentric impulse, PP = peak power, and JH = jump height.

Chapter 4 – Discussion

This study's primary goal was to understand how different CA tempos with the same load, but different number of repetitions, can influence neuromuscular performance. To the best of our knowledge, this is the first study to use three repeated-session trials to explore two different tempos and one control condition, while taking into account the most effective method to assess all four variables.

4.1. Condition-Based Effect

When analyzing data for condition-based effects, the results showed that there was no significant difference in TPF across the three conditions. This implies that participants' force to jump vertically does not improve thus, their post-TPF did not change from its baseline after CA. Further, this means that both fast and slow tempos exercise do not affect TPF. This may be as a result of the CA having less training volume, intensity, duration (Seitz et al., 2014; Wilson et al., 2013), as well as level of practice (Häkkinen et al., 1987). This is consistent with de Oliveira et al. (2018) who found greater effect with intensities of 91%, 85%, and 70% of 1 RM, however 60% intensity of 1 RM did not significantly differ from the control group. Thus, if the average intensity of the CA falls below 70% of 1RM, it may result in smaller potentiation as observed in this study.

Further, Chen et al. (2023) admitted that frequency of CA is also one of the influencing factors of PAPE. For instance, these studies (Bottaro et al., 2007; Keeler et al., 2001; Morrissey et al., 1998; Munn et al., 2005; Neils et al., 2005; Westcott et al., 2001) ensured participants had at least six weeks training sessions. This coincides with Kobal et al. (2019) and Naclerio et al. (2015) who posited that training volume of the CA is a common attribute that determines the level of performance enhancement effect (Masel & Maciejczyk, 2022). In addition, Kobal et al. (2019) and de Oliveira et al. (2018) affirm that the intensity of the CA may also contribute to the level of performance enhancement. This additionally aligns with Masel and Maciejczyk (2022) and Gołaś et al. (2016), who reported improvements using 80% of participants' 1RM. Similarly, Rixon et al. (2007) also added that potentiation effects are also contingent upon the individual's training experience. Since, the aim of the current study was to assess whether PAPE could be observed in untrained participants with acute training duration and intensity, using fast and slow tempos, comparing with a control condition (no CA), the results help inform that untrained individuals may benefit from PAPE if they experience a chronic training session prior to testing.

Correspondingly, despite no main effect of conditions and times, the two-way condition × time interaction implies that while time does not impact outcome overall, each of the conditions affects how time impacts the outcome. That is, the effect of time depends on each of the conditions. Interestingly, Mitchell et al. (2022) noted that concentric impulse has been found to be the most reliable indicator of jump height.

Further, participants' post-PP remains the same with its baseline results (Please see Table 3.2 above). Likewise, the significant condition × time interaction with a moderate effect size for JH suggests that movement tempo influenced the magnitude of adaptation to training. The lack of a difference between fast and slow tempo indicates that, within the parameters used here, the velocity of concentric action alone was not sufficient to drive differential changes in JH. However, the decline in the CON relative to slow tempo suggests that slow tempo training may have provided a protective effect against detraining or served as a minimal effective dose to maintain JH, whereas CON did not. This suggests that tempos and controlled eccentric/concentric movements with the characteristic of slow/fast tempos, may enhance force production and tendon stiffness even in the absence of high velocity movements. All this emphasizes the above statement that individuals may benefit from engaging in fast and/or slow tempo movements rather than doing nothing at all. Therefore, we fail to reject our hypothesis.

4.2. Condition Effects Over Time

When analyzing data for time-based effect, the absence of time-based changes in TPF and PP is likely attributable to the acute nature of the protocol. With only a single training session per condition, it is improbable that neuromuscular adaptations underpinning take-off peak force and peak power would manifest within this timeframe. Adaptations in TPF and PP typically require repeated exposure to induce changes in motor unit recruitment, firing frequency, and musculotendinous stiffness. Similarly, PP is highly dependent on both force and velocity, and a single bout may be insufficient to alter the force-velocity profile. The lack of condition × sex interactions further suggests that neither slow (2-0-2-0) nor fast (<1-0-<1-0) tempo, when performed acutely, provide a stimulus distinct enough to alter these explosive characteristics. This contrasts with chronic training studies where multiple weeks are required to see changes in temporal force variables (Bottaro et al., 2007; Keeler et al., 2001; Morrissey et al., 1998; Munn et al., 2005; Neils et al., 2005; Westcott et al., 2001). Consequently, from a practical perspective, these findings indicate that tempo manipulation in a single session is not sufficient to acutely enhance TPF, CI, PP, or JH. Further, Cohen et al. (2026) noted that to accurately measure participants' PP, they have to be instructed to jump as high and fast as they can. It should be noted that in this study, participants were only asked to jump as high as possible, not realizing how that might have impacted their PP. However, a pairwise comparison determined that participants' post-CI for DMAC improved more than its pre-CI. Accordingly, although TMAC

(Please see Table 3.2) was not significantly different pre-post, mean data showed that participants post-CI was better than its pre-CI. while CON post-CI got worse than its pre-CI. However, DMAC (Please see Table 3.2) post-CI got better than its pre-CI. This implies that individuals may benefit more from fast tempo (DMAC) (Munn et al., 2005) or slow tempo (TMAC) (Watanabe et al., 2013) than doing nothing at all (CON) and may benefit more from fast tempo exercises (Morrissey et al., 1998; Munn et al., 2005).

Furthermore, while participants' pre- and post-JH remained the same for both TMAC and DMAC, the CON significantly dropped (Please see Table 3.2) compared to both CA, especially TMAC. This implies that both fast (DMAC) and slow (TMAC) tempos maintain JH pre-to-post. That is, both tempos are effective at preserving power output (JH) compared to doing no training. Ultimately, CA prior to performance with a fast or slow tempo may help improve performance (Morrissey et al., 1998). Notably, despite post-CI better than pre-CI, post-JH was not significantly better than pre-JH in both TMAC and DMAC. This may be because of the acute CA protocol as noted by Naclerio et al. (2015) and Wilson et al., (2013). Naclerio et al. (2015) reported significant difference for moderate and high volumes but no effect for low volume likewise, Wilson et al., (2013) reported that multiple sets produced a greater potentiation of power output compared to a single set. Additionally, exercise intensity may affect response and not be enough to induce potentiation (Batista et al., 2010). In addition, this aligns with (Merrigan et al., 2022d) who added that CMJ demands optimal coordination and timing of force production to maximize impulse, take-off velocity, and resultantly vertical center of mass displacement (i.e., jump height).

4.3. Sex-Based Effect

When analyzing the data for sex-based effects, there was a main effect of sex in all variables. For the TPF. This implies that males outperformed females in all the variables thus, our results align with typical biological and physiological differences between both sexes as found by other researchers (Behm et al., 2025; Inglis et al., 2017; Ives et al., 1993). Additionally, there was an interaction effect of condition × sex, with a moderate effect size. A pairwise comparison determined that males outperformed females in all conditions. Cidrais & Mendonça (2026) and Nuzzo (2022) suggested that the sex disparities may be explained by the types of muscle fibres, with males possessing larger skeletal muscle mass with a higher fraction of fast type II fibers (Hilton & Lundberg, 2020; Hunter et al., 2023; Petek et al., 2023).

4.4. Limitations

The minimum resistance training experience was set for two months only, while some participants had a few months of resistance training experience, others possessed years of resistance training experience which may have affected the results.

This study also lacks the representation of certain populations such as older adults, people younger than the age of 18 years old, and competitive athletes.

Given the acute nature of this study, findings are limited to immediate responses and cannot be extrapolated to long-term training effects.

The outcome variables included jump height, peak power, takeoff peak force, and concentric impulse. However, mechanistic measures such as electromyography or muscle-tendon properties were not obtained, limiting insight into the neuromuscular factors that may have contributed to performance changes.

Chapter 5 – Conclusion

5.1. Major findings

This study sought to better understand the effects of varying CA tempos with the same load, but varying numbers of repetitions on neuromuscular performance. This study gave clues to the most effective duration and intensity of CA to support PAPE. In addition, understanding the effects of various tempos may be beneficial to occupational settings to evaluate high-intensity job demands, and may overall have performance and health-related benefits to a variety of populations.

This study provides evidence that males outperformed females in all the variables. In addition, although not significant, slow tempo helped increase participants' CI, while fast tempo significantly increases participants' CI pre=post. However, CON reduced participants' performance. Furthermore, compared to both slow and fast tempo exercises, the CON post JH reduced drastically, while slow and fast tempos helped participants to maintain performance. Although it was not significant, the DMAC was better than both TMAC and CON in the PP. Likewise, the TMAC was better than both DMAC and CON in both CI and JH. This may imply that TMAC may help individuals gain better impulse in jumping and attain a better jump height. At no point was the CON better than both CAs. This, again, emphasizes that it is better for individuals to do either fast or slow tempo exercise, rather than doing nothing.

5.2. Recommendations

This study found that slow and fast tempo exercises helped participants improve CI. During rehabilitation, concentric impulse asymmetry has been found to be a crucial feature to keep an eye on (Read et al., 2020). However, it has been argued that the reason that the CI could not improve JH may be because of less CA volume, intensity, and/or frequency. Consequently, future research may consider the same protocol with high training volume, intensity, and frequency.

Additionally, future research should aim to reduce variability amongst participants, allowing participants to have a similar level of resistance training experience. This would also ensure consistency in jumping performance across all data.

Future research should also consider other misrepresented populations in the study, such as older adults, people younger than the age of 18 years old, and competitive athletes.

Future studies should examine multi-week TMAC, DMAC and CON interventions with the study protocol to assess whether tempo manipulation can produce chronic changes in TPF, CI, PP, and JH.

Ultimately, future research should also consider testing participants' skeletal muscle for fibre types, to evaluate the degree of association between fast and slow twitch muscle fibre types and velocity of neuromuscular performance. Neural elements that are considered to work in unison to produce PAPE include enhanced motor unit recruitment, motor neuron excitability, and muscle fibre (Anthi et al., 2014; Blazevich & Babault, 2019).

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Appendix I

PAPE Studies in PICO Format

S/N	Study	Population	Intervention	Comparison	Outcome
1.	(Smith et al., 2018)	24 men and women	PAP warm-up that included a sled resistance sprint at either 0%, 10%, 20%, or 30% of their body mass	40-yard (yd) sprint pretest on four nonconsecutive days	The findings showed that there were no appreciable variations in the post-40-yard dash times between sled loads and the load by time interaction. After the 10% load, the average improvement in the athletes' 40-yard sprint timings was 1.2%. Dash time improvements above 2% for the 0%, 20%, and 30% loads. Lighter and heavier loads

					differed statistically significantly based on the sprint kinematics analysis.
2.	Chen et al. (2013)	10 male Division I college volleyball players	(a) a drop jump (DJ) protocol with 1 set per 5 repetitions. (b) a drop jump (DJ) protocol with 2 sets per 5 repetitions.	pretest of 3 CMJs	Both DJ training volumes significantly increased the HCMJ
3	(Boullosa et al., 2020)	20 elite endurance runners	a warm-up with the inclusion of 5 DJs	a warm-up without the inclusion of 5 DJs	Male athletes in the DJ condition had a "very likely" faster first split (38.8 vs. 40.3 s) and a "possible" faster 1000-m time (162.4 vs. 165.3 s).
4.	(Silva et al., 2014)	11 trained cyclists	10-minute after 4 sets of 5RM strength exercise	20-km cycling time trial (TT20km)	A higher power production in the first 10% of the

			bouts (potentiation condition)	(Control condition)	TT20km (i.e., trend; $p = 0.06$) and cycling economy ($p < 0.01$) in the potentiation condition.
5.	(Feros et al., 2012)	10 national level rowers	Potentiated warm-up (PW)	Rowing warm-up only (NW)	In comparison to the NW, the PW reduced 500-m time by 1.9% ($p < 0.01$) and increased mean power output by 6.6% ($p < 0.01$) and mean stroke rate by 5.2% ($p < 0.01$) throughout the first 500 meters.
6.	(González-Mohíno et al., 2018)	11 well-trained runners	(i) 9x20-sec level strides (105%vVO2max; 1% gradient) with 60 s of recovery (level);	7 min at 60%vVO2max as control condition (control)	Compared to control WUs (144.82±6.60s), the uphill and level WUs performed better during

			(ii) 6x6-sec uphill strides (105%vVO2max; 5% gradient)		TLimT (160.0±6.62s and 152.64±10.88s, respectively). Blood lactate (BLC) declined in control WUs and rose in uphill and level WUs.
7.	(Barranco-Gil et al., 2020)	15 male cyclists	a) Potentiation postactivation (PAP warm-up; 5 min at 60% of VO2peak) b) Standard warm-up (10 min at 60% of VO2peak)	No warm-up	Standard and PAP warm-up (9.7% [4.7%] and 12.9% [6.5%], respectively, $P < .001$), improved jumping ability and reduced heart-rate variability (−7.9% [14.2%], $P = .027$; −20.3% [24.7%], $P = .006$; and −1.7% [10.5%], $P = .366$), compared with no

					warm-up (−0.9% [4.8%], P = .074).
8.	(De Almeida Azevedo et al., 2022)	11 male cyclists	Maximal cycling incremental test (MIT) followed by 15 min of passive rest before a 4-km cycling TT	Moderate-intensity exercise for 5 min (Control)	In comparison to CON condition, TT performance (+2.6%) and average PO (+5.7%) increased in MIT.
9.	(Low et al., 2019)	12 male endurance-trained athletes	Conditioning exercise intervention (4x5 repetition maximum band-resisted squat jumps)	Control condition	The PAP stimulus decreased the time to finish the first kilometer (8%; $d = 1.08$, $p = 0.014$) and the run (3.6%; $p = 0.07$, $d = 0.51$). PAP led to increases in jump height ($p = 0.02$; 9.2%) and reactive strength index ($p = 0.035$; 16%).
10.	Gołaś et al.	31 well trained	Heavy loaded	N/A	The findings from

	(2016)	athletes	conditioning activity (80-130%1RM)		the experiment demonstrated that PAP is beneficial for skilled athletes performing explosive motor exercises including pushing, throwing, and jumping.
11.	(Masel & Maciejczyk, 2022)	15 strength trained males	A single set of 3 repetitions of a trap bar deadlift at 80 % of 1RM using solely free weight resistance (FW - condition with solely free weight) or with the addition of approximately 15 % of 1RM elastic band tension (FW +	CNTR - control condition	The FW + AR condition considerably enhanced the SJ performance that followed ($p < 0.05$, effect size 0.34).

			AR - condition with the addition of accommodating resistance)		

Appendix II

Approved Get Active Questionnaire

CSEP | SCPE

Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications) or health care provider is advisable. **This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.**

☐ I am completing this questionnaire for myself.

☐ I am completing this questionnaire for my child/dependent as parent/guardian.

PREPARE TO BECOME MORE ACTIVE

The following questions will help to ensure that you have a safe physical activity experience. Please answer **YES** or **NO** to each question before you become more physically active. If you are unsure about any question, answer **YES**.

YES	NO	
		1 Have you experienced **ANY** of the following (A to F) **within the past six months**?
○	○	**A** A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?
○	○	**B** A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?
○	○	**C** Dizziness or lightheadedness during physical activity?
○	○	**D** Shortness of breath at rest?
○	○	**E** Loss of consciousness/fainting for any reason?
○	○	**F** Concussion?
○	○	**2** Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
○	○	**3** Has a health care provider told you that you should avoid or modify certain types of physical activity?
○	○	**4** Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

NO to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

YES to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

CSEP | SCPE

Get Active Questionnaire

ASSESS YOUR CURRENT PHYSICAL ACTIVITY

Answer the following questions to assess how active you are now.

1 During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)? ☐ DAYS/WEEK

2 On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity? ☐ MINUTES/DAY

For adults, please multiply your average number of days/week by the average number of minutes/day: ☐ MINUTES/WEEK

Canadian *24-Hour Movement Guidelines* recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see csep.ca/guidelines).

GENERAL ADVICE FOR BECOMING MORE ACTIVE

Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do **vigorous-intensity physical activity** (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.

DECLARATION

To the best of my knowledge, all of the information I have supplied on this questionnaire is correct. If my health changes, I will complete this questionnaire again.

I answered **NO** to all questions on Page 1

Sign and date the Declaration below

I answered **YES** to any question on Page 1

Check the box below that applies to you:

☐ I have consulted a health care provider or Qualified Exercise Professional (QEP) who has recommended that I become more physically active.

☐ I am comfortable with becoming more physically active on my own without consulting a health care provider or QEP.

Name (+ Name of Parent/Guardian if applicable) [Please print] | Signature (or Signature of Parent/Guardian if applicable) | Date of Birth

Date | Email (optional) | Telephone (optional)

With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

☐ Check this box if you would like to consult a QEP about becoming more physically active. (This completed questionnaire will help the QEP get to know you and understand your needs.)

Appendix III

Approved Consent Form

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Participant Informed Consent Form

Study Title: Influence of Post-Activation Performance Enhancement on Lower-Limb Muscles, After Conditioning Activities, Amongst Selected Exercise Participants.

Student Principal Investigator: Israel Adeogo Abejoye, master's student, Faculty of Kinesiology and Recreation Management, University of Manitoba, email: abejoyei@myumanitoba.ca

Student Advisor:
Dr. Stephen Cornish, Associate Professor, Faculty of Kinesiology and Recreation Management, University of Manitoba, email: Stephen.Cornish@umanitoba.ca

Funder (or Sponsor if applicable): None

Conflicts of Interest and Undue Influence: There is no conflict of interest.

You are being invited to participate in a research study. This consent form, a copy of which you can download or print, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, feel free to ask any of the people named above. Please take the time to read this document and any accompanying information carefully. It is very important that you understand:

- what is being asked of you,
- what the risks and benefits of participation are, and
- how the information you provide will be used and stored.

Purpose of the Study: I am doing this research for a thesis under the supervision of Dr. Stephen Cornish. This research study is about the effect of post-activation performance enhancement (PAPE) after two conditioning activities and a control condition are performed by research participants. We are hoping to learn about how different tempos of conditioning activity will affect post-activation performance enhancement.

Study Procedures: If you decide to take part in the study, we will meet four times over a two-week period at the High-Performance Training Center, in the Active Living Center at the University of Manitoba, Fort Garry Campus.

Meeting 1 will consist of baseline measurements like weight (kg), height (cm), resting blood pressure, resting heart rate, body mass index (BMI), body composition, age, gender and one repetition maximum, and participants will also be randomized: **45 minutes.**

Meeting 2 will consist of 15 minutes for warm-up activities, 16 minutes for rest periods between activities and 30 seconds between countermovement jump performances for 3 attempts (30 sec x 2 = 60 sec = 1 minute). Total makes 15 + 16 + 1 = **32 minutes.**

Version #4: December 2, 2024 Page 1 of 5

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Meeting 2 will consist of 15 minutes for warm-up activities, 16 minutes for rest periods between activities and 30 seconds between countermovement jump performances for 3 attempts (30 sec x 2 = 60 sec = 1 minute). Total makes 15 + 16 + 1 = 32 minutes.

Meeting 3 will consist of 15 minutes for warm-up activities, 5 minutes rest between 3 sets and additional 5 minutes rest after last set, before countermovement jump (5 x 3 = 15 minutes), 2 seconds eccentric, 0 second pause, 2 seconds concentric for 5 repetitions (2 x 2 x 5 = 20 seconds = 20 seconds x 3 sets = 60 seconds = 1 minute), including 30 seconds between three countermovement jump performances (30 sec x 2 = 60 seconds = 1 minute). Total makes 15 + 15 + 1 + 1 = 32 minutes.

Meeting 4 will consist of 15 minutes for warm-up activities, 5 minutes rest between sets and after last set (5 x 3 = 15 minutes), ~1 second eccentric, ~1 second concentric for 10 repetitions x 3 sets (1 + 1 = 2 sec x 10 repetitions = 20 seconds = 20 seconds x 3 sets = 60 seconds = 1 minute), and 30 seconds between countermovement jump performances for 3 attempts (30 sec x 2 = 60 seconds = 1 minute). Total makes 15 + 15 + 1 + 1 = 32 minutes.

Countermovement jumps will be performed on ForceDecks, which would automatically generate the variables (countermovement rate of force development, countermovement jump height, countermovement peak power, and countermovement peak velocity) and there will be three trials with 30 seconds recovery between the three trials.

Individual parking passes will be available to participants who require them for the study visit.

This study will take approximately 3 hours of your time over all meetings.

Study Risks: A potential risk is injury when exercising. This will be minimized by using a proper warm-up and cool-down procedures, as well as ensuring that each participant begins the procedure with their body mass and good biomechanics until they feel comfortable adding external weight. Participants will also be asked to stop exercise if they feel pain or discomfort thus, will mitigate the risk of developing an increase in potential risks associated with the testing or exercise intervention. Also, all participants will be screened before any fitness testing or exercise training by the Get Active Questionnaire (GAQ) which will indicate if there are any potential contraindications to exercise testing or training in this population.

Study Benefits: Participating in this study may help provide knowledge into the 'best' duration of conditioning activity to support post-activation performance enhancement. You will also indirectly benefit from the study by learning about your one-repetition maximum, body composition, resting blood pressure, resting heart rate, body mass index, weight, and age. Participating in the study will help you know all these vital physiological indicators. In addition, you will benefit from your participation in physical activities.

Compensation: Participants who require parking during the study visit will be provided with free parking tickets.

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Use and Storage of Information:
All the information you provide as a participant in this study is confidential which means we as the research team must keep it safe. We will do our best, however, it is not possible to guarantee absolute confidentiality. We will only share your personal information if required through court order or law (e.g., suspected child or elder abuse).

Your information will be stored on a secure platform approved by the University of Manitoba. We will have a file that links your name and contact information to your research information using a code. We will keep the file with your name, contact information, and code separate from the research information you share with us. When we share the results of this study, we will combine everybody's responses. This means no one will see your answers, name, or contact information.

Your research information may be shared outside of the University of Manitoba with researchers, and/or publishing organization (journal). The information is being shared for further analysis or testing, as part of the research study, and/or because it is required by a journal. It will not include your name or any information that could directly identify you.

Upon completion of this study, all physical copies of confidential data will be destroyed via an anonymous paper shredding company and all electronic copies of confidential data will be destroyed by formatting the storage hard drive. All personal data collected will be stored until analyses are complete and then destroyed by **December 2032**.

Dissemination: The study results will be shared through:

1) the publication of a master's thesis;
2) journal publications and presentations in relevant academic fields; and/or
3) a summarized report of the study results to be sent to interested participants

Withdrawing: Your participation in this research study is voluntary. You can choose to do only the activities and/or answer only the questions that you are comfortable with. You may withdraw from the study for any reason. You do not have to explain why. You will not be penalized in any way. Should you withdraw partway through the study, all of your information will be destroyed unless you have consented to allowing us to keep it. You may withdraw from the study until **December 2025**. After this date, we will start our analysis so it may not be possible to withdraw your information as it will not be linked to your name. To withdraw, please contact the Principal Investigator (Israel Abejoye) or Advisor (Dr. Stephen Cornish) in person, by email, or phone number above.

Questions or Concerns

Designated University of Manitoba personnel (and/or Funder) may check that this study is being done safely and properly. To do this, they may visit the study site or review the research records. We will tell you if someone outside the research team will be there while you are participating. If this makes you

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uncomfortable, please tell a member of the research team, who will ask the personnel to return at another time. This study has been reviewed and approved by a Research Ethics Board at the University of Manitoba. However, this does not mean that participation is risk-free. If you have questions about your rights as a research participant, you may contact the Office of Human Research Ethics at humanethics@umanitoba.ca or (204) 474-7122. If you have any questions, concerns, or complaints about this study, you may contact any members of the research team listed on the first page or the Office of Human Research Ethics.

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Consent

By signing this document, I agree that:

- I have read the above information or had it read to me.
- I have had the opportunity to ask and have answered all of my questions.
- I understand what is being asked of me.
- I will be taking part in a research study.
- I may freely stop or leave the research study activities at any time.
- My information may be shared outside the University of Manitoba.
- I do not waive my legal rights by participating in the study.

Notice Regarding Collection, Use, and Disclosure of Personal Information

Your personal information is being collected under the authority of The University of Manitoba Act. The University of Manitoba is committed to preserving your right to privacy. The information you provide will be used by the University to support our research. Your personal information will not be used or disclosed for other purposes, unless permitted by The Freedom of Information and Protection of Privacy Act or The Personal Health Information Act. If you have any questions about the collection of personal information: Ph: 204-474-9462 or Email: fippa@umanitoba.ca

I agree to participate in this study.	☐ Yes ☐ No

______________ ________________ ______________

Name of Participant Participant's Signature Date

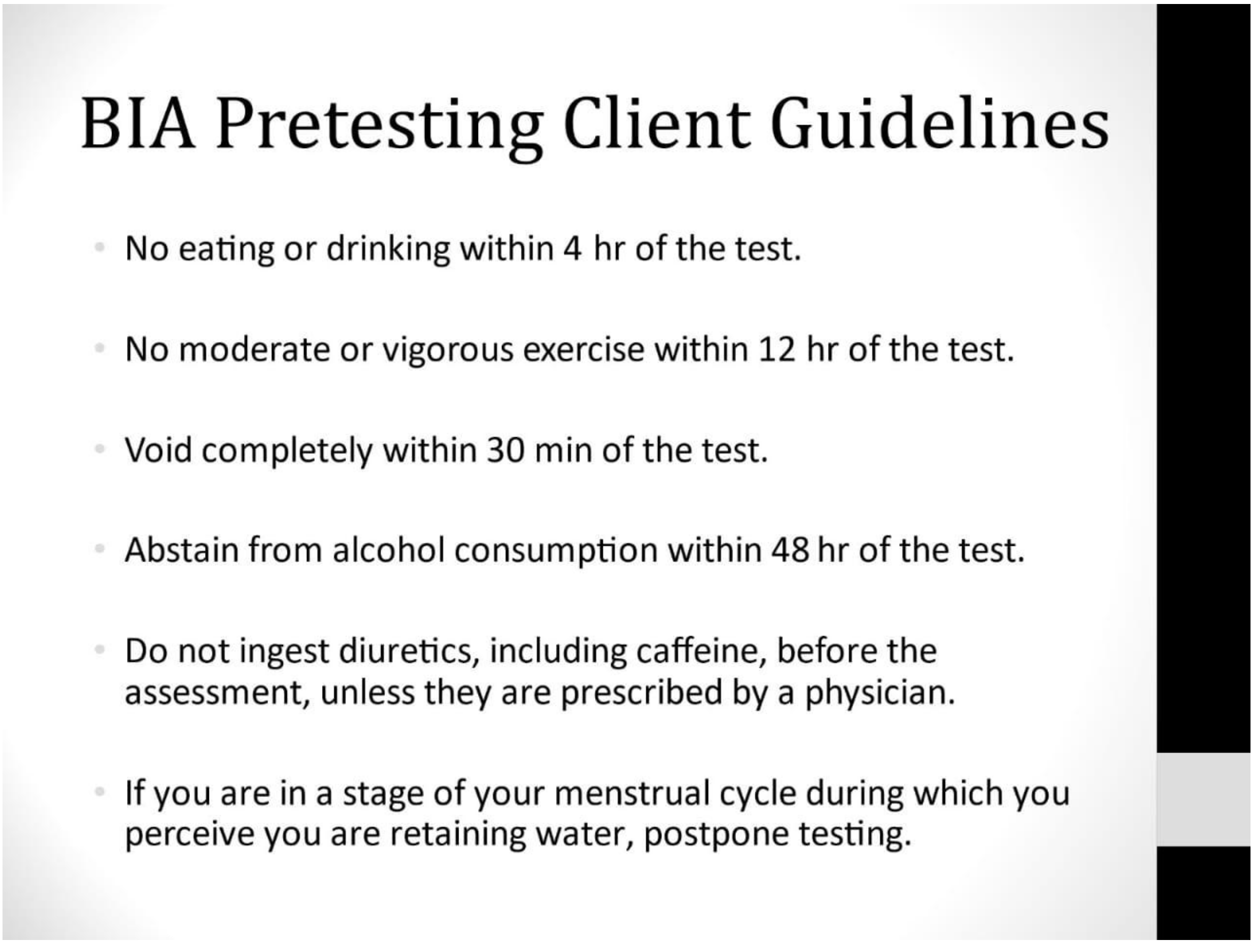
Summary of Results

Participants will receive a copy of their own individual results as well as aggregate data from the whole cohort. This will occur through email to the individual participants. They can expect to receive this by December 2025.

Please provide an email address below if you would like to be sent a summary of the study results and/or my individual results. Email address: ______________________________

Appendix IV

Pretesting client guidelines



Appendix V

First study protocol approval

University of Manitoba | Research Ethics and Compliance

Human Research Ethics - Fort Garry
66 Chancellors Circle
Winnipeg, MB R3T 2N2
humanethics@umanitoba.ca

PROTOCOL APPROVAL

Effective: March 7, 2025 Expiry: March 6, 2026

Principal Investigator:	Israel Abejoye
Advisor(s):	Stephen Cornish
Protocol Number:	HE2025-0010
Protocol Title:	*Influence of Post-activation Performance Enhancement on Lower Limb Muscles After Conditioning Activities Amongst Selected Exercise Participants*

Natalie Riediger, Acting Chair, REB1

Research Ethics Board 1 has reviewed and approved the above research. The Office of Human Research Ethics (OHRE) is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans- TCPS 2 (2022).*

Please note the following important information about your protocol approval:

i. Approval is granted for the research and purposes described in the protocol only.

ii. Any changes to the protocol or research materials must be approved by the OHRE **before implementation**.

iii. Any **deviations** to the research or **adverse events** must be reported to the OHRE immediately through an **REB Event**.

iv. This approval is valid **for one year only.** A Renewal Request must be submitted and approved prior to the above expiry date.

v. A **Protocol Closure** must be submitted to the OHRE when the research is complete or if the research is terminated.

vi. The University of Manitoba may request to audit your research documentation to confirm compliance with this approved protocol, and with the UM *Ethics of Research Involving Humans* policies and procedures.

Appendix VI

New study protocol approval

University of Manitoba | Research Ethics and Compliance

Human Research Ethics - Fort Garry
66 Chancellors Circle
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RENEWAL APPROVAL

Effective: February 10, 2026 New Expiry: March 6, 2027

Principal Investigator:	Israel Abejoye
Advisor(s):	Stephen Cornish
Protocol Number:	HE2025-0010
Protocol Title:	*Influence of Post-activation Performance Enhancement on Lower Limb Muscles After Conditioning Activities Amongst Selected Exercise Participants*

Office of Human Research Ethics as designated by REB1

Research Ethics Board 1 has reviewed and renewed the above research. The Office of Human Research Ethics (OHRE) is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans- TCPS 2 (2022).*

Please note the following important information about your renewal approval:

i. Any changes to the protocol or research materials must be approved by the OHRE **before implementation.**

ii. Any **deviations** to the research or **adverse events** must be reported to the OHRE immediately through an **REB Event**.

iii. This renewal is valid for **one year only**. A Renewal Request must be submitted and approved prior to the above expiry date.

iv. A **Protocol Closure** must be submitted to the OHRE when the research is complete or if the research is terminated.

Appendix VII

Checklist of CONSORT 2010 statement: extension to randomized crossover trials

RESEARCH METHODS AND REPORTING

CONSORT 2010 statement: extension to randomised crossover trials

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Evidence shows the quality of reporting of randomised controlled trials is not optimal. The lack of transparent reporting impedes readers from judging the reliability and validity of trial findings, prevents researchers from extracting information for systematic reviews, and results in research waste. The Consolidated Standards of Reporting Trials (CONSORT) statement was developed to improve the reporting of randomised controlled trials. The primary focus of the statement was on parallel group trials with two treatment groups. Crossover trials are a particular type of trial for chronic conditions in which participants are randomised to a sequence of interventions. They are a useful and efficient design because participants act as their own control. However, the reporting of crossover trials has been variable and incomplete, which hinders their use in clinical decision making and by future researchers. We present the CONSORT extension to randomised crossover trials, which aims to facilitate better reporting of crossover trials. The CONSORT 2010 checklist is revised for crossover designs, and introduces a modified flowchart and baseline table to enhance transparency. Examples of good reporting and evidence based rationale for CONSORT crossover checklist items are provided.

Inadequate reporting of randomised controlled trials (RCTs) is associated with bias in the estimation of treatment effects[1 2]; it also impairs the critical appraisal of the quality of randomised trials, which is important when assessing the validity of the results of the individual trial and when conducting systematic reviews. To attempt to address this issue, the Consolidated Standards of Reporting Trials (CONSORT) statement was developed and includes a set of recommendations for the reporting of RCTs.[3] The statement comprises a checklist of essential items that should be included in reports of RCTs and a diagram to document the flow of participants through the trial from before group assignment through to the final analysis. These items are evidence based when possible. An explanation and elaboration of the rationale for the checklist items are provided in an accompanying article.[4] Many journals now require that reports of RCTs conform to the recommendations in the CONSORT statement.[5]

The primary focus of the CONSORT statement is the most common type of RCT with two treatment groups (two "arms") using an individually randomised, parallel group, superiority design.[5] Almost all the elements of the CONSORT statement apply equally to RCTs with other designs, but some elements need adaptation, and in some cases additional issues need to be discussed. Members of the CONSORT group have published several extension papers that augment the CONSORT statement for different types of interventions and data. Extensions of CONSORT 2010 to different trial designs have also been published, including cluster randomised trials,[6] non-inferiority and equivalence trials,[7] N-of-1 trials,[8] pragmatic trials,[9] and within person trials.[10] As part of that series, in this paper we extend the CONSORT 2010 recommendations to simple crossover RCTs in which participants receive two treatments sequentially over two periods and the order in which treatments are received is randomised.

SUMMARY POINTS

- The Consolidated Standards of Reporting Trials (CONSORT) statement provides a minimum set of 25 items to be reported with rationale and exemplars for all randomised trials
- CONSORT extension to crossover trials extends 14 items of the CONSORT statement
- The use of the CONSORT extension to crossover trials will improve reporting of randomised crossover trials

Scope of this paper

Firstly, we summarise the key methodological features of crossover trials. Secondly, we consider the empirical evidence about how common crossover trials are and review published studies about the quality of reporting of such trials. After these literature reviews, we make suggestions for amendments to the CONSORT checklist adapted for crossover trials and give illustrative examples of good reporting. In this guideline we

Table 1 | CONSORT checklist of information to include when reporting randomised crossover trials

Section/topic	Item No	Description	Page No*
Title†	1a	Identification as a randomised crossover trial in the title	i
Abstract†	1b	Specify a crossover design and report all information outlined in table 2	ii
Introduction:			
Background‡	2a	Scientific background and explanation of rationale	1
Objectives‡	2b	Specific objectives or hypotheses	13
Methods:			
Trial design†	3a	Rationale for a crossover design. Description of the design features including allocation ratio, especially the number and duration of periods, duration of washout period, and consideration of carry over effect	16 - 17
Change from protocol‡	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	
Participants‡	4a	Eligibility criteria for participants	18 - 19
Settings and location‡	4b	Settings and locations where the data were collected	16
Interventions†	5	The interventions with sufficient details to allow replication, including how and when they were actually administered	15 - 27
Outcomes‡	6a	Completely defined prespecified primary and secondary outcome measures, including how and when they were assessed	
Changes to outcomes‡	6b	Any changes to trial outcomes after the trial commensed, with reasons	
Sample size†	7a	How sample size was determined, accounting for within participant variability	17 - 18
Interim analyses and stopping guidelines‡	7b	When applicable, explanation of any interim analyses and stopping guidelines	
Randomisation:			
Sequence generation‡	8a	Method used to generate the random allocation sequence	15
Sequence generation‡	8b	Type of randomisation; details of any restriction (such as blocking and block size)	15
Allocation concealment mechanism‡	9	Mechanism used to implement the random allocation sequence§ (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	15
Implementation†	10	Who generated the random allocation sequence,§ who enrolled participants, and who assigned participants to the sequence of interventions	15
Blinding‡	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	15
Similarity of interventions‡	11b	If relevant, description of the similarity of interventions	
Statistical methods†	12a	Statistical methods used to compare groups for primary and secondary outcomes which are appropriate for crossover design (that is, based on within participant comparison)	28
Additional analyses‡	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	28
Results			
Participant flow (a diagram is strongly recommended)†	13a	The numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome, separately for each sequence and period	17 - 19
Losses and exclusions†	13b	No of participants excluded at each stage, with reasons, separately for each sequence and period	17 - 19
Recruitment‡	14a	Dates defining the periods of recruitment and follow-up	17
Trial end‡	14b	Why the trial ended or was stopped	
Baseline data†	15	A table showing baseline demographic and clinical characteristics by sequence and period	29
Numbers analysed†	16	Number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	29
Outcomes and estimation†	17a	For each primary and secondary outcome, results including estimated effect size and its precision (such as 95% confidence interval) should be based on within participant comparisons.¶ In addition, results for each intervention in each period are recommended	29- 32
Binary outcomes‡	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	
Ancillary analyses‡	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing prespecified from exploratory	
Harms†	19	Describe all important harms or untended effects in a way that accounts for the design (for specific guidance, see CONSORT for harms[32])	
Discussion:			
Limitations†	20	Trial limitations, addressing sources of potential bias, imprecision, and if relevant, multiplicity of analyses. Consider potential carry over effects	37
Generalisability‡	21	Generalisability (external validity, applicability) of the trial findings	39
Interpretation‡	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	33 - 37
Other information:			
Registration‡	23	Registration number and name of trial registry	
Protocol‡	24	Where the full trial protocol can be accessed, if available	
Funding‡	25	Sources of funding and other support (such as supply of drugs), role of funders	

CONSORT=Consolidated Standards of Reporting Trials.
*Note: page numbers are optional depending on journal requirements.
†Modified original CONSORT item.
‡Unmodified CONSORT item.