The Effect of Kinesiology Tape on Countermovement Jump Performance in Recreationally Active and Varsity Volleyball Females

by

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Abstract

Context: The countermovement jump (CMJ) is commonly used to assess lower-extremity explosive performance and stretch-shortening cycle (SSC)-related force-time characteristics in volleyball athletes. Although kinesiology tape (KT) has been proposed to influence muscle function through mechanical and sensory effects, research examining its influence on vertical jump performance has produced inconsistent findings. Most previous jumping studies have also focused on jump height or isolated kinetic measures, while the effects of KT applied specifically to the superficial quadriceps on phase-specific CMJ mechanics remain unclear. ***Objective:*** To examine the effects of acute bilateral KT application to the superficial quadriceps on vertical power and CMJ performance assessed through phase-specific kinetic, kinematic, and temporal characteristics between recreationally active females and competitive female volleyball athletes. ***Design:*** Two-group, pre-test post-test mixed design. ***Method:*** Twenty-four females participated, including 12 recreationally active participants (21.8 ± 2.0 years) and 12 competitive volleyball athletes (19.9 ± 2.0 years). KT was applied bilaterally to the rectus femoris, vastus lateralis, and vastus medialis with approximately 25% stretch. Participants completed three maximal-effort CMJs under no-tape and KT conditions, with condition order randomized and counterbalanced within each group. Vertical ground reaction force was recorded at 1000 Hz using an Advanced Mechanical Technology, Inc. force platform and processed using MATLAB. Dependent variables included jump height, reactive strength index (RSI), peak unweighting velocity, countermovement depth, braking rate of force development (RFD), vertical ground reaction force (vGRF) at zero velocity, peak propulsion power, total time to take-off, and unweighting, braking, and propulsion phase times. Separate 2 x 2 mixed ANOVAs were conducted for each dependent variable, with follow-up simple effects tests performed when significant interactions were identified. Statistical significance was established at $\alpha = .05$. ***Results:***

No significant main effect of taping condition was identified for jump height, RSI, peak propulsion power, braking RFD, vGRF at zero velocity, peak unweighting velocity, countermovement depth, total time to take-off, braking time, or propulsion time. Peak propulsion power demonstrated a significant main effect of group (F(1,22) = 7.76, $p < .05$, $\eta^2 = .26$), with the competitive volleyball group producing greater values than the recreationally active group regardless of taping condition. Unweighting phase time demonstrated a significant Group x Taping Condition interaction (F(1,22) = 7.41, $p < .05$, $\eta p^2 = .25$). Follow-up analysis indicated that mean unweighting time decreased from 0.61 s in the no-tape condition to 0.56 s with KT in the competitive volleyball group (t(11) = 2.97, $p < .05$, $d = .86$), whereas no significant change occurred in the recreationally active group. The reduction in unweighting time was not accompanied by improvements in subsequent kinetic variables, jump height, or RSI. ***Conclusions:*** Acute bilateral KT applied to the superficial quadriceps with 25% stretch did not provide evidence of improved CMJ performance or the measured phase-specific force-time characteristics in recreationally active females or competitive female volleyball athletes. Although KT reduced unweighting time in the competitive volleyball group, the isolated temporal change was not accompanied by enhanced kinetic output or jump performance. Competitive volleyball athletes demonstrated greater peak propulsion power than recreationally active females, but this difference did not correspond with significantly greater jump height or RSI. These findings are specific to the acute quadriceps KT application and stretch magnitude examined.

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List of Abbreviations

ANOVA – analysis of variance

BW – Body weight

CMJ – Countermovement jump

COM – Centre of mass

EMG – Electromyography

GAQ – Get Active Questionnaire

vGRF – Vertical ground reaction force

KT – Kinesiology tape

NT – no tape

RFD – Rate of force development

RSI – reactive strength index

SSC – stretch-shortening cycle

Review of Literature

Kinesiology tape (KT) is an elastic therapeutic tape commonly used in sport and rehabilitation settings with the intent of providing support while permitting unrestricted movement (Wu et al., 2015). Its increased visibility during international sporting events has contributed to widespread clinical and athletic use and increased research interest regarding its proposed effects (Williams et al., 2012). Despite the tape's popularity, evidence supporting an ergogenic effect of KT remains inconsistent with many investigations reporting little or no improvement in jump performance (Alabbad & Muaidi, 2021; MacDowall et al., 2015). Interpretation of this literature is complicated by substantial methodological variation in the muscles taped, magnitude of tape stretch, duration of application, participant populations, and jumping protocols. Consequently, evaluating the potential influence of KT on jumping requires consideration not only of jump height, but also of the mechanical characteristics through which CMJ performance is produced.

The countermovement jump (CMJ) is commonly used to assess lower-extremity explosive performance and incorporates a stretch-shortening cycle (SSC), in which active musculotendinous lengthening precedes shortening (Komi, 2000; Van Hooren & Zolotarjova, 2017). From a mechanical perspective, CMJ performance is governed by the impulse-momentum relationship: the net vertical force applied over time determines the change in centre-of-mass velocity until take-off to determine jump height (Taber et al., 2016). Phase-specific variables such as peak unweighting velocity, countermovement depth, braking RFD, vGRF at zero velocity, peak propulsion power, and phase duration can provide additional information regarding the force-time strategy used to complete the movement.

The mechanical characteristics of the CMJ may also differ according to training background. Athletes with greater jumping and power-training experience typically demonstrate greater downward velocity, braking force characteristics, and propulsion-phase output (Cormie et al., 2009, 2010). Similar distinctions have been reported when comparing individuals with higher and lower reactive strength, where superior performance was associated with increased force, velocity, and power across substantial portions of the eccentric and concentric phases (McMahon, Jones, et al., 2018). Sex-related differences in CMJ force-time characteristics have also been reported, with females generally demonstrating lower force and power outputs than males (McMahon et al., 2017). These findings support examining female populations independently and considering whether athletes with different training backgrounds use different strategies to achieve CMJ performance.

KT applied to the quadriceps provides a potential application through which these mechanical characteristics may be influenced. Previous investigations have reported changes in quadriceps torque following KT application during controlled single-joint tasks, although findings are inconsistent and do not establish that similar effects occur during a dynamic multi-joint CMJ (Choi & Lee, 2018; Vithoulka et al., 2010). Proposed effects of KT include cutaneous sensory input and local mechanical interactions with underlying tissues; however, the extent to which these mechanisms alter force production during active movement remains uncertain. Furthermore, most research examining KT during jumping has focused primarily on jump height or has applied tape to muscles other than the complete superficial quadriceps group. Whether bilateral KT applied to the rectus femoris, vastus lateralis, and vastus medialis influences phase-specific CMJ mechanics, and whether the response differs according to training background remains unclear.

Accordingly, this literature review first examines the mechanical structure of the CMJ, including its phases and the kinematic, kinetic, and temporal variables relevant to the present investigation. The impulse-momentum relationship and SSC are then considered to establish how force-time characteristics contribute to CMJ performance. Literature describing

CMJ characteristics in females and populations with different training backgrounds is reviewed to provide context for comparisons between recreationally active females and competitive female volleyball athletes. The anatomical contribution of the lower extremity, with particular emphasis on the superficial quadriceps is subsequently discussed before reviewing the proposed mechanisms and methodological considerations associated with KT. Finally, research examining the effects of KT on muscle force production, CMJ kinetics, and vertical jump performance is evaluated to identify the limitations of the existing literature and establish the rationale for the present investigation.

The Countermovement Jump

The vertical jump is a fundamental skill essential for success in many sports such as volleyball, basketball, and soccer (Karatrantou et al., 2019). Vertical jumping requires the body to be accelerated upward against gravity through coordinated lower-extremity extension, with extension of the hips and knees and plantarflexion of the ankles contributing to take-off. When an arm swing is permitted, rapid forward and upward movement of the arms can further contribute to vertical jump performance (Bobbert et al., 1996; Harman et al., 1990). One commonly used method of assessing vertical jump performance is the countermovement jump (CMJ), which is frequently used by coaches and researchers to assess lower-extremity power (Dias et al., 2011). The CMJ is distinguished by an initial downward countermovement of the centre of mass (COM), which is immediately followed by an upward movement that continues until the individual leaves the ground (Bobbert et al., 1996; Harman et al., 1990). This preceding downward movement differentiates the CMJ from jumping tasks such as the squat jump, in which upward propulsion begins from a stationary flexed position (Petrigna et al., 2019). Although the CMJ does not fully replicate the task-specific constraints of sport (i.e., goal or task), it provides a simple and reliable method of assessing a natural movement pattern involving the stretch-shortening cycle (SSC; Linthorne, 2001; Moran &

Wallace, 2007; van Hooren & Zolotarjova, 2017). The CMJ has been divided into six phases: the preliminary, unweighting, braking, propulsion, flight, and landing phases (McMahon, Suchomel, et al., 2018). For the purposes of the present study, emphasis is placed on the unweighting, braking, and propulsion phases because these phases describe the force-time characteristics leading up to take-off.

The preliminary phase occurs before movement begins while the participant maintains an upright and stationary standing position, typically with the feet approximately shoulder-width apart (Petrigna et al., 2019; see Figure 1a). During this phase, COM velocity is approximately zero and vertical ground reaction force (vGRF) remains close to body weight, providing the stable baseline from which movement onset can be identified during analysis (McMahon, Suchomel, et al., 2018). The unweighting phase then initiates the countermovement and is characterized by a downward acceleration of the COM by reducing the vGRF to below body weight (McMahon, Suchomel, et al., 2018). During unweighting, the hips and knees flex, the ankles dorsiflex, and, when an arm swing is used, the arms move downward and backward as the shoulders extend (Petrigna et al., 2019; see Figure 1a–b). The unweighting phase ends at peak downward COM velocity (McMahon, Suchomel, et al., 2018).

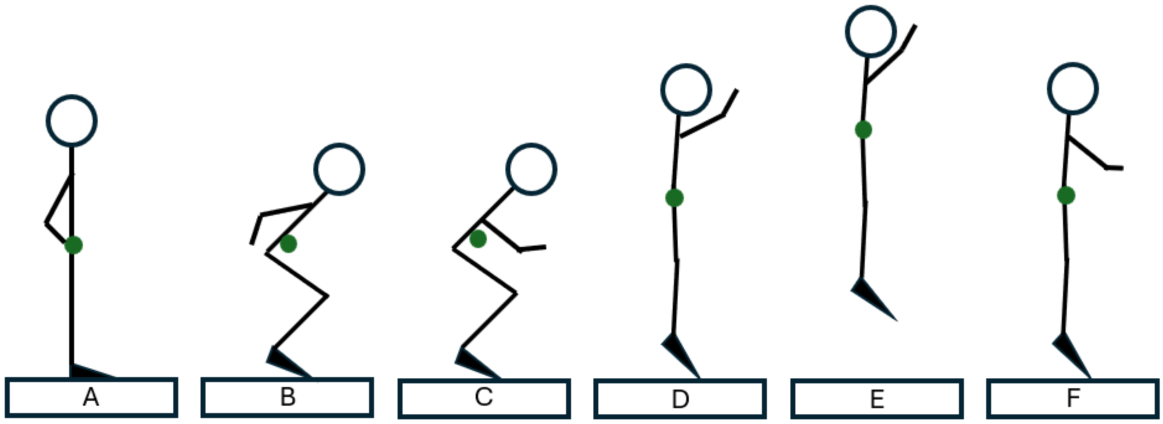
Downward COM movement continues into the braking phase, during which vGRF increases to reverse the direction of acceleration as the lower-extremity musculature acts eccentrically to decelerate downward movement (Acero et al., 2012; McMahon, Suchomel, et al., 2018; see Figure 1b). Braking continues until COM velocity returns to zero, or the instant the COM reaches its lowest vertical position, and maximum countermovement depth is attained (McMahon, Suchomel, et al., 2018). This point also represents the end of braking and the transition between the downward and upward portions of the CMJ. The term amortization is commonly used to describe this transition between eccentric braking and concentric propulsion and coincides with zero COM velocity at the lowest position of the countermovement (Davies et al., 2015; McMahon, Suchomel, et al., 2018). Thus, the primary distinction between unweighting and braking is that the COM accelerates downward during unweighting but decelerates while continuing to move downward during braking.

Although these phases are commonly used to describe CMJ force-time characteristics, definitions of the boundary between unweighting and braking vary across the literature. Some researchers define the start of the braking phase as the instant of peak downward COM velocity, which reflects the beginning of COM deceleration (McMahon, Suchomel, et al., 2018). However, other researchers define the phase to begin at the point of minimum vGRF (Cabarkapa et al., 2023, 2024; Heishman et al., 2018). Minimum force occurs before peak downward COM velocity and therefore produces a different temporal boundary between the unweighting and braking phases (Krzyszkowski et al., 2021). These methodological differences are important when comparing studies because they can influence the magnitude of phase-specific variables, including unweighting velocity, braking RFD, and unweighting and braking phase durations.

Following the completion of braking and the zero-velocity point at maximum countermovement depth, the propulsion phase begins as the COM starts to move upward and continues until take-off (McMahon, Suchomel, et al., 2018). During propulsion, coordinated explosive extension of the hips and knees and ankle plantarflexion accelerate the COM upwards (McMahon, Suchomel, et al., 2018). Additionally, the arms rapidly flex at the shoulder and elbow during the propulsion phase when incorporating an arm-swing and contributing to overall jump action (Acero et al., 2012; Linthorne, 2001; see Figure 1c). The propulsion phase ends at the instant of take-off, after which the participant enters the flight phase before subsequently landing (Acero et al., 2012; see Figure 1d-f). Because the present study examined variables derived before take-off, the unweighting, braking, and propulsion phases are emphasized throughout this review. Collectively, these phases constitute the time to take-off and have been reported to occur over approximately 0.80 s to 0.95 s in female volleyball and other CMJ populations, although the duration varies according to population and jumping strategy (Cabarkapa et al., 2024; Donahue et al., 2023; Vaverka et al., 2016).

Figure 1

Countermovement Jump Sequential Phases



Note. Sequential phases of the countermovement jump are displayed in order by frame (A-F). Frame A: The preliminary phase. Frame A-B: The unweighting phase. Frame B: The braking phase until propulsion phase. Frame C: Onset of propulsion phase. Frame D: The take-off phase. Frame E: The flight phase. Frame F: The landing phase. The green dot represents the athlete's centre of gravity.

Kinematics of the Countermovement Jump

In the field of biomechanics, kinematics examines motion irrespective of the forces that produce the motion and is characterized by both linear and angular body and joint positions along with their time derivatives (Robertson & Caldwell, 2014). These time derivatives may include displacement, velocity, and acceleration (Robertson & Caldwell, 2014). During the CMJ, kinematic variables are frequently measured using motion capture systems or inversely calculated using force data (Leard et al., 2007; Linthorne, 2001). Although joint angles are commonly examined in CMJ research, the present study is focused on linear kinematic variables including unweighting velocity and countermovement displacement. These variables were selected because they describe the movement strategy used during the downward phase of the CMJ and may influence the force-time characteristics that occur before take-off (Cormie et al., 2009; Moran & Wallace, 2007).

Countermovement depth represents the downward displacement of the COM from its initial standing position to its lowest position at the end of the braking phase, immediately before propulsion begins. The depth of the countermovement can influence jump performance by altering both the displacement over which the body moves and the time available to generate the forces required for take-off (Sánchez-Sixto et al., 2018). Moran and Wallace (2007) demonstrated this relationship in elite male volleyball athletes by comparing CMJs initiated from different knee-flexion positions. Jump height was greater when propulsion began from the deeper condition than from the shallower condition (approximately 0.36 m vs. 0.31 m). The deeper countermovement also increased propulsion duration, despite reductions in knee and ankle torque at the beginning of the phase (Moran & Wallace, 2007). Similarly, Sánchez-Sixto et al. (2018) reported that increasing countermovement depth increased jump height and take-off velocity. Vanrenterghem et al. (2004) further demonstrated that greater countermovement depth was accompanied by longer downward and upward movement times across CMJs performed at different effort levels. Collectively, these findings support the idea that a deeper countermovement may enhance performance by increasing the time and displacement available for force application to generate upward impulse (Moran & Wallace, 2007; Sánchez-Sixto et al., 2018; Vanrenterghem et al., 2004).

However, increasing countermovement depth may not necessarily result in superior CMJ performance. Mandić and colleagues (2016) demonstrated that participants frequently use a countermovement that is shallower than the depth that maximized their jump height. It should be highlighted that using a larger countermovement depth was found to decrease peak force and power measures (Mandić et al., 2016). Gheller et al. (2015) similarly found that deeper and preferred countermovement conditions produced greater jump heights and relative net impulse than the shallow condition, whereas a shallower countermovement produced increased peak force and power values when examining male collegiate volleyball and basketball athletes (n = 20). Similarly, Pérez-Castilla et al. (2019) reported that using a larger countermovement achieved a greater jump height and peak velocity, while incorporating a shorter countermovement resulted in greater force, power, and RSI values.

Evidence from self-selected CMJs further indicates that countermovement depth alone does not determine jumping performance. McErlain-Naylor et al. (2014) examined kinetic and kinematic determinants of CMJ performance in males (n = 18) with varying levels of jumping experience who were permitted to use a self-selected countermovement and arm-swing. The researchers reported that kinematic characteristics explained a significant proportion of the variation in jump height, with ankle plantarflexion and shoulder flexion at take-off contributing to the prediction model while minimum knee and ankle angles were not retained as significant predictors. However, the authors noted that coordination may be more difficult as depth increases (McErlain-Naylor et al., 2014). Collectively, these findings suggest that countermovement depth influences vertical jump performance through a trade-off between displacement, time available for force application, and the magnitude of force production. Therefore, the influence of countermovement depth should be interpreted alongside kinetic and temporal variables that describe how force is produced before take-off rather than in isolation.

Temporal factors can provide further insight into the CMJ strategy used. Vaverka and colleagues (2016) examined the contribution of arm-swing on jump performance in elite male volleyball players (n = 18) and reported phase-specific (unweighting, braking, and propulsion) temporal measures during no arm-swing and arm-swing trials. Although unweighting phase time (M = 0.39 s, M = 0.42 s) and total take-off duration (M = 0.87 s, M =

0.86 s) were not significantly different between conditions, arm-swing significantly shortened the braking phase (M = 0.21 s, M = 0.16 s) and prolonged the propulsion phase (M = 0.26 s, M = 0.29 s; Vaverka et al., 2016). It is essential to highlight that jump height increased by approximately 14 cm in the arm-swing trial (Vaverka et al., 2016). Therefore, performance enhancements reported by Vaverka and colleagues (2016) was accompanied by an altered temporal distribution during braking and propulsion to maximize force-time characteristics in the latter phase. Because the arm swing can also alter the force and velocity characteristics of the jump (Feltner et al., 2004; Harman et al., 1990), the increase in jump height cannot be attributed to the temporal changes alone.

Laffaye et al. (2014) further demonstrated that temporal characteristics are related to CMJ performance in a large sample (n = 273) of elite athletes from various sporting backgrounds. The researchers reported that jump height was negatively associated with total time, eccentric time, and the ratio of eccentric time to total take-off (Laffaye et al., 2014). Conversely, kinetic measures (i.e., average propulsion force and eccentric RFD) demonstrated stronger positive relationships with vertical jump height (Laffaye et al., 2014). Although their definition of eccentric time differs, the observation agrees with Vaverka and colleagues (2016) who suggested that enhanced temporal profiles involve reducing braking time and shifting a greater proportion of time spent in the propulsion phase. Furthermore, these findings indicate that shorter braking phase durations can characterize better-performing jumps but do not independently explain performance (Laffaye et al., 2014). This is where the consideration of the impulse-momentum relationship is important, because reducing the time available for force application would not be advantageous unless sufficient force is produced to generate the required net impulse (Hall, 2019). Specific to the CMJ, maintaining higher force over a longer period in propulsion increases net impulse and results in greater jump heights (Garhammer & Gregor, 1992). Therefore, a CMJ where the allocation of time shifts from braking to propulsion may be considered an optimized temporal strategy; however, temporal characteristics are most informative when considered together with the force, displacement, and velocity characteristics occurring during the corresponding phases of the CMJ.

COM velocity provides essential information regarding both CMJ performance and the movement strategy used before take-off. From an impulse-momentum perspective, as body mass remains constant the change in momentum due to net vertical impulse generated before take-off determines the change in COM velocity (Taber et al., 2016). Consequently, greater positive net impulse achieved during propulsion results in a quicker take-off velocity, which directly determines the vertical rise of the COM following take-off (Linthorne, 2001; Robertson & Caldwell, 2014). Cormie et al. (2009) demonstrated differences in CMJ velocity characteristics when comparing Division I athletes with healthy non-athletes. The athletes achieved greater jump height (M = 0.58 m, M = 0.43 m) and greater peak upward velocity (M = 3.6 m·s^{-1}, M = 3.0 m·s^{-1}) than the non-athletic participants. Furthermore, the non-athletic group showed significant improvements in jump height (M = 0.52 m) and peak upward velocity (M = 3.66 m·s^{-1}) following 12 weeks of power training (Cormie et al., 2009). Therefore, it should be anticipated that competitive volleyball athletes who frequently perform jumping tasks (in training and competition) will demonstrate greater take-off velocity than generally active individuals.

However, take-off velocity is an outcome variable that provides minimal information regarding how the countermovement was performed. Peak unweighting velocity represents the greatest downward COM velocity attained before braking begins (McMahon, Suchomel, et al., 2018). The mechanical relevance of the measure is demonstrated by McMahon, Jones, et al. (2018), who found that athletes with higher RSImod demonstrated greater peak downward velocity than athletes with lower RSImod (1.37 m·s^{-1} vs. 1.14 m·s^{-1}).

Furthermore, the higher-performing group also demonstrated increased peak eccentric force, a shorter braking phase, and produced more impulse during propulsion (McMahon, Jones, et al., 2018). These findings are important because a greater downward velocity produces a greater magnitude of downward momentum that must be reduced to zero during the subsequent braking phase (McMahon, Suchomel, et al., 2018). This is partly because a quicker downward velocity increases downwards momentum, requiring greater impulse demands in the subsequent braking phase to stop the downwards movement (McMahon, Jones, et al., 2018; McMahon, Suchomel, et al., 2018). Although increasing unweighting velocity may not be inherently advantageous in isolation, it increases the potential kinetic contributions in the braking phase that may benefit impulse generating abilities during propulsion (McMahon, Suchomel, et al., 2018).

In summary, investigations of CMJ kinematics and temporal characteristics suggest that countermovement strategy can influence jump performance by altering the displacement, velocity, and time available for force application. Greater countermovement depth may increase the distance and time over which force can be applied, whereas a shallower or faster countermovement may increase force, power, or RSImod without necessarily increasing jump height (Gheller et al., 2015; Moran & Wallace, 2007; Pérez-Castilla et al., 2019). Similarly, unweighting velocity may provide insight into how rapidly the COM is lowered before braking. However, the practical importance of unweighting velocity depends on whether subsequent force production is also enhanced (Cormie et al., 2009, 2010; McMahon, Jones, et al., 2018). Phase-specific temporal variables (unweighting, braking, and propulsion time) help describe how the CMJ is performed, but they should not be interpreted as isolated indicators of performance (Laffaye et al., 2014; Vaverka et al., 2016). Therefore, kinematic and temporal variables should be considered alongside kinetic measures to determine whether a change in movement strategy meaningfully influences jump height. Previous sex-based comparisons demonstrated that female jumpers typically use less countermovement displacement, slower unweighting velocities, and decreased jump height than males despite similar temporal patterns (Laffaye et al., 2014; McMahon et al., 2017). Thus, implementing a procedure to increase countermovement depth and utilize a more rapid unweighting phase may be an adaptation strategy that could improve jump height in female populations.

Kinematic Methodological Considerations When Conducting Research

Methodological decisions regarding arm-swing and countermovement depth are important when examining CMJ performance. These factors are frequently standardized in research to reduce variability between participants and trials; however, they also influence the movement strategy of the CMJ (Petrigna et al., 2019). Researchers frequently standardize arm-swing and countermovement depth to improve consistency between participants and trials, but these constraints also modify the kinematic and kinetic characteristics being assessed (Chiu et al., 2014; Petrigna et al., 2019). Therefore, the degree of standardization used in a CMJ protocol should reflect the purpose of the assessment. Greater movement constraint can improve experimental consistency, whereas allowing participants to use their preferred movement strategy may better preserve the characteristics of their maximal CMJ.

Arm-swing is a key methodological consideration because it is commonly used during natural jumping tasks and can influence CMJ performance. Previous research suggests that incorporating an arm-swing during the CMJ increases performance by altering force and time characteristics (Feltner et al., 2004; Harman et al., 1990; Vaverka et al., 2016). For example, Feltner et al. (2004) suggested that arm-swing enhances jump performance by prolonging the duration of the propulsion phase. Similarly, Vaverka et al. (2016) reported that elite male volleyball athletes jumped higher by decreasing time braking, prolonging time in propulsion, and increasing vertical net impulse when incorporating an arm-swing. Accordingly, whether arm swing is permitted or restricted should be clearly defined and applied consistently within a study because the two conditions represent mechanically different CMJ strategies. When the objective is to assess maximal CMJ performance using a movement pattern that more closely reflects an individual's preferred jumping strategy, permitting arm swing may therefore be appropriate.

Countermovement depth is another methodological factor frequently considered for standardization. Pérez-Castilla et al. (2019) reported that incorporating a larger countermovement produced a greater jump height and peak velocity than a shorter countermovement. Conversely, the shorter countermovement produced greater force and power compared to the larger countermovement trials (Pérez-Castilla et al., 2019). Interestingly, the researchers showed that the shape of the force-time curve differed according to countermovement depth (Pérez-Castilla et al., 2019). Deep countermovements consistently demonstrated a bimodal force-time profile, characterized by two distinguishable peaks in vertical force (Pérez-Castilla et al., 2019). In comparison, shallow countermovements frequently demonstrated a unimodal profile, characterized by a single predominant force peak (Pérez-Castilla et al., 2019). These reports demonstrate that manipulating countermovement depth does more than alter COM displacement, it can change how force is distributed throughout the movement. Standardizing countermovement depth may therefore reduce between-trial variability but can also constrain the strategy an individual would otherwise select when attempting to maximize jump performance.

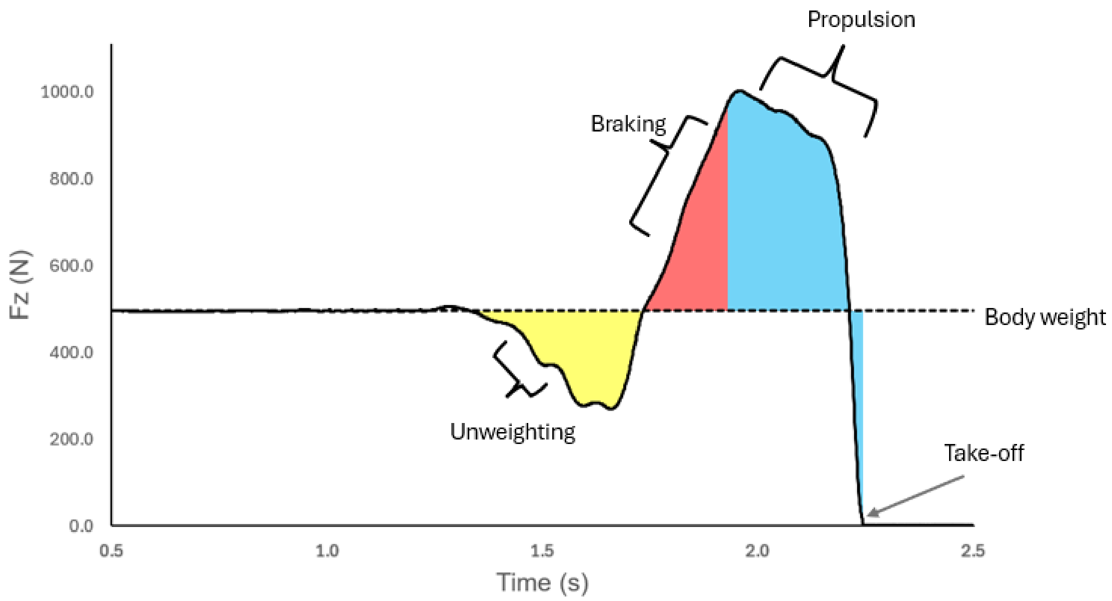
The issue of standardizing CMJ protocol is relevant because not all jumpers use the same kinematic strategy, even in proficient jumpers. For instance, Rauch and colleagues' (2020) examination of NBA athletes (n = 178) demonstrated the use of three different strategies, which they categorized as stiff-flexors (n = 77; i.e., less than average angular displacement at each joint), hyper-flexors (n = 49; i.e., above average angular displacement at each joint), and hip flexors (n = 52; i.e., above average angular displacement at the hip with normal displacement at knee and ankle). While the three groups achieved similar jump heights, the kinetic, kinematic, and temporal variables differed between groups (Rauch et al., 2020). The findings may suggest that standardizing CMJ protocol may not represent the most effective jumping strategy for each participant equally. In accordance, allowing participants to individualize their arm-swing and countermovement strategy may provide a more accurate assessment of natural CMJ performance. The natural assessment of CMJ performance may be particularly beneficial to observe in applied studies examining if an acute intervention influences jumping ability.

Kinetics of the Countermovement Jump

Kinetics is the study of force (i.e. cause of motion), which is a quantifiable vector based on its magnitude, direction, and point of application (Caldwell et al., 2014). When analysing the CMJ, force platform analysis allows researchers to examine changes of vertical ground reaction force (vGRF) over time by recording data at high frequencies (Bui et al., 2014; Caldwell et al., 2014). While force platforms measure forces applied directly to the device, Newton’s third law (i.e., law of reaction) allows force to be interpreted as the equal and opposite GRF acting on the jumper (Caldwell et al., 2014; Hall, 2019). The primary mechanical principle used to understand the kinetics of the CMJ is Newton’s second law (i.e., law of acceleration), which states that the accelerations of a body is produced based on the magnitude and direction of force applied and is inversely related to the mass of the body (Hall, 2019). During the CMJ, net vertical force is determined by the difference between the jumper’s body weight and current vGRF (Linthorne, 2001). The net vertical force produces an acceleration on the COM, which depends on the magnitude and direction of net force (Linthorne, 2001). By recording these changes in force at high frequencies, the data can be plotted to create a force-time curve that can be used to visually examine how force changes throughout the CMJ phases (see Figure 2; Caldwell et al., 2014; McMahon, Suchomel, et al., 2018).

Figure 2

Representative Vertical Ground Reaction Force-Time Curve Illustrating Phase-Specific Net Impulse During a Countermovement Jump



Note. Representative vertical ground reaction force-time curve from a participant in the present study. Fz represents vertical ground reaction force. The horizontal body-weight line represents the force required to maintain zero vertical acceleration. Shaded regions illustrate net vertical impulse during the unweighting (yellow), braking (red), and propulsion phases (blue). Phase boundaries correspond to the definitions used in the present investigation, with take-off marking the end of the propulsion phase.

The fundamental mechanical framework for interpreting the force-time curve of the CMJ is the impulse-momentum relationship. Momentum refers to the quantity of motion a body possesses and is the product of the system's mass and linear velocity, whereas impulse represents the integral of force with respect to time (Caldwell et al., 2014; Hall, 2019). The impulse-momentum relationship states that when an impulse is applied to a system, it will experience an equal change in its momentum (Caldwell et al., 2014). Because the jumper's mass remains constant, net vertical impulse produces a change in COM velocity. When considering the force-time graph, the area between the vGRF curve and the individual's body weight represents net vertical impulse during each phase of the CMJ (see Figure 2; McMahon, Suchomel, et al., 2018). Force begins to fall below body weight in the unweighting phase, producing a negative net impulse and increasing downwards COM velocity until braking initiates (see Figure 2; McMahon, Suchomel, et al., 2018). Subsequently, force rapidly rises above body weight to create a positive impulse to decelerate the downwards motion and return COM velocity to zero (McMahon, Suchomel, et al., 2018). Because the COM begins the countermovement with approximately zero vertical velocity and returns to zero velocity at the end of braking, the negative unweighting impulse and positive braking impulse are approximately equal in magnitude and opposite in direction (McMahon, Suchomel, et al., 2018). However, these impulses can be produced through different combinations of force and time, resulting in distinct force-time profiles across the two phases (see Figure 2). More specifically, the shape of the braking phase is typically represented by a taller and narrower force-time curve than the unweighting phase because greater force is applied over a shorter period (see Figure 2; McMahon, Suchomel, et al., 2018). The propulsion phase then continues to produce an upwards (positive) net impulse required to generate a take-off velocity that determines jump height (Linthorne, 2001; McMahon, Suchomel, et al., 2018). Therefore, variables influencing the ability to demonstrate a propulsive impulse should be considered when examining the CMJ.

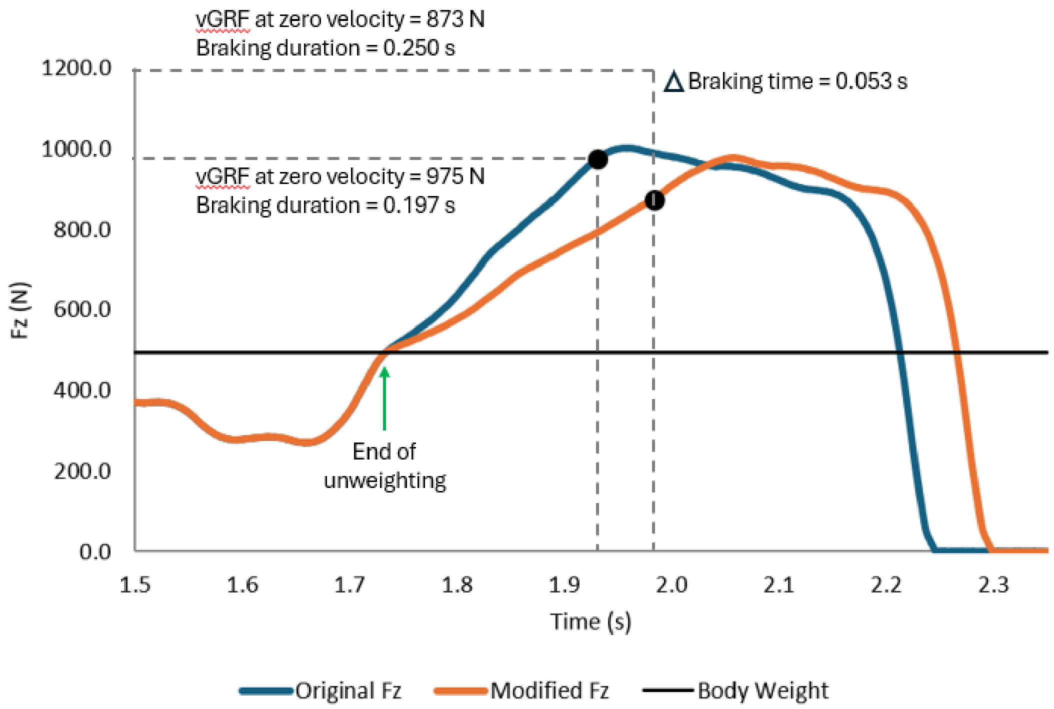
Commonly examined kinetic variables associated with CMJ performance include peak and mean force and power measures (Moura & Okazaki, 2022). For example, McLellan et al. (2011) investigated physically active males and found that absolute peak force (M = 1972 N) shares a significant relationship with CMJ height (M = 0.55 m). Similarly, Bermúdez and Fábrica (2014) observed that absolute maximum force significantly predicted jump height during non-fatigued (M = 1733 N) conditions in 10 male athletes. However, a recent review of literature on jump performance determinants suggested that peak force as a stand-alone variable was not a reliable predictor of jump performance (Moura & Okazaki, 2022). The limitation of this measure can be explained mechanically because impulse depends on both the magnitude of net force and the duration over which it is applied (Garhammer & Gregor, 1992). Peak force may be especially difficult to interpret as an isolated predictor because it can be influenced by the countermovement strategy used by the jumper. For instance, significantly smaller values of relative peak force coincided with greater jump heights have been observed when employing a larger countermovement (M = 2.38 $N \cdot BW^{-1}$, M = 0.46 m) than a short countermovement (M = 2.81 $N \cdot BW^{-1}$, M = 0.42 m) in basketball and soccer (n = 29) athletes (Sánchez-Sixto et al., 2018). Various other investigations have demonstrated that using a shallower countermovement produces higher forces, whereas a deeper countermovement may produce greater jump heights despite lower peak force values by increasing time to generate an impulse (Gheller et al., 2015; Mandić et al., 2016; Pérez-Castilla et al., 2019). These findings suggest that greater peak force does not necessarily indicate a superior jump strategy when considered independently from countermovement depth, movement time, and impulse. Therefore, kinetic variables should be interpreted in relation to the shape of the force-time curve and the movement strategy used during the CMJ.

Mean force provides information about force production over a greater portion of the movement but similarly requires consideration of phase duration. Laffaye et al. (2014) reported that average propulsion force was associated with jump height in elite court and field athletes, and that females demonstrated lower average propulsion force than males during the CMJ (M = 19.8 $N \cdot kg^{-1}$, M = 21.0 $N \cdot kg^{-1}$, respectively). However, mean force values still do not fully describe CMJ performance because they do not independently account for the duration over which force is applied. Vaverka et al. (2016) demonstrated this point in their analysis of elite male volleyball players by comparing arm-swing and no arm-swing CMJs. Although average braking and propulsion forces differed only modestly between conditions, phase-specific impulse showed clearer differences in which the arm-swing condition produced a lower braking impulse and greater propulsion impulse. These findings are mechanically important because impulse accounts for both force magnitude and time of application. Similarly, Kirby et al. (2011) reported that vertical net impulse was strongly associated with CMJ height across countermovement depths while peak force was negatively related to jump height. Collectively, these findings reinforce that force magnitude should be interpreted within the broader force-time strategy of the CMJ. This interpretation may be particularly true when movement time, arm-swing, or countermovement depth are not strictly controlled. Therefore, variables that describe the magnitude and timing of force application, such as braking rate of force development (RFD), provide important information about how impulse is generated during the CMJ.

RFD is an indicator of explosive strength, representing how quickly an individual can generate force during rapid voluntary muscular contractions (Maffiuletti et al., 2016). More specifically, RFD is the rate of change in force per unit of time and is commonly expressed in Newtons per second ($N \cdot s^{-1}$; Nuzzo et al., 2008). Explosive strength is considered essential when performing tasks where the amount of time to produce force is limited (Folland et al., 2013). Although many sport-specific skills (i.e., sprinting, change-of-direction ability, jumping) are facilitated by muscular power output, some researchers attribute RFD as the underlying mechanism for increasing an athlete's power (Taber et al., 2016). During the CMJ, braking RFD is particularly relevant because it describes how rapidly vGRF increases during the braking phase as downward COM velocity is reduced to zero before propulsion begins (McMahon, Suchomel, et al., 2018). Importantly, braking RFD and braking impulse describe related but distinct characteristics of the force-time strategy. Net braking impulse determines the change in downward momentum, whereas braking RFD describes how rapidly the force required to produce that impulse is developed (McMahon, Suchomel, et al., 2018; Philipp et al., 2023). Consequently, similar braking impulses may be achieved through different combinations of force magnitude and braking duration. As illustrated in Figure 3, the original and modified force-time curves produced equivalent net braking impulses (46.3 N·s), despite the modified curve demonstrating a lower braking RFD (1512.4 $N \cdot s^{-1}$ vs. 2435.7 $N \cdot s^{-1}$) and longer braking duration (0.250 s vs. 0.197 s). The lower braking RFD and longer braking duration in the modified curve were also accompanied by a lower vGRF entering propulsion (873 N vs. 975 N), demonstrating that equivalent changes in momentum do not necessarily require the same force-time strategy at the transition into propulsion. Furthermore, the difference between the illustrative curves persisted into the subsequent propulsion phase, with the modified curve producing a lower net propulsion impulse (105.4 N·s vs. 109.5 N·s) and reducing jump height by approximately 1.75 cm. Therefore, enhancing force development during braking could benefit the jumper by improving jump heights while performing the movement in less time. In a practical setting, increasing braking RFD may be relevant to volleyball because blocking and spiking often require rapid jump execution. Consequently, athletes who can develop braking force quickly during the CMJ may be better positioned to transition efficiently from downward movement into propulsion during time-constrained jump tasks.

Figure 3

Illustrative Influence of Different Braking Rates of Force Development on Countermovement Jump Force-Time Characteristics



Note. Illustrative vertical ground reaction force-time curves demonstrating different braking strategies during a countermovement jump. The original curve represents a force-time trace from preliminary data, whereas the modified curve was generated from the original trace to illustrate a lower braking rate of force development (RFD) and longer braking duration while maintaining an equivalent net braking impulse. Braking RFD was 2435.7 N·s⁻¹ and 1512.4 N·s⁻¹ and braking duration was 0.197 s and 0.250 s for the original and modified curves, respectively. Vertical ground reaction force at zero velocity was 974.7 N for the original curve and 873.0 N for the modified curve. The altered force-time profile subsequently resulted in net propulsion impulses of 109.5 N·s and 105.4 N·s for the original and modified curves, respectively. Fz = vertical ground reaction force.

Evidence supporting braking RFD as a relevant force-time descriptor of the CMJ has primarily been derived from correlational and training-based research. Laffaye et al. (2014) reported sex-based differences in both absolute braking RFD (females: M = 3.26 kN·s⁻¹; males: M = 5.12 kN·s⁻¹) and relative braking RFD (females: M = 52.91 N·kg⁻¹·s⁻¹; males: M = 61.00 N·kg⁻¹·s⁻¹) in elite field and court sport athletes. The authors further reported that absolute and relative braking RFD were positively associated with jump height ($r = 0.52$ and $r = 0.40$, respectively) and average propulsion force ($r = 0.56$ and $r = 0.55$, respectively), while being negatively associated with eccentric time ($r = -0.66$ and $r = -0.62$, respectively). These findings suggest that athletes who developed force more rapidly during braking generally expressed greater force during propulsion and jumped higher. Conversely, Barker et al. (2018) reported that eccentric RFD ($r < 0.10$) was not strongly related to jump height in Division-I soccer athletes. One explanation for the difference between the two studies is the time each measured RFD (Barker et al., 2018; Laffaye et al., 2014). Laffaye et al. (2014) calculation of RFD corresponded to the braking phase; however, Barker et al. (2018) measured the force rise from minimum force to the first vGRF peak rather than strictly across the braking phase. Because the latter approach includes portions of both downward and upward COM acceleration, it may not consider the braking phase in the same manner. Furthermore, data from these studies are correlational and should not be interpreted as absolute evidence that increasing braking RFD independently enhances jump height.

McHugh et al. (2020) provide additional evidence more specific to braking phase mechanics. When Division I athletes were separated according to jump performance, above-average jumpers demonstrated approximately 57% greater braking RFD than below-average jumpers ($M = 1163\%\ BW{\cdot}s^{-1}$, $M = 740\%\ BW{\cdot}s^{-1}$), despite using similar countermovement depths. The above-average jumpers also completed the braking phase more quickly and demonstrated increased braking force characteristics (McHugh et al., 2020). These findings support braking RFD as a relevant phase-specific measure because it quantifies how rapidly force is developed to reduce the downward momentum of the COM during braking. As braking immediately precedes propulsion, braking RFD may also provide insight into whether rapid force development during the downward phase is accompanied by greater force expression at the braking-to-propulsion transition and during the subsequent propulsion phase.

While braking RFD describes the rapid rise of force during the braking phase, vertical ground reaction force (vGRF) at zero velocity represents the magnitude of force at the instant downward COM velocity has been decelerated to zero, marking the transition between the braking and propulsion phases (McMahon, Suchomel, et al., 2018). Although vGRF at zero velocity does not consider the application of time, the measure has a definable point of interest within the sequence of the CMJ on the force-time curve. Furthermore, this variable is particularly relevant because it quantifies the force already developed at the braking-to-propulsion transition. A greater vGRF at zero velocity indicates that the propulsion phase begins with a larger magnitude of force already being expressed, which can contribute to producing a greater impulse by increasing the area under the force-time graph in the early instants of the phase provided the elevated force is maintained through take-off (McMahon, Suchomel, et al., 2018). Therefore, vGRF at zero velocity provides a phase-specific measure to help explain whether braking phase behaviours influenced propulsion phase mechanics and jump performance.

McHugh et al. (2020) demonstrated the relevance of the braking-to-propulsion transition point when comparing above and below-average jumpers within Division I athletes. When comparing below average (M = 0.38 m) to above average (M = 0.49 m) jumpers, vGRF at zero velocity (M = 229% BW, M = 272% BW) was approximately 19% higher in the above average jumpers (McHugh et al., 2020). These differences occurred alongside the previously noted 57% difference in braking RFD, despite using similar countermovement depths. These observations by McHugh and colleagues (2020) may suggest that more proficient jumpers (in elite sports) express more force while using similar amounts of motion. Regardless, differences in vGRF at zero velocity may have assisted the above average jumpers to generate more impulse during propulsion. Reports of subsequent propulsive phase metrics found that the above-average jumpers spent less time (M = 0.29 s, 0.27 s, approximately 9%) while producing greater average force (M = 196% BW, 220% BW, approximately 12%) during the phase (McHugh et al., 2020). Despite a shorter propulsion phase, the greater force applied was sufficient to produce more impulse for increased jump heights in the above average jumpers (McHugh et al., 2020). Together, these observations suggest that increased force present at the completion of braking may form part of a broader force-time strategy in which greater braking phase force development is carried into the subsequent propulsion phase.

Propulsion phase performance also depends on how force and velocity interact throughout the upward phase of the jump. Mechanical power is frequently treated as a primary performance-related variable during CMJ analysis because it integrates both force and velocity characteristics, with power output calculated as the product of vGRF and vertical velocity (Cormie et al., 2009; Linthorne, 2001). Although jump height can be calculated from take-off velocity using kinetic data, peak propulsion power is useful during CMJ analysis because it reflects the maximum mechanical output attained during propulsion (Cormie et al., 2009; McHugh et al., 2020).

Direct measures of CMJ power have been associated with jump performance. McLellan et al. (2011) reported that peak power (M = 4774 W, r = 0.73) and average propulsion power (M = 2359 W, r = 0.68) were significantly related to CMJ height in physically active males. The researchers' report suggest that high-performing jumps are typically associated with increased maximum and average power production through the propulsion phase. Marković et al. (2014) further suggested that peak power may be especially useful when relating mechanical output to jump performance after accounting for body mass and countermovement strategy. Movement strategies likely influence peak power to a lesser extent due to it occurring around the time of takeoff when force and velocity are near their peaks (Cormie et al., 2009). As a result, examining peak power may better distinguish differences between groups when not controlling for body mass between samples or countermovement strategy during testing. Since peak propulsion power represents the greatest instantaneous interaction between force and velocity during the upward phase (Cormie et al., 2009; McHugh et al., 2020), it provides a phase-specific measure of the maximum mechanical output achieved before take-off. Accordingly, measuring peak propulsion power can help determine whether differences in CMJ performance between groups, or following an intervention response, are accompanied by differences in the capacity to simultaneously express force and velocity during propulsion.

Braking RFD, vGRF at zero velocity, and peak propulsion power are relevant kinetic variables that can provide information to distinguish differences in CMJ performance. Although variability exists between players, volleyball athletes competing at a high level endure large jumping demands during competition and training throughout a season (Skazalski et al., 2018). Competitive volleyball athletes also routinely participate in training intended to improve explosive lower-extremity performance and jumping ability (Ramírez-Campillo et al., 2023). Repeated exposure to these demands may therefore be associated with force-time characteristics that differ from those of recreationally active individuals. Evidence from strength and power training research provides support for distinguished kinetic characteristics between these populations. Cormie et al. (2010) reported that power training was accompanied by substantial increases in braking RFD ($M = 68.0$ $N \cdot kg^{-1} \cdot s^{-1}$ to 152.9 $N \cdot kg^{-1} \cdot s^{-1}$), vGRF at zero velocity ($M = 22.4$ $N \cdot kg^{-1}$ to 30.1 $N \cdot kg^{-1}$), peak propulsion power ($M = 59.1$ $W \cdot kg^{-1}$ to 68.5 $W \cdot kg^{-1}$), and jump height ($M = 0.43$ m to 0.50 m) when performing the CMJ. These adaptations indicate that greater explosive performance can be characterized by a more rapid development of braking force and a greater magnitude of force present when

COM velocity reaches zero. Differences in propulsion phase output have also been observed according to athletic background. Cormie et al. (2009) reported greater peak power in experienced jumpers than non-jumpers (M = 71.7 $W \cdot kg^{-1}$, 55.9 $W \cdot kg^{-1}$), which was accompanied by greater jump height and upward velocity. Similarly, Ugrinowitsch et al. (2007) reported greater jump height, take-off velocity, and concentric impulse in power-trained athletes than strength-trained and physically active participants. Collectively, this literature indicates that populations exposed to greater jumping and power-oriented training may demonstrate greater braking RFD, vGRF at zero velocity, and propulsion phase power. These characteristics provide a mechanical basis for expecting competitive volleyball athletes to demonstrate greater braking RFD, vGRF at zero velocity, peak propulsion power, and ultimately CMJ performance than recreationally active individuals.

In summary, kinetics of the CMJ should be interpreted through the impulse-momentum relationship. Vertical jump performance depends on the magnitude and timing of force application used to generate take-off velocity, with jump height commonly calculated from take-off velocity derived from net propulsive impulse relative to body mass (Linthorne, 2001). Although peak and mean force values are frequently associated with jump performance, the magnitude of force alone does not fully explain CMJ performance because it is influenced by countermovement strategy, movement time, and the shape of the force-time curve (Cormie et al., 2009). Braking RFD and vGRF at zero velocity provide additional phase-specific information by describing how rapidly force is developed during braking and the magnitude of force present at the transition into propulsion (McHugh et al., 2020). Comparatively, peak propulsion power describes the interaction between force and velocity during the upward phase of the jump and may be especially useful when comparing individuals with different training backgrounds (Cormie et al., 2010). Previous literature also suggests that kinetic differences may exist between males and females, with females demonstrating lower propulsion force and braking RFD values than males during CMJ performance (Laffaye et al., 2014). Therefore, researchers should anticipate varying kinetic outcomes and should consider training and sex-based groupings when conducting research involving interventions. Moreover, braking RFD, vGRF at zero velocity, and peak propulsion power should be interpreted collectively to determine whether differences in CMJ performance reflect meaningful changes in force-time strategy rather than isolated changes in a single kinetic variable.

The Stretch-Shortening Cycle

The term countermovement refers to a movement pattern that is associated with the stretch-shortening cycle (SSC), which involves active muscle lengthening (eccentric contraction) followed by a rapid transitional isometric period (amortization) into explosive muscle shortening (concentric contraction; Komi, 2000; Lloyd et al., 2012). The CMJ is commonly used to assess SSC-related jumping performance because the unweighting and braking phases occur before propulsion, allowing the jumper to use the eccentric portion of the movement to develop force and transition into the concentric take-off phase (Cormie et al., 2010; McHugh et al., 2020). SSC tasks are frequently classified as fast or slow depending on the time required to complete the movement. Schmidtbleicher (1992) suggested that SSC movements can be classified as fast (< 250 ms) or slow (> 250 ms) depending on contraction times. Because CMJ movement time from initiation to take-off is typically greater than 250 ms, the CMJ is generally considered a slow SSC task (Laffaye et al., 2014). This classification of the CMJ differs from other vertical jumps (i.e., squat jump and drop jump) commonly used in research evaluating aspects of the stretch-shortening cycle (Moran & Wallace, 2007). The squat jump begins from a static semi-squat position to eliminate contribution of prior eccentric loading, whereas the drop jump increases eccentric loading by requiring the jumper to land from a box before immediately performing a vertical jump for increased eccentric loading (Linthorne, 2001; Moran & Wallace, 2007; Pedley et al., 2017). Therefore, comparison across the vertical jump tasks should be made cautiously due to the specificity of the SSC. Since the present review is concerned with CMJ performance, the following sections focus on SSC mechanisms and outcomes associated with the CMJ.

Proposed Mechanisms of the Stretch-Shortening Cycle

Mechanics of the Musculotendinous Unit. Various mechanisms have been proposed to explain how involvement of the SSC may enhance propulsion during the CMJ, including the mechanical behaviour of the musculotendinous unit. Extensibility, elasticity, and the ability to develop tension are the three mechanical behaviours of the musculotendinous unit (Hall, 2019). The musculotendinous unit can develop tension through the contractile component (actin and myosin units), while elastic and extensible structures within the muscle (parallel elastic component) and tendon (series elastic component) can be stretched and recoil back to normal lengths with movement (Hall, 2019; Turner & Jeffreys, 2010). The parallel elastic component provides resistance when the muscle is passively stretched, whereas the series elastic component stores elastic energy when muscles are actively stretched (Hall, 2019; Turner & Jeffreys, 2010). Since active muscle contraction resists its ability to stretch (i.e., muscular stiffness), tendons are the primary site of elastic energy storage during the stretch-shortening cycle (Kubo et al., 1999; Turner & Jeffreys, 2010). This storage of elastic energy in the tendons developed during eccentric loading may contribute to force production during the subsequent concentric action (Kubo et al., 1999; Turner & Jeffreys, 2010). Therefore, performing a countermovement may enhance jump performance by storing elastic energy and allowing the jumper to enter propulsion with increased force-producing potential compared to jumping with isolated concentric action.

However, the contribution of elastic energy storage depends on the coordination of force and timing between the eccentric and concentric portions of movement. For example, Wilson et al. (1994) found that benefits of the SSC had a half-life of approximately 0.85 seconds when performing a bench press. While the lower extremity may experience different mechanics regarding the SSC half-life, the study highlights that there is a trade-off between eccentric loading and movement time (Wilson et al., 1994). Researchers highlight this trade-off by suggesting that potential benefits of the SSC may be reduced if the transition between braking and propulsion is delayed or if forces exceed and individual's capacity during eccentric loading (Flanagan & Comyns, 2008; Turner & Jeffreys, 2010). Flanagan and Comyns' (2008) review of literature on plyometric training explained that trained athletes have a greater capability to handle increased eccentric loads before detrimental effects of movement time (and performance) occur when compared to untrained athletes. Comparisons between previous investigations provide supporting evidence on training status and eccentric loading, where Snyder et al. (2018) observed a decrease in jump height with increased eccentric loading in resistance trained adult men. Conversely, Moran and Wallace (2007) found that elite volleyball athletes were able to increase jump heights by increasing eccentric loading in the drop jump than the CMJ. Thus, it may be anticipated that individuals with sufficient training can handle increased loading and utilize it for enhanced jumping while those without enough training may be negatively affected if they are unable to handle the required braking forces. In practical terms, SSC-related performance is not simply improved by increasing eccentric loading and reducing time braking. Instead, the jumper must have the ability to generate and transfer force within a time frame that supports an efficient propulsion phase. Accordingly, force-time variables such as braking RFD, vGRF at zero velocity, and braking phase time may provide indirect information about how efficiently the individual performs the countermovement to prepare for propulsion.

Neurophysiological Model. Muscles exhibit a neurophysiological property known as irritability, which allows them to respond to a stimulus by developing tension (Hall, 2019).

Potential sources of stimuli affecting muscles include external forces acting on the muscle and electrochemical information from attached nerves (Hall, 2019). Two sensory receptors (or proprioceptors) in the musculotendinous unit known as muscle spindles and the Golgi tendon organ are essential for understanding the neurophysiological aspects of the stretch-shortening cycle. Muscle spindles run parallel to the fibres of a muscle, functioning as detectors of muscle length and its rate of change (Powers et al., 2021). A spinal cord reflex known as the stretch reflex is initiated by the muscle spindles during loading (Turner & Jeffreys, 2010). During rapid muscle stretching (i.e., countermovement), muscle spindles trigger the stretch reflex by sending signals to the spinal cord via sensory neurons, which synapse with alpha motor neurons to stimulate muscle contraction and resist further stretching (Powers et al., 2021). When considering the CMJ, the jumper quickly lowers their body during unweighting which is immediately followed by rapid force development in braking (McMahon, Suchomel, et al., 2018). Hence, the stretch reflex is initiated when the muscles rapidly lengthen in unweighting to increase muscle stimulation and tension that is used during braking and propulsion (Cormie et al., 2010). While measuring electromyography (EMG) can provide direct information on the timing and magnitude of muscle stimulation, this form of analysis is beyond the scope of the current research project. Nevertheless, measures such as unweighting velocity (rate of lengthening) and countermovement depth (magnitude of lengthening) may provide approximate information regarding a jumper's use of the stretch reflex.

Comparatively, Golgi tendon organs reside in the tendons to detect tension and provide feedback to prevent excessive force production in the muscles (Powers et al., 2021). The spinal cord reflex associated with the Golgi tendon organs inhibits motor neuron activity and may limit muscular stiffness if overloaded (Turner & Jeffreys, 2010). Hence, the Golgi tendon organ limits the function of muscle spindles and the stretch reflex. It is crucial to note that previous researchers have suggested that the function of Golgi tendon organs can be minimized with adequate plyometric training (Flanagan & Comyns, 2008; Turner & Jeffreys, 2010). The ability to mute the response of Golgi tendon organs would result in increased muscular stiffness, allowing greater tendon stretch during rapid eccentric contractions (Turner & Jeffreys, 2010). Therefore, populations with an extensive training background may better mute the influence of the Golgi tendon organs allowing them to unload more rapidly during unweighting than those without sufficient training.

Active State. Active state refers to the force-generating capacity of muscle that develops following neural stimulation and actin-myosin cross-bridge formation (Bobbert et al., 1996; Bobbert & Casius, 2005). Because muscle tension does not develop immediately following neural activation (i.e., electromechanical delay), tension develops at a finite rate which can limit the amount of force produced during rapid movements such as the CMJ (Hall, 2019; Bobbert & Casius, 2005). Bobbert and colleagues (1996) suggested that a likely reason why the squat jump typically results in lower vertical displacements than the CMJ is that part of the upward movement in the squat jump occurs while the involved muscles are still developing active state. In contrast, performing a countermovement allows active state to develop during the eccentric portions of the CMJ before the propulsion phase begins (Bobbert & Casius, 2005). As a result, the jumper may enter propulsion with greater force-generating capacity to allow greater force expression during the early portion of the upward phase. From an impulse-momentum perspective, this may enhance jump performance when the increased force at the start of propulsion contributes to a greater net propulsive impulse and therefore take-off velocity. Although it would be difficult to assess active state at an individual muscle level, vGRF at zero velocity provides valuable information on developed active state of the system (i.e., COM of jumper) entering propulsion.

Quantifying Stretch-Shortening Cycle Performance

The reactive strength index (RSI) is a performance-based measure commonly used to quantify SSC-related jumping ability by expressing jump height relative to the time required to complete the jump (Flanagan & Comyns, 2008; Ramírez-Campillo et al., 2023). Higher RSI values can be achieved by increasing jump height, decreasing movement time, or a combination of both (Barker et al., 2018). Therefore, RSI provides information beyond jump height alone because it reflects the ability to produce vertical displacement within a given time constraint. Although RSI is typically calculated during drop jump tasks by dividing jump height by ground contact time, a modified measurement has been used during CMJ analysis by replacing ground contact time with time to take-off (McMahon, Jones, et al., 2018). Time to take-off represents the total time of the unweighting, braking, and propulsion phases and is calculated from the onset of movement to the moment of take-off (McMahon, Jones, et al., 2018). Previous research has reported high reliability for CMJ-derived RSI in collegiate athletes, supporting its use as a lower-body performance measure (Kipp et al., 2016; Suchomel et al., 2015). Even though jump height is a component of RSI, researchers should consider the two variables as discrete parameters. For example, Pérez-Castilla et al. (2019) reported significantly different RSI scores (M = 0.31, M = 0.40) during self-selected and fast CMJ at self-preferred countermovement depth despite similar jump heights. In this case, RSI differed because participants completed the movement in less time without reducing jump height, demonstrating that RSI can capture temporal aspects of CMJ performance that jump height alone does not describe.

Philipp et al. (2023) further demonstrated the potential value of RSI when examining athletic populations. The researchers investigated CMJ characteristics in male and female Division-I collegiate basketball players who were divided into high- and low-minute groups based on average playing time (Philipp et al., 2023). In female athletes, the high-minute group demonstrated greater RSI (M = 0.51 vs. 0.41, $p = 0.03$) and jump height (M = 34.1 cm vs. 28.1 cm, p = 0.02) than the low-minute group (Philipp et al., 2023). In comparison, differences between high- and low-minute male athletes were not statistically significant for RSI (M = 0.87 vs. 0.76, p = 0.11) or jump height (M = 53.4 cm vs. 48.8 cm, p = 0.21; Philipp et al., 2023). Interestingly, the female subgroups did not differ in average propulsion power or countermovement depth (Philipp et al., 2023). The results of the study support the use of RSI as a practical measure of CMJ performance but also highlights that RSI should be interpreted alongside additional kinetic and kinematic measures. However, the findings should be interpreted cautiously because the investigation used small sample sizes in the high- (n = 6) and low-minute (n = 8) female subgroups (Philipp et al., 2023).

Barker et al. (2018) further demonstrated that RSI provides information distinct from jump height alone. The researchers investigated Division-I male soccer players and reported mean values of jump height (M = 0.37 m), RSI (M = 0.50), and time to take-off (M = 0.76 s; Barker et al., 2018). Correlational analysis showed that RSI was significantly related to both jump height (r = 0.573) and time to take-off (r = -0.812), whereas jump height and time to take-off (r = -0.008) shared no relationship with one another (Barker et al., 2018). Because RSI is calculated using both jump height and time to take-off, relationships with these component variables should be expected. However, the stronger relationship between RSI and time to take-off in this sample suggests that movement time contributed more substantially to between-athlete differences in RSI (Barker et al., 2018). Therefore, this investigation highlights how RSI is relevant when evaluating SSC-related performance during time-constrained jumping tasks by identifying athletes who achieve jump height with shorter movement durations.

Additionally, Barker et al. (2018) examined the relationships between RSI and kinetic variables during the CMJ. The researchers reported mean values for peak propulsion force (M = 24.5 $N \cdot kg^{-1}$), average propulsion force (M = 20.3 $N \cdot kg^{-1}$), peak power (M = 54.6 $W \cdot kg^{-1}$), and GRF at zero velocity (M = 24.5 N·kg^{-1}; Barker et al., 2018). Peak propulsion force was not strongly related to either jump height (r = 0.081) or RSI (r = 0.320), whereas peak power demonstrated stronger relationships with both jump height (r = 0.781) and RSI (r = 0.623; Barker et al., 2018). Interestingly, GRF at zero velocity and average propulsion force demonstrated stronger relationships with RSI (r = 0.725 and r = 0.823, respectively) than with jump height (r = 0.110 and r = 0.302, respectively; Barker et al., 2018). These findings suggest that RSI may be sensitive to kinetic variables that influence the ability to produce force within shorter movement durations. Since RSI incorporates both jump height and time to take-off, kinetic variables may help explain differences in RSI beyond jump height and time alone.

McHugh et al. (2020) suggested that vGRF at zero velocity provides insight into efficient use of the SSC. The researchers identified that vGRF profiles with peak force coinciding (within a 1% threshold) near the zero-velocity point is a qualitative biomechanical marker of stretch-shortening cycle efficiency (McHugh et al., 2020). It was found that slightly over half (n = 52) of the athletic sample (n = 100) demonstrated vGRF profiles where the zero-velocity point and peak force occurred simultaneously, and these athletes also demonstrated greater jump height and RSI than athletes whose peak force did not align with the zero-velocity instant (McHugh et al., 2020). Furthermore, the jumpers with the efficient force-time profiles were characterized by a shorter braking phase (by ~19%), increased braking RFD (by ~46%), and greater vGRF at zero velocity (by ~16%) despite no differences in countermovement depth or peak propulsion power (McHugh et al., 2020). These findings may reflect that a rapid and forceful braking phase can enhance force in the early instants of propulsion improving net impulse. Furthermore, it may highlight the combined influence of elastic energy storage, active state development, and the ability to transfer force to the propulsion phase (Bobbert & Casius, 2005; McMahon, Suchomel, et al., 2018; Turner & Jeffreys, 2010).

Other phase-specific variables should also be considered when interpreting SSC performance. McMahon, Jones, et al. (2018) examined professional male rugby players and compared the top (M = 0.53) and bottom (M = 0.36) twenty athletes based on RSI scores. The high-RSI group demonstrated greater jump height (M = 37.7 cm vs. 31.8 cm) and shorter time to take-off (M = 0.71 s vs. 0.88 s) than the low-RSI group (McMahon, Jones, et al., 2018). These observations suggest that substantial differences in jump performance can be found within samples of an elite athletic population (McMahon, Jones, et al., 2018). Moreover, phase-specific analysis further indicated that the high-RSI group completed the unweighting (M = 0.31 s vs. 0.39 s), braking (M = 0.15 s vs. 0.20 s), and propulsion phases (M = 0.24 s vs. 0.29 s) in less time than the low-RSI group (McMahon, Jones, et al., 2018). The high-RSI group also achieved a greater unweighting velocity (M = 1.37 $m \cdot s^{-1}$ vs. 1.14 $m \cdot s^{-1}$), indicating a faster countermovement strategy (McMahon, Jones, et al., 2018). Consequently, athletes of the high-RSI group developed a greater impulse in the braking phase to stop negative COM displacement (McMahon, Suchomel, et al., 2018). The greater braking impulse was accompanied by a quicker rise in force and increased peak braking force (M = 25.5 $N \cdot kg^{-1}$ vs. 21.7 $N \cdot kg^{-1}$) in the high-RSI group (McMahon, Suchomel, et al., 2018). The findings suggest that individuals that demonstrate high RSI scores during the CMJ coordinate a force-time strategy involving faster COM unweighting with a shorter braking phase involving rapid force development before propulsion.

The phase-specific differences reported by McMahon, Jones, et al. (2018) may be interpreted through the theoretical mechanisms of the SSC. A faster unweighting phase and greater downward COM velocity may increase the demand for rapid force development during braking, while a shorter braking phase and higher force at zero velocity may indicate a more effective transition into propulsion (Krzyszkowski et al., 2020; McHugh et al., 2020). From an SSC perspective, these characteristics may reflect a coordinated interaction between elastic energy storage, reflexive contributions during rapid muscle lengthening, and active state development before the propulsion phase (Turner & Jeffreys, 2010). However, these mechanisms should be interpreted as theoretical explanations for the observed force-time strategy rather than as isolated contributors. Therefore, phase-specific kinetic and kinematic variables may provide useful indirect information about SSC-related CMJ performance by describing how effectively the jumper redirects downward motion and forces into upward propulsion.

Countermovement Jump Characteristics in Recreationally Active and Competitive Female Volleyball Athletes

Previous research examining CMJ performance and force-time characteristics in highly experienced female volleyball athletes has primarily involved professional or Division I collegiate populations (Cabarkapa et al., 2023, 2024; Donahue et al., 2023; Kipp et al., 2016; Suchomel et al., 2015). Across these studies, descriptive values have ranged from 24.5 cm to 33.8 cm for jump height, 0.79 s to 1.01 s for time to take-off, and 0.28 to 0.42 for RSI. However, methodological differences likely explain some of the variation across studies. For example, Donahue et al. (2023) instructed participants to "jump as high as possible" and compared arm-swing to no arm-swing CMJ trials. The researchers reported greater average jump height during the arm-swing condition (M = 33.8 cm vs. 28.9 cm) and a longer time to take-off (M = 0.99 s vs. 0.87 s), resulting in similar RSI values (M = 0.34 vs. 0.33) between conditions (Donahue et al., 2023). The results suggest that the greater jump height achieved with an arm swing was accompanied by a longer movement duration. In contrast, Cabarkapa et al. (2024) reported the highest RSI values in a no-arm-swing protocol that included verbal encouragement to push through the ground as explosively as possible. Because external verbal cues can influence CMJ performance metrics (Kershner et al., 2019), cueing strategy may partly explain why shorter time to take-off and relatively high RSI values were observed in that sample (Cabarkapa et al., 2024).

Fewer studies have investigated CMJ performance (with RSI) in healthy recreationally active females (Harry et al., 2021; Krzyszkowski et al., 2021). Harry and colleagues (2021) defined recreationally active females as individuals that engage in resistance training two to four times per week for a minimum of one year. The researchers reported mean values for jump height (M = 0.22 m), time to takeoff (M = 1.01 s), and RSI (M = 0.23) for this recreationally active female sample (Harry et al., 2021). Krzyszkowski et al. (2021) found similar jump heights (M = 0.23 m) in recreationally active females; however, time to take-off (M = 0.75 s) was shorter and RSI (M = 0.30) was higher. One explanation for these differences may be the definition of recreationally active used across studies. Where Harry et al. (2021) required regular resistance training exposure, Krzyszkowski et al. (2021) required participants to perform sporting activities involving vertical jumps at least twice per week for a minimum of six months. Consequently, recreationally active females with regular exposure to jumping tasks may complete the CMJ in less time while achieving similar jump heights when compared to those with training background is primarily resistance based. When compared to the values reported in research involving competitive volleyball athletes, the recreationally active females may demonstrate decreased or more variable outcomes in performance described though RSI and jump height. Hence, competitive volleyball athletes would likely demonstrate better performance than recreationally active individuals when testing the CMJ under the same protocols.

Phase-specific temporal variables may provide additional information when comparing SSC performance across female jumping populations. Cabarkapa and colleagues (2023) reported unweighting, braking, and propulsion phase times of 0.23 s (25.3%), 0.38 s

(41.7%), and 0.30 s (33.0%), respectively, in Division-I female volleyball athletes during pre-season testing. It should also be noted that the researchers found no temporal changes in the other four testing sessions conducted throughout the season (Cabarkapa et al., 2023). Cabarkapa et al. (2024) found similar relative times in starting volleyball athletes from a professional European league as indicated in the unweighting, braking and propulsion phases 0.18 s (22.8%), 0.32 s (40.5%), and 0.29 s (36.7%) of the CMJ, respectively. These relative timing patterns differ from the collegiate volleyball athletes described by Donahue et al. (2023), in particular to the distribution of time between the unweighting and braking phases. The temporal distribution reported by the researchers respectively of the unweighting, braking, and propulsion phases were 0.45 s (45.4%), 0.20 s (20.2%), and 0.34 s (34.3%) during arm-swing CMJ trials and 0.36 s (41.4%), 0.19 s (21.8%), and 0.32 s (36.8%) during no-arm-swing trials (Donahue et al., 2023). However, direct comparison between studies should be made cautiously because phase definitions differed. Cabarkapa et al. (2023, 2024) defined the braking phase as the period from minimum force to the start of the propulsion phase, whereas other phase-based approaches define braking from peak downward COM velocity to zero COM velocity (Donahue et al., 2023; McMahon, Suchomel, et al., 2018). As a result, differences in reported unweighting and braking times may reflect variations in definitions rather than true differences in temporal strategies.

The literature examining recreationally active females use phase definitions that resemble the transition between unweighting and braking at the point of peak downward COM velocity (Harry et al., 2021; Krzyszkowski et al., 2021). In the first sample, Harry et al. (2021), reported unweighting, braking, and propulsion times of 0.46 s, 0.23 s, and 0.31 s, respectively. These findings were longer when compared to the other recreationally active sample, where Krzyszkowski et al. (2021) reported unweighting, braking, and propulsion times of 0.33 s, 0.17 s, and 0.28 s, respectively. However, these variations in temporal outcomes between the two recreationally active female samples may in part reflect the differences in defined sample (Harry et al., 2021; Krzyszkowski et al., 2021). When compared between populations, the results suggest temporal differences occur during the unweighting and braking phases between the recreationally active females and competitive volleyballers (Donahue et al., 2023; Harry et al., 2021; Krzyszkowski et al., 2021). More specifically, less time was spent in the unweighting (8.3 % difference) and braking (15.0 % difference) phases in the recreationally active females with jump experience compared to the competitive volleyball players; however, the resistance trained females required more time in the unweighting (21.7 % difference) and braking (13.0 % difference) phases than the competitive volleyballers (Donahue et al., 2023; Harry et al., 2021; Krzyszkowski et al., 2021). Since neither recreationally active group demonstrated similar jump heights as the competitive volleyball sample (Donahue et al., 2023; Harry et al., 2021; Krzyszkowski et al., 2021), temporal strategies alone may not discern differences between groups and may require further kinetic and kinematic interpretations. From an impulse-momentum perspective, phase time must be interpreted alongside force because the impulse generated during braking and propulsion depends on both the magnitude and duration of force application (McMahon, Suchomel, et al., 2018). Therefore, differences in unweighting and braking time may provide useful information about CMJ strategy, but their relevance to SSC performance depends on whether the temporal changes are accompanied by kinetic and kinematic characteristics that support the transition from downward COM motion into upward propulsion. Additionally, large variability in temporal measures may exist in recreationally active females depending on their exercise background and should be considered accordingly.

Countermovement depth may also distinguish the CMJ strategies observed across recreationally active and competitive female volleyball samples. Donahue et al. (2023) reported countermovement depths of approximately 0.40 m and 0.36 m in female jumpers with collegiate volleyball experience during arm-swing and no arm-swing CMJ, respectively. Comparatively, competitive volleyball samples from other studies performed a smaller countermovement (M = 0.29 m to 0.32 m; Cabarkapa et al., 2023, 2024). Similarly, a countermovement depth between 0.29 m and 0.30 m was observed in recreationally active females (Harry et al., 2021; Krzyszkowski et al., 2021). These findings suggest that countermovement depth may vary across female jumping samples, including within competitive volleyball populations. However, increased countermovement depth found by Donahue and colleagues (2023) may partially reflect the differences in verbal cueing instructions. Regardless, it should be noted that the sample using the greatest countermovement depth also demonstrated the longest propulsion times and jump height other samples of females with competitive volleyball experience or a recreationally active background (Cabarkapa et al., 2023, 2024; Donahue et al., 2023; Harry et al., 2021; Krzyszkowski et al., 2021). A larger countermovement may allow more time and displacement to generate propulsive impulse; however, some researchers suggest that increased downwards displacement must be paired with sufficient execution velocity during unweighting as greater countermovement depths performed too slowly may reduce jump performance (Pérez-Castilla et al., 2019; Sánchez-Sixto et al., 2018). Therefore, countermovement depth and unweighting velocity should be interpreted together when analysing the influence of the SSC in samples performing a CMJ using a self-preferred depth.

Peak unweighting velocity may provide additional insight into the CMJ strategy and the SSC because it describes how rapidly the jumper lowers the COM before the braking phase (McMahon, Jones, et al., 2018). During the CMJ, the unweighting phase precedes eccentric braking and may influence the magnitude of downward momentum that must be decelerated before propulsion (McMahon, Suchomel, et al., 2018). When considering the SSC, a faster unweighting strategy may increase the eccentric demand placed on the musculotendinous system that requires the jumper to rapidly develop braking force (Turner & Jeffreys, 2010). Cabarkapa et al. (2023) reported peak unweighting velocity values ranging from 0.92 $m \cdot s^{-1}$ to 1.05 $m \cdot s^{-1}$ across a competitive season in collegiate female volleyball athletes. Similarly, Cabarkapa et al. (2024) reported peak unweighting velocity values of 1.23 $m \cdot s^{-1}$ and 1.09 $m \cdot s^{-1}$ in starting and non-starting professional female volleyball athletes, respectively. These values of unweighting velocity are in a similar range as males and females from other competitive sports, suggesting that skilled female volleyball athletes may demonstrate relatively high peak unweighting velocities during the CMJ (McMahon et al., 2017). Given the repeated exposure to jumping actions in volleyball, competitive volleyball athletes may be expected to lower the COM more rapidly than recreationally active females (Skazalski et al., 2018). However, measures of unweighting velocity are not reported in the literature involving recreationally active females, making it difficult to discern expected values (Harry et al., 2021; Krzyszkowski et al., 2021). Therefore, there is a gap in the literature that should be explored.

Although differences in reporting methods limit direct comparisons, phase-specific kinetic variables provide additional context for how CMJ strategies may differ between recreationally active and competitive female volleyball athletes. In collegiate female volleyball athletes, Cabarkapa et al. (2023) reported peak eccentric force values between 1388.4 N and 1430.3 N throughout a competitive season. When examining professional European volleyball athletes, Cabarkapa et al. (2024) reported greater amounts of peak eccentric force in both starters (1619.6 N) and non-starters (1779.4 N). A similar pattern was observed during propulsion. Peak propulsion power ranged from 2930.2 W to 2994.3 W in the collegiate sample, whereas values of 3231.8 W and 3321.7 W were reported in professional starters and non-starters, respectively (Cabarkapa et al., 2023, 2024). Provided that the professional volleyball athletes demonstrated greater jump height, RSI score, concentric phase impulse, and unweighting velocity than the collegiate athletes, the findings could suggest that SSC functional differences between samples will likely result in variations in data across multiple measures (Cabarkapa et al., 2023, 2024). Additionally, the findings may suggest that variation in kinetic contributions may exist between samples of competitive volleyball athletes. However, the absence of a direct statistical comparison between studies prevents these differences from being attributed specifically to competitive level or SSC function.

In comparison, studies involving recreationally active females typically report kinetic values relative to body mass or weight, making complete comparisons difficult to perform. Rojano-Ortega et al. (2022) reported a relative peak power of 42.02 $W \cdot kg^{-1}$ in recreational adolescent female volleyball players. In recreationally active adult females, Harry et al. (2021) reported vGRF at zero velocity of 1.46 $N \cdot BW^{-1}$ and jump power of 1.63 $W \cdot BW^{-1}$. Based on the reported mean of body mass (M = 63.3 kg), absolute force at the end of the braking phase would be around 909 N (Harry et al., 2021). Although the end of the braking phase may occur shortly after time of peak force (McMahon, Suchomel, et al., 2018), the differences in measured peak braking force between females that are recreationally active and skilled volleyballers would be substantial (Cabarkapa et al., 2023, 2024; Harry et al., 2021). The comparison of descriptive data between samples may suggest that recreationally active females have limited ability to generate force entering the transition to propulsion, which may be a limiting factor in expressing impulse during propulsion resulting in decreased jump heights. However, it is difficult to be certain on true descriptive differences between research investigating recreationally active and competitive volleyball samples due to differences in reported methods. Furthermore, the absence of direct comparisons between females that are recreationally active and competitive volleyball in kinetic (and other) measures means inferences can only be made on a descriptive level. Therefore, there is a gap in the literature that can provide statistical inferences between the two population and provide information regarding anticipated differences in measures that approximate SSC function.

Lower Extremity Anatomy and the Countermovement Jump

The countermovement jump requires coordinated movement at the hip, knee, and ankle to lower the centre of mass and subsequently propel the body upward (Bobbert et al., 1996). Although each joint has distinct anatomical characteristics, their contributions should not be considered independently because motion and force production occur simultaneously throughout the lower extremity (McErlain-Naylor et al., 2014; Rauch et al., 2020). During the downward portion of the CMJ, the hip and knee flex while the ankle dorsiflexes (Bobbert et al., 1996; Harman et al., 1990). The lower-extremity extensor muscles then produce eccentric force during braking to decelerate the downward motion of the centre of mass before contributing concentrically to propulsion (Moran & Wallace, 2007; Turner & Jeffreys, 2010). Accordingly, the anatomical structures involved in the CMJ are best considered in relation to their phase-specific functions and their collective contribution to the force-time characteristics of the jump.

Anatomy of the Hip

The hip (coxofemoral) is a ball-and-socket joint that allows movement in the sagittal, frontal, and transverse planes (Glenister & Sharma, 2022). Its structure allows it to tolerate substantial loading during dynamic activity, with Cleather et al. (2013) suggesting that hip joint loads exceed 5.5 times and individual's body weight during a bilateral jumping task. Despite its multiplanar capacity, hip movement during the CMJ occurs primarily in the sagittal plane through flexion and extension (Vanrenterghem et al., 2004).

Muscles that contribute to hip extension are considered agonist movers during a CMJ task, which include the gluteus maximus, biceps femoris, semitendinosus, semimembranosus, and adductor magnus (Netter, 2018; Powers et al., 2021). In comparison, muscles performing hip flexion include iliopsoas, pectineus, rectus femoris, sartorius, and tensor fasciae latae (Netter, 2018). The hip extensors contribute to both the braking and propulsion phases of the CMJ. Eccentric action of the hip extensors occurs during braking, where the joint continues flexing as the muscles build tension to resist further movement (Kipp & Kim, 2021). Conversely, the hip extensor muscles rapidly shorten during propulsion to produce a torque resulting in extension and contribute to positive mechanical work (Kipp & Kim, 2022; Moran & Wallace, 2007). Hara et al. (2008) reported that using a countermovement increased hip extension torque near the beginning of propulsion, while arm-swing use increased hip torque later in the upward phase. These findings emphasize that the hip extensors make a significant kinetic contribution to CMJ performance, and that their contribution may be influenced by the movement strategy used.

Anatomy of the Knee

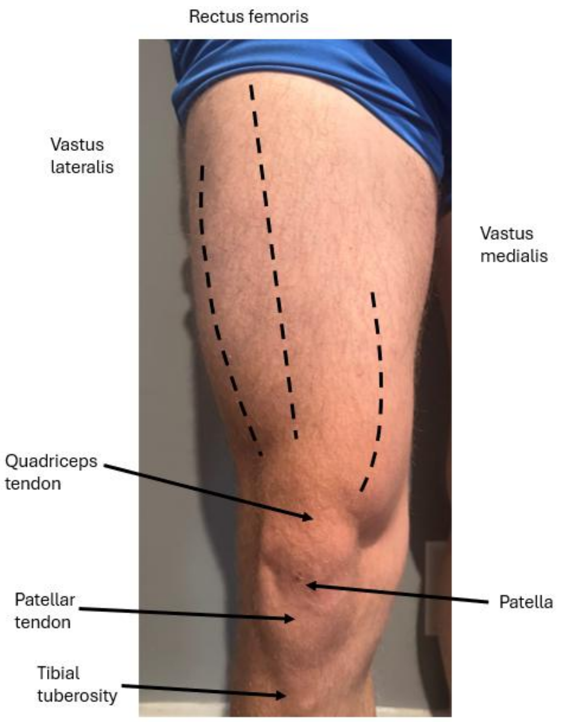
While the hip contributes substantially to proximal force production, the knee provides an important link between the thigh and lower leg during the downward and upward portions of the CMJ (Goldblatt & Richmond, 2003). The knee moves through an extensive range of motion and has the capacity to produce significant amounts of torque as it is positioned between two of the longest bones in the body (i.e., femur and tibia; Anderson, 2017). The knee consists of two joints known as the tibiofemoral and patellofemoral joints (Anderson, 2017). Together, the tibiofemoral joint permits knee flexion and extension (and some amounts of rotation) while the patellofemoral joint assists the knee-extensor mechanism (Goldblatt & Richmond, 2003). The quadriceps tendon attaches to the superior portion of the patella, and the patellar tendon connects the patella to the tibial tuberosity (Netter, 2018). The surface orientation of the superficial quadriceps muscles and their distal continuity through the quadriceps tendon, patella, patellar tendon, and tibial tuberosity are illustrated in Figure 4. It is essential to consider how the patellofemoral joint is positioned, as it provides knee stability and improves the mechanical capacity for the quadriceps to produce torque during extension by increasing the axis of rotation around the joint (Anderson, 2017).

Similar to the hips, the knee extensors are the agonist muscles, while the flexors are the antagonists during a countermovement jump (Powers et al., 2021). The quadriceps femoris consists of the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius (Netter, 2018). As shown in Figure 4, the rectus femoris, vastus lateralis, and vastus medialis are superficial, whereas the vastus intermedius lies deep to the rectus femoris and therefore is not visible from the surface. The three vastus muscles act only at the knee, whereas the rectus femoris crosses both the hip and knee (biarticular) and contributes to hip flexion and knee extension (Netter, 2018). Interestingly, many other muscles acting on the knee have biarticular attachments including gastrocnemius, sartorius, biceps femoris, semitendinosus, and semimembranosus (Anderson, 2017; Landin et al., 2016). Consequently, their force-producing capacity may be influenced by movement occurring at the adjacent hip or ankle (Landin et al., 2016). Nagano et al. (2005) reported that biarticular muscles produced less mechanical work than monoarticular muscles during a maximum effort CMJ. Moreover, other researchers have suggested that biarticular muscles assist with coordinating mechanical energy between adjacent joints (Cleather et al., 2015; Jacobs et al., 1996). Therefore, when considering the quadriceps as the agonist movers during a CMJ task, the three vastii muscles likely contribute more force than the rectus femoris.

During the downward portion of the CMJ, the knee flexes as the COM is lowered (Bobbert et al., 1996). The quadriceps produce a significant amount of force during eccentric action to decelerate downwards movement of the COM (Kipp & Kim, 2021; J. D. Wong et al., 2016). Subsequently, the quadriceps must then use the force developed during eccentric action and begin rapidly shortening during propulsion to produce a knee extension torque (Hara et al., 2008; McErlain-Naylor et al., 2014). Therefore, the quadriceps contribute to the transition of force from the downward to upward COM motion in the braking and propulsion phases of the CMJ (Kipp & Kim, 2022). This phase-specific function of the quadriceps is relevant to variables such as braking RFD and vGRF at zero velocity, which respectively describe the rate of whole-body force development during braking and the magnitude of force present at the transition from braking to propulsion (McHugh et al., 2020). Consequently, an intervention that increases quadriceps force near the end of braking may increase the force available to contribute to impulse during the subsequent propulsion phase.

Figure 4

Surface Orientation of the Superficial Quadriceps Muscles and Knee Extensor Mechanism



Note. Anterior view of the thigh and knee illustrating the approximate surface locations of the rectus femoris, vastus lateralis, and vastus medialis muscles and components of the knee extensor mechanism. Dashed lines indicate the approximate longitudinal orientation of the superficial quadriceps muscles. The quadriceps tendon, patella, patellar tendon, and tibial tuberosity are identified to illustrate the distal continuity of the quadriceps mechanism. The vastus intermedius is not shown because it lies deep to the rectus femoris.

Anatomy of the Ankle

The ankle is a complex structure in which movement occurs at three articulations: the talocrural, subtalar, and inferior tibiofibular joints (Anderson, 2017). Most sagittal-plane motion (plantarflexion and dorsiflexion) occurs at the talocrural joint, where the distal tibia and fibula articulate with the talus to form a synovial hinge joint (Brockett & Chapman, 2016; Hall, 2019). The subtalar joint contributes primarily to inversion and eversion, whereas the inferior tibiofibular joint provides stability between the distal tibia and fibula (Brockett & Chapman, 2016). Notably, rapid talocrural plantarflexion and subtalar eversion occur during the terminal phase of force production when jumping (Riley et al., 2013).

The primary plantar flexors are the soleus and gastrocnemius, with a smaller contribution from the plantaris (Netter, 2018). The tibialis anterior, extensor digitorum longus, and extensor hallucis longus contribute to dorsiflexion (Netter, 2018). As the COM is lowered during the CMJ, the ankle begins dorsiflexing placing the musculotendinous structures involved in plantarflexion under stretch (Turner & Jeffreys, 2010). During instants of braking, the plantar flexor muscles eccentrically contract to control continued ankle dorsiflexion and contribute towards the deceleration of downwards COM movement (Papaiakovou, 2013). These muscles subsequently contribute to plantar flexion during propulsion and help generate mechanical output before take-off (Hara et al., 2008). Rapid plantar flexion near the end of propulsion is particularly important because it represents the final lower-extremity action through which force is applied to the ground (Riley et al., 2013).

Kinesiology Tape and the Effects on the Countermovement Jump

Kinesiology tape (KT) is an elastic therapeutic tape developed by Dr. Kenzo Kase in the 1970s and is commonly composed of an elastic polymer surrounded by cotton with a water-resistant adhesive (Anderson, 2017). Unlike rigid athletic tape, KT is designed to stretch with the skin and permit relatively unrestricted movement during physical activity

(Anderson, 2017). A wide variety of purported benefits are associated with KT, including the amelioration of fluid circulation, inflammation, injury prevention, muscle function, and athletic performance (Anderson, 2017; MacDowall et al., 2015). While exact mechanisms remain unclear, two commonly proposed mechanisms involve continuous cutaneous afferent stimulation from the tape and mechanical interactions between the tape, skin, fascia, and underlying musculature (Drouin et al., 2013; Wu et al., 2015). Using magnetic resonance imaging, Pamuk and Yucesoy (2015) demonstrated that KT applied over the tibialis anterior produced measurable deformation of tissues beneath and surrounding the application site, with the greatest changes occurring in the superficial regions closer to the tape. More recent investigations have similarly suggested that the elastic tension generated by KT may alter local tissue strain and mechanical behaviour during movement (F. He et al., 2022; Lopes et al., 2022). These mechanical and sensory effects provide potential pathways through which KT could influence muscle function during dynamic tasks. Because musculotendinous stiffness, force development, and neuromuscular activation contribute to braking and propulsion during SSC movements, alterations in these characteristics may influence jump height and underlying force-time behaviour in the CMJ (Maffiuletti et al., 2016; Turner & Jeffreys, 2010).

Methodological Factors Influencing Kinesiology Tape Research on Jump Performance

Despite its widespread use, research examining the effects of KT on athletic performance has produced inconsistent findings (Reneker et al., 2018). Similar variability has been reported in studies investigating vertical jump performance, with some reporting changes in performance or force-time characteristics and others observing little or no effect (Alabbad & Muaidi, 2021; Huang et al., 2011; Mostert-Wentzel, 2012; Strutzenberger et al., 2015). Differences in methodology when applying KT across studies may contribute to these inconsistencies. In particular, the application site, applied tape stretch, duration between application and testing, and the mechanical properties of different KT products vary considerably across studies. These differences are important because the proposed sensory and mechanical effects of KT depend partly on how and where the tape is applied.

The application site is especially relevant when examining a task such as the CMJ because the contribution of individual muscles changes throughout the movement (Kipp & Kim, 2021). Pamuk and Yucesoy (2015) demonstrated that tissue deformation following KT application was greatest near the application site, suggesting that local effects may depend on which musculature is directly covered by the tape. Previous CMJ research often involves applying KT either individually or in combination to rectus femoris, gastrocnemius, or gluteus maximus (Alabbad & Muaidi, 2021; Boozari et al., 2018; Huang et al., 2011; Mostert-Wentzel, 2012; Strutzenberger et al., 2015). However, the vastii muscles make significant contributions to knee extension force during jumping tasks and may contribute substantially more than the biarticular rectus femoris muscle (Kipp & Kim, 2021; J. D. Wong et al., 2016). Consequently, specificity in the muscles targeted by KT may influence which components of the CMJ force-time profile are most likely to change and may partly explain some of the variation and lack of significant findings across previous studies.

The magnitude of stretch applied to KT represents another essential methodological consideration. Previous investigations have used broad application ranges (i.e., applying KT to a target muscle with tension between 50% and 75%), while others have withheld providing information regarding the amount of tension applied (Anandkumar et al., 2014; Huang et al., 2011; Mostert-Wentzel, 2012). The variability in application methodology is relevant because the mechanical stress produced by KT changes with elongation (Cheatham & Baker, 2021), meaning that two applications using different amounts of stretch may not provide the same mechanical stimulus. Furthermore, standardization is further complicated by differences in limb dimensions because applying the same absolute tape length across individuals does not necessarily produce the same relative elongation (Boonkerd & Limroongreungrat, 2016; Nunes et al., 2013). Therefore, clearly defining tape length and percentage stretch is important when comparing the effects of KT across participants and studies.

Lastly, differences between KT products provide an additional source of methodological variation. Each KT brand differs in its material composition, elasticity, and adhesive characteristics, and these properties can influence the amount of stress produced at a given elongation (Boonkerd & Limroongreungrat, 2016; Matheus et al., 2017). Accordingly, an application performed at the same reported percentage stretch may not create an equivalent mechanical stimulus when different brands are used. Although the differences in KT products used across studies may not necessarily explain the tape's conflicting effects on jump performance, it limits direct comparisons between studies when tape type and application procedures are not consistent. Collectively, variation in application site, magnitude of stretch, application timing, and tape properties should therefore be considered when interpreting the existing literature on KT and CMJ performance.

Quadriceps Kinesiology Tape Application

Previous studies have demonstrated that the knee extensors make an important contribution to force production during vertical jumping, particularly as the knee transitions from flexion during braking to extension during propulsion (Kipp & Kim, 2021; Moran & Wallace, 2007; Wong et al., 2016). When considering the quadriceps, the monoarticular vastii muscles appear to contribute more substantially to knee extensor force expression during vertical jumping than the biarticular rectus femoris (Kipp & Kim, 2021; Wong et al., 2016). The distinction may be relevant when considering KT application as several studies investigating jump performance have applied tape to rectus femoris instead of the vastii muscles. For example, two investigations reported that following KT application to the rectus femoris (in combination with either gastrocnemius or gluteus maximus) found no significant improvements in vertical jump performance (Alabbad & Muaidi, 2021; Cheung et al., 2015). Although these findings do not establish that the chosen muscles for application were responsible for the absence of an effect, they raise the possibility that including the vastus medialis and vastus lateralis may provide a more complete quadriceps application technique to aid knee-extensor function during jumping.

A three-muscle quadriceps application involving the rectus femoris, vastus medialis, and vastus lateralis has been examined during controlled knee-extension tasks (Anandkumar et al., 2014; Choi & Lee, 2018, 2019). Anandkumar et al. (2014) compared therapeutic KT applied with 50 to 75% stretch against sham KT applied without stretch in individuals with knee osteoarthritis. At slower ($90° \cdot s^{-1}$) and faster ($120° \cdot s^{-1}$) angular velocities, the therapeutic KT condition demonstrated greater improvements in peak concentric quadriceps torque than the control condition. Changes in peak eccentric torque were less consistent, with the interaction effect being significant for peak eccentric torque at $120° \cdot s^{-1}$, but not at $90° \cdot s^{-1}$ (Anandkumar et al., 2014). Furthermore, significant increases in peak eccentric torque were found in both isokinetic velocities when only considering the main effect for time (regardless of group; Anandkumar et al., 2014). Although these findings suggest that KT may influence concentric and eccentric knee-extensor torque, the magnitude of the reported torque responses should be interpreted cautiously. Anandkumar et al. (2014) acknowledged that their baseline concentric quadriceps torque values were lower than previously reported values and that the magnitude of the observed improvements may have been influenced partly by testing bias. Additionally, the applicability to healthy athletic populations is further limited by the clinical sample observed and the use of an isolated isokinetic task.

Similar quadriceps applications have subsequently been examined in younger and healthy populations. For example, Choi and Lee (2018) applied KT with approximately 20 to 25% stretch to the rectus femoris, vastus medialis, and vastus lateralis of healthy adults and reported increased quadriceps peak torque following taping regardless of whether the tape was applied from muscle origin to insertion or insertion to origin. When using a similar application of KT in athletes following a quadriceps fatigue protocol, Choi and Lee (2019) reported increased peak torque after KT application regardless of application direction. However, both investigations used a fixed pre-post testing sequence in which quadriceps torque was measured before KT application and then reassessed following taping (Choi & Lee, 2018, 2019). Consequently, repeated testing, familiarization, or warm-up effects cannot be excluded as potential contributors to the observed increases in torque. Together, these findings suggest that quadriceps torque increased following application of KT with a low stretch magnitude to the three superficial quadriceps muscles, but the fixed pre-post testing sequence limits the extent to which these changes can be attributed specifically to KT.

Interestingly, sensory effects have been investigated when using a similar quadriceps application technique. Han and Lee (2014) examined knee joint repositioning error before and after quadriceps fatigue and following KT application to the rectus femoris, vastus medialis, and vastus lateralis. Repositioning error increased from 3.41° before fatigue to 4.25° after fatigue; however, repositioning error decreased to 2.99° following KT application (Han & Lee, 2014). The authors proposed that cutaneous stimulation from KT may have contributed to improved joint position sense (Han & Lee, 2014). Although knee positioning sense is not an interest of the current investigation and may not directly represent the force production or movement strategy used in the CMJ, these findings provide some evidence that KT may provide the wearer more control over knee-extensor movement. Furthermore, increasing joint control may benefit jump performance predictors such as countermovement depth and the timing of force production.

Collectively, studies applying KT across the superficial quadriceps provide some evidence for changes in knee-extensor torque and joint position sense, but these findings have primarily been observed during isolated or fatigued single-joint tasks. It remains unclear whether these effects transfer to coordinating a rapid development of force in eccentric braking that can be maintained in concentric propulsion during a CMJ. This distinction is important because improvements in isolated quadriceps torque or proprioception would only be relevant to jumping performance if they contribute to meaningful changes in the force-time characteristics produced during the whole-body movement.

Evidence for Kinesiology Tape Effects During Jumping Tasks

Effects of Kinesiology Tape on Kinetic Parameters. Force-time characteristics provide a vital basis for examining whether KT alters CMJ performance. From an impulse-momentum perspective, enhancing jump height requires an increase in net propulsive impulse to increase take-off velocity (McMahon, Suchomel, et al., 2018). Thus, a KT intervention strategy intended to influence CMJ performance would be anticipated to produce a change in the magnitude, rate, or timing of force application to see a meaningful change in jump height. Previous reports in KT research have produced mixed effects in kinetic characteristics, with some evidence of altered magnitude and rate of knee-extensor torque during isolated tasks (Choi & Lee, 2018, 2019; Vithoulka et al., 2010; Yeung et al., 2015).

Evidence from examining an isokinetic knee-extensor tasks provide some evidence for the possibility that KT could influence force production. For example, Vithoulka et al. (2010) examined healthy inactive females (n = 20) under a no-tape, placebo-tape, and quadriceps KT condition. The tape was applied over rectus femoris, vastus lateralis, and vastus medialis for the experimental quadriceps KT condition, although the researchers did not clearly report the magnitude of applied stretch (Vithoulka et al., 2010). It was found that peak concentric torque did not differ between conditions; however, peak eccentric torque was significantly greater with KT (M = 149.76 Nm) than with placebo taping (M = 139.89 Nm) or no tape (M = 141.39 Nm; Vithoulka et al., 2010). The observation on concentric torque differs from other researchers who taped the superficial quadriceps and performed an isokinetic knee-extension task (Anandkumar et al., 2014; Choi & Lee, 2018, 2019), where the researchers reported significant increases in concentric torque following KT application. The collective findings across these investigations provide some evidence that the taping technique may influence the force-producing capacity of the knee extensors, but the effects during eccentric and concentric contractions have not been consistent across studies (Anandkumar et al., 2014; Choi & Lee, 2018, 2019; Vithoulka et al., 2010). When considering the CMJ, the eccentric findings of Vithoulka et al. (2010) and Anandkumar et al. (2014) suggest a possible influence during muscle lengthening occurring during braking. In comparison, the concentric findings indicate the effects possibly continuing into propulsion where force production occurs with muscle shortening. Nevertheless, potential benefits to force capacity from KT application during isokinetic tasks may not translate to braking or propulsion kinetics during a rapid, dynamic, and multi-jointed task such as the CMJ.

The effects of KT on RFD are less clear. For starters, Serra et al. (2015) found no differences in peak force, RFD, time to peak force, or time to peak RFD during maximal isometric knee extension in soccer athletes following KT application. It is crucial to note that the methodology presents issues such as applying the experimental KT and placebo simultaneously to each participant on separate legs (Serra et al., 2015). In contrast, Magalhães et al. (2016) reported greater RFD during the first 30 ms, 50 ms, and 100 ms of an isometric plantar-flexion contraction when KT was applied to facilitate the gastrocnemius. However, the researchers reported no changes in peak torque (Magalhães et al., 2016). In an investigation making similar observations for the knee extensors, Yeung et al. (2015) found a greater rate of peak torque development following KT applied over the vastus medialis despite no significant differences in peak isometric knee-extension torque. Moreover, O. M. Wong et al. (2012) also reported that KT applied over the vastus medialis shortened the time required to reach peak extension torque by approximately 36 to 101 ms across several isokinetic velocities with peak torque remaining unchanged. Although it should not be interpreted as evidence since the researchers did not directly report RFD, reducing the time to peak torque without changing the magnitude of torque suggest that an increased rate of development occurred (O. M. Wong et al., 2012). Nevertheless, these findings are better interpreted as evidence of altered force-development timing rather than a demonstrated increase in RFD (O. M. Wong et al., 2012). Collectively, the studies suggest that KT may affect the early development of force in some isolated contractions without necessarily increasing maximal force.

Whether these changes to the development and magnitude of force transfer to the CMJ remain questionable. Huang et al. (2011) reported that despite no changes in jump height, a small but significant increase in normalized vGRF occurred following KT application to the triceps surae. However, the authors did not define this force measure relative to a specific biomechanical event (on the force-time curve) and is not indicative whether vGRF at zero velocity was altered by KT (Huang et al., 2011). Comparatively, Mendez-Rebolledo et al. (2018) reported a significant effect of time on both normalized peak propulsion-phase vGRF and CMJ height following KT applied to several lower-extremity muscles. The post hoc analysis indicated that both normalized vGRF and jump height were significantly greater 72 hours ($M = 25.4$ N·kg^{-1}; $M = 29.1$ cm) after KT application compared with baseline ($M = 23.9$ N·kg^{-1}; $M = 26.0$ cm), whereas no differences were observed after 24 hours ($M = 24.4$ N·kg^{-1}; $M = 27.3$ cm; Mendez-Rebolledo et al., 2018). Although the findings may suggest that prolonged KT application may be associated with greater propulsion-phase force and jump height, all participants completed the testing conditions in the same temporal sequence and the study did not include a control group (Mendez-

Rebolledo et al., 2018). Therefore, the results were exposed to potential timing effects and observed changes cannot be attributed exclusively to KT.

In contrast, limited changes in CMJ force-time characteristics following KT application have sometimes been demonstrated. Boozari et al. (2018) specifically examined RFD, peak force, and power during the CMJ and reported no significant effects of gastrocnemius KT application before or after a plantar-flexor fatigue protocol. It is essential to note that RFD was calculated as the mean slope of the force-time curve during the first 30 ms of the concentric phase (Boozari et al., 2018). This measure differs from braking RFD, which describes the rapid increase in force used to decelerate downward COM motion before propulsion (Laffaye et al., 2014). Consequently, the findings of Boozari et al. (2018) suggest minimal effectiveness with gastrocnemius KT on early concentric force development but do not establish whether the tape applied to the quadriceps can alter the development of force during the braking phase when the muscles are lengthening. In addition, differences in muscle-specific contributions to the CMJ may also influence the effects of KT. Kipp and Kim (2021) showed that the vastii muscles generated considerably more muscle forces than the soleus and gastrocnemius while developing the force earlier in the countermovement. Therefore, a quadriceps KT application technique may target muscles that contribute more significantly to braking phase force production than when applied to the gastrocnemius. However, it is uncertain whether the application of KT to the quadriceps would result in greater responsiveness.

Phase-specific kinetic distinctions are essential to consider because an intervention may influence how force is developed before propulsion without a necessary change in jump height (Donahue et al., 2023). Braking RFD describes how rapidly force increases when downwards motion is decelerating, whereas vGRF at zero velocity describes the magnitude of force present when the COM reaches its lowest position of the countermovement before transitioning to the propulsion phase (McHugh et al., 2020). Peak propulsion power then describes the interaction between force and velocity during subsequent upwards motion (McHugh et al., 2020). Some researchers have reported lower eccentric RFD and propulsion phase forces in females when compared with male jumpers (Laffaye et al., 2014; McMahon et al., 2017). These findings support examining phase-specific force-time characteristics directly in female populations rather than assuming that relationships observed predominantly in male or mixed samples are equivalent across sexes. Furthermore, established sex-based differences in CMJ force-time characteristics highlight the importance of examining potential kinetic responses to KT directly in female populations rather than assuming that findings from predominantly male or mixed samples are equally applicable to female jumpers (McMahon et al., 2017; Mendez-Rebolledo et al., 2018).

Overall, the available KT literature provides limited and inconsistent evidence that taping can alter force magnitude or RFD. Positive findings have occurred primarily during isolated quadriceps or plantar-flexor contractions, whereas studies using dynamic CMJ tasks have generally reported smaller or absent kinetic effects. Moreover, previous CMJ investigations have not examined the specific braking-to-propulsion characteristics that may be most relevant to a quadriceps-focused application during dynamic movement. Braking RFD, vGRF at zero velocity, and peak propulsion power provide phase-specific measures that can distinguish potential changes through the different phases of the CMJ.

Effects of Kinesiology Tape on Jump Performance. The effects of KT on vertical jump performance remain inconsistent, with most studies reporting little or no improvement in jump height (Boozari et al., 2018; Cheung et al., 2015; Huang et al., 2011; Nunes et al., 2013; Schiffer et al., 2015; Strutzenberger et al., 2015). For example, Nunes et al. (2013) compared KT and non-elastic athletic tape applied along the lateral borders of the gastrocnemius and found no significant differences in single-leg vertical jump height (M =

0.18 m, M = 0.17 m) or horizontal jump distance between conditions. Similarly, Strutzenberger et al. (2015) reported comparable CMJ heights among no-tape (M = 0.33 m), KT (M = 0.32 m), and placebo (M = 0.33 m) conditions when KT was applied over the gluteus maximus. Following a fatigue protocol, little evidence was provided regarding KT preserving jump performance as jump height decreased similarly across all three conditions (Strutzenberger et al., 2015). Collectively, the findings suggest that KT applied to the plantar flexor or hip extensor muscles do not efficiently improve vertical jump performance.

Nevertheless, while the findings have generally been inconsistent, other investigations have reported small or condition-specific improvements. Alabbad and Muaidi (2021) applied KT to the gluteus maximus, rectus femoris, soleus and gastrocnemius on elite weightlifters and found no significant between-group (experimental vs. sham-taping without stretch) differences in single-legged vertical or horizontal jump performance 30-minutes post application. However, horizontal jump distance (M = 173.0 cm, M = 181.3 cm) increased significantly post application within the experimental KT group. Similarly, Mostert-Wentzel (2012) reported small changes in bilateral CMJ height following gluteus maximus taping; however, differences between groups receiving experimental and placebo taping were not conclusive. These observations suggest that while KT may influence small changes in jump height, the limited differences between experimental and placebo taping limit the evidence that KT independently improves jump performance.

MacDowall et al. (2015) reported mixed findings between tasks after applying a gastrocnemius facilitation technique combined with Achilles tendon corrective taping in varsity athletes. It was found that KT significantly increased single-legged squat jump height by 2.43 cm following application (MacDowall et al., 2015). Although it was noted that minor increases in jump height were observed in the other three jumping conditions (i.e., bilateral squat jump, single-legged CMJ, and bilateral CMJ) following KT application, these changes were considered insignificant (MacDowall et al., 2015). Furthermore, no changes in gastrocnemius or soleus EMG activity were reported following KT application for any jumping condition (MacDowall et al., 2015). In contrast to the EMG reports, Huang et al. (2011) reported altered medial gastrocnemius EMG activity (in both legs) and a small increase in normalized vGRF post taping in the experimental KT group, which was not observed in the control or placebo-taped groups. However, these changes were not accompanied by a significant improvement in vertical jump height (Huang et al., 2011). Therefore, changes in muscle activity or force-related measures following plantar-flexor KT applications techniques do not necessarily translate into greater vertical displacement.

Differences in methodology used to determine jump height may influence the ability to detect small resulting changes from KT application. Several investigations reporting small or insignificant changes used reach-based devices such as the Vertec (Alabbad & Muaidi, 2021; MacDowall et al., 2015; Mostert-Wentzel, 2012). Because the Vertec measures reach height in fixed increments (1.27 cm), its resolution is lower than laboratory force-platform methods and may be less sensitive to small changes in jump height (Nuzzo et al., 2011). This limitation should not be assumed to explain the null findings, but it complicates interpretation when the expected magnitude of a KT effect is small. Moreover, assessment with a force platform can provide a more sensitive evaluation of jump performance while also allowing jump height to be interpreted alongside the force-time characteristics responsible for take-off velocity. Thus, future researchers should consider using laboratory-grade force platforms using the impulse-momentum relationship when observing the effects of KT on jump performance (Bui et al., 2014).

Additionally, the application site represents another vital distinction of existing literature. Previous investigations have predominantly applied KT to the gastrocnemius, gluteus maximus, rectus femoris, or combinations of several lower-extremity muscles

(Alabbad & Muaidi, 2021; Boozari et al., 2018; Huang et al., 2011; MacDowall et al., 2015; Mostert-Wentzel, 2012; Nunes et al., 2013; Strutzenberger et al., 2015). However, muscle-based analyses of the CMJ indicate that the monoarticular vastii make a considerably greater contribution to knee-extension force than the biarticular rectus femoris (Kipp & Kim, 2021; J. D. Wong et al., 2016). Although the gastrocnemius can produce large muscle forces, its contribution to the ankle plantar-flexion moment is relatively limited through most of the CMJ partially because the muscle experiences unfavourable force-length characteristics with deeper knee flexion (Arampatzis et al., 2006; Kipp & Kim, 2021). In contrast, Kipp and Kim (2022) reported more favourable force-velocity behaviours for both the vastii and gluteus maximus during the CMJ, whereas it was estimated that a substantially greater peak muscle force was demonstrated in the vastii muscles than in the gluteus maximus. Consequently, the findings from gastrocnemius, gluteus maximus, or rectus-femoris-focused applications may not reflect the same effect when taping the superficial quadriceps. The distinction between targeted muscles is particularly relevant because KT applied across the rectus femoris, vastus lateralis, and vastus medialis has produced changes in knee-extensor torque in controlled single-joint tasks (Anandkumar et al., 2014; Choi & Lee, 2018, 2019; Vithoulka et al., 2010). Whether these changes in quadriceps force-producing capacity transfer to greater CMJ performance remains unclear, particularly when the vastus medialis and vastus lateralis are included within the taping procedures.

Overall, the current available evidence does not demonstrate a consistent improvement in CMJ performance following KT application. Positive findings have generally been small, dependent on the jumping condition, or observed within groups without corresponding between-group differences to those receiving placebo taping. Furthermore, the majority of previous jump investigations have not examined an application that simultaneously targets the superficial rectus femoris, vastus lateralis, and vastus medialis.

Considering the contribution of the vastii to knee-extension force during the CMJ and the reported effects of quadriceps KT during isolated knee-extension tasks, the transfer of this taping approach to whole-body CMJ performance remains unresolved.

Research Problem

Kinesiology tape (KT) is widely used in sport and rehabilitation as a non-invasive intervention intended to influence musculoskeletal function (Williams et al., 2012). The vertical countermovement jump (CMJ) is a fundamental skill performed in various sports and is commonly observed in research to examine performance-based effects (Karatrantou et al., 2019); however, research examining the effects of KT on vertical jump performance has produced inconsistent findings, with various studies reporting null, small, or condition-specific changes in jump height and force-related outcomes (Alabbad & Muaidi, 2021; Boozari et al., 2018; Huang et al., 2011; MacDowall et al., 2015; Mendez-Rebolledo et al., 2018; Strutzenberger et al., 2015). These inconsistent observations may relate to differences in taping procedures, as the application site, magnitude of stretch, application duration, and tape properties (between KT brands) may contribute to the variability between studies (Cheatham et al., 2021). The differences in taping methods between investigations become relevant as it can influence the interaction with the skin and targeted underlying muscles. Consequently, the effect of KT on jump performance should not be considered independently of the muscles targeted or the mechanical characteristics used to assess the jump.

The CMJ is a useful task for examining these effects because performance depends on the coordinated use of the stretch-shortening cycle (SSC) across the unweighting, braking, and propulsion phases. The order of motion in the CMJ involved downward COM motion developing during unweighting before rapid deceleration in braking and redirected upwards during propulsion (McMahon, Suchomel, et al., 2018). Efficiency of the stretch-shortening cycle is determined primarily by three neuromuscular mechanisms, which relate to the mechanical properties of the musculotendinous unit, sensory contributions during muscle lengthening, and the development of active state before propulsion (Bobbert & Casius, 2005; Turner & Jeffreys, 2010). It has been proposed that KT may influence sensory and mechanical characteristics of underlying tissue, with imaging demonstrating increased tissue effect closer to the application site (F. He et al., 2022; Lopes et al., 2022; Pamuk & Yucesoy, 2015). These observations provide a theoretical basis for predicting whether a quadriceps KT application can modify muscular function during an SSC task. However, it should be noted that they do not establish if KT enhances active state development, influence the sensory or mechanical behaviours of the musculotendinous unit, or benefit force production during the CMJ.

Previous investigations provide some evidence that KT applied the superficial quadriceps can alter knee-extensor function under controlled conditions. Various increases in concentric or eccentric isokinetic knee-extension torque have been reported following application to the rectus femoris, vastus lateralis, and vastus medialis, although there were some variations in findings between contraction type and isokinetic velocities (Anandkumar et al., 2014; Choi & Lee, 2018, 2019; Vithoulka et al., 2010). The evidence concerning rapid force development demonstrated some inconsistent results. These investigations often reported increased rate of force development (RFD) or decreased time to peak force while finding no changes in the magnitude of peak force (Magalhães et al., 2016; Serra et al., 2015; O. M. Wong et al., 2012; Yeung et al., 2015). Thus, the application of KT may improve force generating abilities to benefit CMJ performance. Importantly, these findings have been obtained during isolated isometric or isokinetic contractions and therefore do not indicate whether comparable changes occur during the eccentric braking and concentric propulsion of a dynamic multi-joint CMJ. Thus, a goal of this thesis is to determine whether potential force developing benefits seen in isolated single-joint tasks are transferable to rapid multi-joint movement.

The application site represents a limitation in the existing jump literature involving KT. These vertical jumping studies have typically targeted gastrocnemius, gluteus maximus, rectus femoris, or combinations of several lower-extremity muscles with KT application (Alabbad & Muaidi, 2021; Boozari et al., 2018; Huang et al., 2011; MacDowall et al., 2015; Mostert-Wentzel, 2012; Nunes et al., 2013; Strutzenberger et al., 2015). Conversely, muscle analysis indicates that the monoarticular vastii muscles make substantial contributions to knee-extension force during the CMJ (Kipp & Kim, 2021; J. D. Wong et al., 2016). Despite the contribution from these knee-extensor muscles, the effects of applying KT simultaneously to the superficial quadriceps (rectus femoris, vastus lateralis, and vastus medialis) on CMJ performance and force-time characteristics have not been performed. Consequently, findings involving the effects of KT to the gastrocnemius, gluteus maximus, and rectus femoris may respond differently than an application involving the superficial quadriceps.

Training background may further influence the response of KT because CMJ strategies differ across individuals with different exposure to jumping and power-based activity. Training-based research suggests that athletes with greater exposure to SSC-related tasks demonstrate faster downward COM velocities, shorter braking times, and greater phase-specific force and power characteristics than lower-performing jumpers (Cormie et al., 2009, 2010; McMahon, Jones, et al., 2018; Turner & Jeffreys, 2010). Competitive volleyball athletes are repeatedly exposed to jumping and landing tasks during practice and competition (Skazalski et al., 2018), whereas recreationally active individuals may have less consistent exposure to these demands. Accordingly, competitive volleyball athletes and recreationally active individuals may begin with different force-time characteristics and may not respond similarly to an intervention intended to influence muscular function during a CMJ task. The existing literature has not established whether an individual's training experience modifies the effects of KT during the CMJ. Previous research has also demonstrated lower jump height and several decreased kinetic outputs in females compared with males, such as lower braking RFD and propulsion force (Laffaye et al., 2014; McMahon et al., 2017). These findings support examining phase-specific CMJ characteristics in females and comparing recreationally active and competitive volleyball groups within the same sex.

Collectively, the primary research problem is that it remains unclear whether KT applied across the superficial quadriceps can influence CMJ performance or the phase-specific force-time characteristics that contribute to that performance. Existing evidence from isolated knee-extensor tasks suggests that KT may influence quadriceps function. However, these findings have not been investigated to clearly show that a KT application involving rectus femoris, vastus lateralis, and vastus medialis will benefit function during a dynamic SSC task such as the CMJ. Furthermore, previous jumping studies have not provided data regarding the potential of differing KT responses according to training background. Therefore, examining jump height and RSI alongside braking RFD, vGRF at zero velocity, peak propulsion power, unweighting velocity, countermovement depth, and phase-specific temporal measures may provide a more complete assessment of whether quadriceps KT alters CMJ performance or the strategy used to produce it in recreationally active and competitive female volleyball athletes.

Purpose

The purpose of this study was to examine the effects of bilateral KT application to the superficial quadriceps on vertical power and phase-specific kinetic, kinematic, and temporal characteristics between female jumpers that are recreationally active and competitive volleyball athletes.

Hypotheses

Based on previous evidence that training and repeated exposure to jumping can influence CMJ force-time characteristics, competitive female volleyball athletes were expected to demonstrate greater SSC-related performance than recreationally active females (Cormie et al., 2010; Ramírez-Campillo et al., 2023; Skazalski et al., 2018). Because KT has demonstrated some effects on quadriceps force production during isolated tasks (Anandkumar et al., 2014; Choi & Lee, 2018, 2019; Vithoulka et al., 2010), it was also hypothesized that the response to KT would differ according to training background. Specifically, greater KT-related changes were expected in the recreationally active group, whereas minimal changes were expected in the competitive volleyball group.

Performance Measures

It was hypothesized that the competitive volleyball group would demonstrate greater jump height and RSI than the recreationally active group. Following KT application, jump height and RSI were expected to increase in the recreationally active group, whereas no significant changes were expected in the competitive volleyball group.

Kinematic Measures

The competitive volleyball group was expected to demonstrate greater peak unweighting velocity and countermovement depth than the recreationally active group, reflecting a faster and larger downward countermovement strategy. Following KT application, countermovement depth was expected to increase in the recreationally active group, whereas no significant change was expected in the competitive volleyball group. However, KT was not expected to produce a consistent change in unweighting velocity in either group.

Kinetic Measures

It was hypothesized that the competitive volleyball group would demonstrate greater braking RFD, vGRF at zero velocity, and peak propulsion power than the recreationally active group. Following KT application, braking RFD, vGRF at zero velocity, and peak propulsion power were expected to increase in the recreationally active group based on previous evidence that quadriceps KT may influence eccentric and concentric knee-extensor force production (Anandkumar et al., 2014; Choi & Lee, 2018, 2019; Vithoulka et al., 2010). No significant KT-related changes in these kinetic variables were expected in the competitive volleyball group.

Temporal Measures

The competitive volleyball group was expected to demonstrate a shorter total time to take-off than the recreationally active group, characterized by shorter unweighting, braking, and propulsion phase times. This hypothesis was based on previous findings indicating that higher-performing jumpers can complete the CMJ within shorter movement durations while rapidly developing the force required to reverse downward COM motion and initiate propulsion (Laffaye et al., 2014; McMahon, Jones, et al., 2018). No significant change in total time to take-off was expected following KT application in either group. However, KT was expected to decrease unweighting and braking phase times while increasing propulsion phase time within the recreationally active group. The shorter unweighting and braking phases were anticipated to reflect a more rapid transition through the downward portion of the CMJ, whereas the expected increase in countermovement depth was anticipated to provide greater displacement and time for force application during propulsion. In contrast, no significant KT-related changes in unweighting, braking, or propulsion phase time were expected in the competitive volleyball group.

Method

Experimental Design

A 2 x 2 mixed repeated measures design was used to examine the effects of bilateral KT application to the superficial quadriceps during the CMJ. The between-subjects factor was group, consisting of recreationally active females and competitive female volleyball athletes, while the within-subjects factor was taping condition, consisting of no-tape and KT conditions. CMJ performance was assessed using performance, kinetic, kinematic, and temporal variables to determine whether KT altered jump performance or the phase-specific force-time characteristics of the movement and if these responses differed between groups.

Participants and Recruitment Process

Twenty-four female participants were recruited and equally divided into recreationally active (n = 12) and competitive volleyball players (n = 12) for this study. A priori analysis (ANOVA: Repeated measures, within-between interaction) estimated that 34 participants (i.e., 17 participants in each group) were required for a medium effect size (η^2 = 0.06) to reject the null hypothesis with 80% power at $\alpha = .05$ (Lakens, 2013). The final sample did not reach the estimated sample-size requirement, which reduced the statistical power available to detect interaction effects of this magnitude. Although previous CMJ investigations have used similar group sizes when examining related variables (Cormie et al., 2010; Krzyszkowski et al., 2021), the smaller-than-planned sample should be considered when interpreting the findings.

Upon receiving approval from the Lakehead University Research Ethics Board, participants were recruited using purposive sampling techniques to distinguish between recreationally active and competitive volleyball athletes. Participants in the recreationally active group were recruited via posted advertisements (see Appendix A) and direct communication from the student researcher to healthy individuals that frequently engage in exercise. Competitive volleyball athletes were recruited through communication with the coach and members of the Lakehead University women's varsity volleyball team (see Appendix B). Potential participants were provided with an information letter outlining the purpose, procedures, and expectations of participation (see Appendix C). Individuals interested in participating subsequently contacted the student researcher to ask questions and arrange a testing session.

Inclusion and Exclusion Criteria

Participants ranged between the age of 18 to 26 years old in the Thunder Bay region. They were eligible for this study if they were female and met the criteria for either the recreationally active or competitive volleyball athletes. Recreationally active participants were required to have participated in physical activity, such as resistance training or recreational sport, at least twice per week for the previous six months and to have no previous professional or varsity-level sporting experience (Krzyszkowski et al., 2021). Participants meeting these criteria reported completing an average of 4.4 ± 1.2 exercise sessions per week. Competitive volleyball participants were current members of the Lakehead University women's varsity volleyball team and were tested during the five weeks immediately following completion of their competitive season. These athletes reported participating in an average of 5.2 ± 0.4 training sessions per week.

Before participation, individuals completed the Get Active Questionnaire (GAQ; see Appendix D), a pre-screening tool endorsed by the Canadian Society for Exercise Physiology to identify health-related concerns associated with participation in physical activity (Canadian Society for Exercise Physiology, 2019). Participants also completed an additional questionnaire to identify study-specific exclusion criteria (see Appendices E and F). Consistent with previous research examining jump performance in healthy individuals, participants were excluded if they reported a lower-extremity injury within the previous three months that prevented participation in training, practice, or competition (MacDowall et al., 2015). Individuals were also excluded if they reported contraindications to KT application, including an adhesive allergy, open wound at the application site, or deep vein thrombosis. These screening procedures were used to reduce health and safety risks associated with participation and KT application.

Force Platform Instrumentation

Vertical ground reaction force (vGRF) during the CMJ was collected using an AMTI force platform (Advanced Mechanical Technology, Inc., Watertown, MA, USA). Force-platform assessment provides a direct measure of ground reaction force and is commonly used to derive CMJ performance and phase-specific force-time variables (Bui et al., 2014). Previous research using an AMTI force platform in female varsity volleyball athletes has demonstrated acceptable reliability for jump height and several phase-specific CMJ variables (ICC $\geq$ .84; CV $\leq$ 5.77%; Donahue et al., 2023). Although the force platform measured forces and moments in three dimensions, only the vertical force component (Fz) was used in the present analysis. The analogue voltage signal generated by the force platform was passed through an amplifier and subsequently transmitted to a PowerLab data acquisition system (ADInstruments Inc., Colorado Springs, CO, USA), where the signal was converted to digital data and recorded using LabChart software. Vertical force was sampled at 1000 Hz to provide sufficient temporal resolution for identifying the phase-specific events and force-time characteristics of the CMJ (Beckham et al., 2014).

The student researcher ensured all electronics (i.e., force platform, amplifier, analog-to-digital converter, and computer) were turned on for a minimum of 20 minutes before the start of the testing session so all the data collecting equipment warmed up to stabilize thermal and instrumental noise (Beckham et al., 2014). Following this warm-up period, a two-point calibration was performed in LabChart immediately before data collection to convert the recorded voltage signal to force in Newtons under the testing conditions. The first calibration point represented zero force and was recorded with the platform unloaded. For the second point, the participant's body mass was measured using a scale and converted to body weight by multiplying mass by gravitational acceleration (9.81 $m \cdot s^{-2}$). The participant then stood motionless on the force platform for one second, and the mean voltage recorded during this period was assigned to the calculated body-weight value. This calibration established the voltage-to-force relationship used to convert the recorded Fz signal to Newtons for subsequent analysis.

Testing Procedures

Participants attended a single session and were tested individually in room SB-1028 in the C.J. Sanders Fieldhouse at Lakehead University. At the beginning of the session, the researcher explained the testing procedures and provided participants with an opportunity to ask questions. Participants then reviewed the information letter (see Appendix C) and provided written informed consent (see Appendix G) before completing the GAQ (see Appendix D) and demographic questionnaire (see Appendix E). The demographic questionnaire collected information regarding age, height, body mass, sporting background, training experience, and history of lower-extremity injury. Participant characteristics for the total sample and each group are presented in Table 1.

Table 1

Participant Demographic Data

	All participants (n = 24)	Recreationally active (n = 12)	Competitive volleyball (n = 12)
Age (years)	20.9 (2.2)	21.8 (2.0)	19.9 (2.0)
Height (cm)	171.7 (7.1)	165.9 (3.8)	177.5 (4.1)
Body mass (kg)	66.5 (11.4)	58.0 (8.5)	75.0 (6.4)

Note. Data is presented as the mean with the standard deviation in brackets. The demographic data indicates significant differences in age ($p < .05$), height ($p < .001$), and mass ($p < .001$) between the two groups.

Following completion of the screening and demographic procedures, bilateral measurements were taken along the intended KT application paths for the rectus femoris, vastus lateralis, and vastus medialis (see Appendices H and I). These measurements were used to determine the required tape length for each muscle while accounting for approximately 25% stretch during application and additional unstretched length for the tape anchors (Choi & Lee, 2018, 2019). Participants were positioned supine with the lower leg extending beyond the end of the treatment table. For the rectus femoris, the application distance was measured from 10 cm inferior to the anterior superior iliac spine to the superior border of the patella (Anandkumar et al., 2014). The vastus lateralis was measured from the greater trochanter to the lateral border of the patella, whereas the vastus medialis was measured from the middle third of the medial thigh to the medial border of the patella (Anandkumar et al., 2014). Measurements were completed bilaterally to provide participant-specific tape lengths for the subsequent KT condition.

Kinesiology Tape

Participants completed two taping conditions: no tape and KT. The order of conditions was randomized and counterbalanced within each group to reduce potential order effects, with six participants completing the no-tape condition first and six completing the KT condition first. When KT was the first condition, the tape was applied following completion of the standardized warm-up and before the first set of CMJ trials, with a standardized rest period of 5-minutes provided when transitioning to the no-tape trials to resemble similar circumstances when performing opposite order of taping conditions. When the no-tape condition was completed first, KT was applied immediately following completion of the no-tape trials and before the subsequent KT trials.

All KT applications were performed by the student researcher, who had completed the Basic and Advanced RockTape Functional Movement Training (FMT) Kinesiology Taping certifications and had previous experience with athletic tape application. RockTape Kinesiology Tape (RT2: Standard; RockTape, USA) was used for all participants to maintain consistency in the mechanical properties of the tape. The application procedure incorporated general kinesiology taping recommendations and methods previously used when examining quadriceps function (Anandkumar et al., 2014; Choi & Lee, 2018, 2019; Han & Lee, 2014; Kumbrink, 2012).

Before application, excess hair was trimmed when necessary and the skin was cleaned with an alcohol wipe to improve tape adhesion. The corners of each strip were rounded to reduce premature lifting of the tape (Boozari et al., 2018; Kumbrink, 2012). Six strips were prepared using the bilateral application measurements recorded for each participant (see Appendix I). The length of each strip was calculated so that the portion of tape covering the muscle was applied a standardized amount of 25% stretch, while additional tape length was provided for the proximal and distal anchors (Choi & Lee, 2018, 2019). This participant-specific procedure was used to standardize relative tape elongation despite differences in lower-extremity dimensions.

KT was applied bilaterally over the rectus femoris, vastus lateralis, and vastus medialis, in that order (Figure 5 and Table 2). During application, participants were positioned supine and the knee was flexed to approximately 90° before placement of the distal portion of each strip. The rectus femoris strip extended from the anterior thigh to the superior border of the patella, whereas the vastus lateralis and vastus medialis strips followed the respective lateral and medial portions of the thigh before continuing around the corresponding border of the patella toward the tibial tuberosity. Following placement, each strip was rubbed firmly to activate the adhesive properties of the tape. The same researcher, tape product, anatomical landmarks, percentage stretch, and application sequence were used for all participants.

Figure 5

Bilateral Kinesiology Tape Application of the Superficial Quadriceps

Table 2

Steps of Kinesiology Tape Application

Muscles Taped	Application Steps
Rectus femoris	1. Applied the first 3 cm anchor 7 cm below the anterior superior iliac spine. 2. With the kinesiology tape stretched to 25%, the tape was applied along the rectus femoris muscle to the superior border of the patella. 3. Ensuring the participant's knee was flexed to 90-degrees, the distal anchor (3 cm) was applied over the patella. Then a hand was rubbed along the tape to activate the adhesive.

Vastus lateralis	1. Applied the first 3 cm anchor just below the greater trochanter. 2. With the kinesiology tape stretched to 25%, the tape was applied along the vastus lateralis muscle to the lateral border of the patella. 3. Ensuring the participant's knee was flexed to 90-degrees, the distal anchor (7 cm) was applied around the lateral border of the patella to the tibial tuberosity. Then a hand was rubbed along the tape to activate the adhesive.
Vastus medialis	1. Applied the first 3 cm anchor in the middle third of the medial thigh. 2. With the kinesiology tape stretched to 25%, the tape was applied down along the vastus medialis muscle to the medial border of the patella. 3. Ensuring the participant's knee was flexed to 90-degrees, the distal anchor (7 cm) was applied around the medial border of the patella to the tibial tuberosity. Then a hand was rubbed along the tape to activate the adhesive.

Warm-Up

Following completion of the screening procedures and KT application measurements, participants performed a standardized warm-up before completing the CMJ trials. The warm-up began with five minutes of cycling on a stationary bicycle at a self-selected comfortable intensity, followed by a dynamic warm-up routine (Boozari et al., 2018; Donahue et al., 2023; Holt & Lambourne, 2008). Static stretching was not included because prolonged static stretching immediately before explosive exercise may negatively affect subsequent jump performance (Holt & Lambourne, 2008). Following the dynamic warm-up, participants completed three submaximal CMJs to become familiar with the testing instructions and force-platform setup. Three familiarization jumps have previously been used during CMJ testing in recreationally active participants (Krzyszkowski et al., 2021). The same familiarization procedure was provided to both recreationally active and competitive volleyball participants to standardize preparation before the experimental trials. After completing the familiarization jumps, participants proceeded to their first randomly assigned taping condition and the corresponding CMJ trials.

Countermovement Jump

All CMJ trials were performed with participants standing on the AMTI force platform. A Vertec jump device was positioned adjacent to the force platform and used as an external target to encourage maximal jump effort (Ford et al., 2005; Laffaye et al., 2014). The Vertec was not used to calculate jump height. To standardize the position of the Vertec across participants, the device was placed on the participant's dominant side with the vanes positioned approximately 10 cm in front of the participant (Buckthorpe et al., 2012).

Participants completed three valid CMJ trials during each taping condition to provide multiple trials for adequate precision in subsequent analysis (Hopkins, 2000). A trial was discarded and repeated when excessive or abnormal fluctuations in the force signal were observed before movement initiation, as these fluctuations could interfere with identification of baseline body weight and CMJ onset (Harry et al., 2020). Participants received one minute of rest between trials within each condition to reduce the potential influence of fatigue on subsequent performance (Trossman & Li, 1989). A standardized five-minute interval was provided between taping conditions. The same interval was used regardless of condition order so that recovery time between the first and second sets of CMJ trials remained consistent across participants.

Before each trial, participants were instructed to stand upright and motionless on the force platform with their feet approximately shoulder-width apart. Force-platform recording began while the participant remained stationary for a minimum of two seconds, providing a stable baseline from which body weight and subsequent force-time events could be identified (McMahon, Suchomel, et al., 2018). Accurate determination of body weight was important because it was subsequently used to identify movement onset and calculate net vertical force for the derivation of CMJ velocity and displacement. Following the stationary period, the researcher provided the verbal command to begin the jump.

Participants were permitted to use a self-selected countermovement depth and arm swing during all trials. This approach was used to preserve the individual's preferred CMJ strategy because constraining countermovement depth or arm movement can alter the kinematic and kinetic characteristics of the jump (Pérez-Castilla et al., 2019). Allowing a self-selected strategy was also relevant when comparing recreationally active and competitive volleyball participants because differences in habitual jumping strategy could be retained rather than imposed through a standardized depth. Although the movement strategy was self-selected, the performance objective and verbal instruction were standardized because external instructions can influence CMJ force-time characteristics (Krzyszkowski et al., 2021). Before each trial, participants received the following instruction: "Jump and reach to displace the highest vane on the Vertec that you can while using your preferred amount of knee flexion and arm swing."

Data Processing

Raw vertical ground reaction force (vGRF) data was exported from LabChart and processed using a custom MATLAB script (R2023b; MathWorks, Inc., Natick, MA, USA). A low-pass filter with a 50-Hz cutoff frequency was applied to the raw force signal. This cutoff has been shown to preserve the magnitude of GRF and phase-specific rate of force development (RFD) during CMJ analysis (Harry et al., 2020). Body weight was determined separately for each trial as the mean vertical force recorded during the first 1,000 samples of the motionless standing period before the CMJ. At a sampling frequency of 1,000 Hz, this represented a one-second averaging period. Body mass was subsequently calculated by dividing body weight by gravitational acceleration (9.81 $m \cdot s^{-2}$; Krzyszkowski et al., 2021). Net vertical force was calculated as the difference between vGRF and body weight, and

COM acceleration was determined by dividing net vertical force by body mass (Chavda et al., 2018). COM velocity was obtained through numerical integration of acceleration with respect to time, and COM displacement was subsequently obtained through numerical integration of the velocity-time signal.

Movement onset was identified as the first sample at which vGRF decreased below a threshold equal to body weight minus five standard deviations of the quiet-standing force signal (Chavda et al., 2018; McMahon, Suchomel, et al., 2018). To establish the initial conditions for numerical integration before the detected movement onset, integration began 30 ms before this threshold was crossed (Owen et al., 2014). The detected movement onset represented the beginning of the unweighting phase and was used as the temporal start of the CMJ. The unweighting phase extended from movement onset until peak downward COM velocity. The braking phase began at peak downward COM velocity and continued until COM velocity returned to zero. The zero-velocity point represented the transition between braking and propulsion and corresponded with the lowest vertical position of the COM. The propulsion phase extended from zero COM velocity until take-off. Take-off was identified as the first sample at which vGRF decreased below 20 N (Chavda et al., 2018; Harry et al., 2021). Similar force- and velocity-based methods have been used to identify CMJ phases in previous investigations (Donahue et al., 2023; Krzyszkowski et al., 2021; McMahon, Suchomel, et al., 2018).

Force-platform data were then used to calculate performance, kinetic, kinematic, and temporal dependent variables for each trial. Performance variables included jump height and RSI. Jump height was calculated from COM velocity at take-off using the impulse-momentum approach rather than a flight-time method, which can be influenced by differences in body positions between take-off and landing (Linthorne, 2001). Take-off velocity was defined as COM velocity at the sample corresponding with take-off and was used to calculate the jump height for the trial (see Table J1). The calculation did not account for the change in COM position between quiet standing and take-off. RSI was calculated by dividing jump height by total time to take-off.

Three phase-specific kinetic variables were calculated: braking RFD, vGRF at zero velocity, and peak propulsion power. Braking RFD represented the average slope of the force-time curve across the braking phase and was calculated as the change in vGRF between the beginning and end of braking divided by braking phase duration (Krzyszkowski et al., 2021; Laffaye et al., 2014). vGRF at zero velocity was defined as the vertical force recorded at the end of the braking phase when COM velocity returned to zero. This measure represented the magnitude of force present at the braking-to-propulsion transition. Instantaneous vertical power was calculated throughout the CMJ as the product of vGRF and COM velocity. Peak propulsion power was subsequently identified as the greatest positive power value occurring during the propulsion phase before take-off. Braking RFD, vGRF at zero velocity, and peak propulsion power were normalized to body mass for analysis (see Table J1).

Peak unweighting velocity and countermovement depth were derived from the COM velocity and displacement signals, respectively. Peak unweighting velocity was defined as the greatest downward COM velocity and occurred at the transition between the unweighting and braking phases. Countermovement depth was defined as the maximum downward COM displacement relative to the initial standing position and occurred when COM velocity returned to zero at the end of braking (McMahon, Suchomel, et al., 2018).

Temporal variables included total time to take-off and the absolute durations of the unweighting, braking, and propulsion phases. Total time to take-off was calculated from movement onset to take-off. Unweighting time extended from movement onset to peak downward COM velocity, braking time extended from peak downward COM velocity to zero

COM velocity, and propulsion time extended from zero COM velocity to take-off. Each phase duration was calculated from the elapsed time between its respective phase boundaries.

Statistical Analysis

For each dependent variable, the mean of the three valid CMJ trials completed by each participant within each taping condition was calculated and entered into SPSS (Version 31.0; IBM Corp., Armonk, NY, USA) for statistical analysis. Descriptive statistics were calculated for each group and taping condition and are presented as mean and standard deviation.

A 2 x 2 mixed-design analysis of variance (ANOVA) was performed separately for each performance, kinetic, kinematic, and temporal dependent variable. Group represented the between-subjects factor and consisted of recreationally active females and competitive female volleyball athletes. Taping condition represented the within-subjects factor and consisted of the no-tape and KT conditions. Each ANOVA was used to examine the main effect of group, the main effect of taping condition, and the Group x Taping Condition interaction.

When a significant interaction was identified, simple-effects analyses were performed to determine the source of the interaction. Paired-samples *t*-tests were used to compare the no-tape and KT conditions within each group, whereas independent-samples *t*-tests were used to compare the recreationally active and competitive volleyball groups within each taping condition. ANOVA results were reported using *F*-statistics, *p*-values, and partial eta-squared (η^2) effect sizes. Follow-up *t*-tests were reported with the corresponding *t*-statistics, *p*-values, and Cohen's *d* effect sizes. Statistical significance was established at $\alpha = .05$. Because separate ANOVAs were conducted across multiple dependent variables, no adjustment to the alpha level was applied for the number of statistical comparisons.

Results

Absolute mean and standard deviation values for each variable can be viewed in the tables provided in Appendix K.

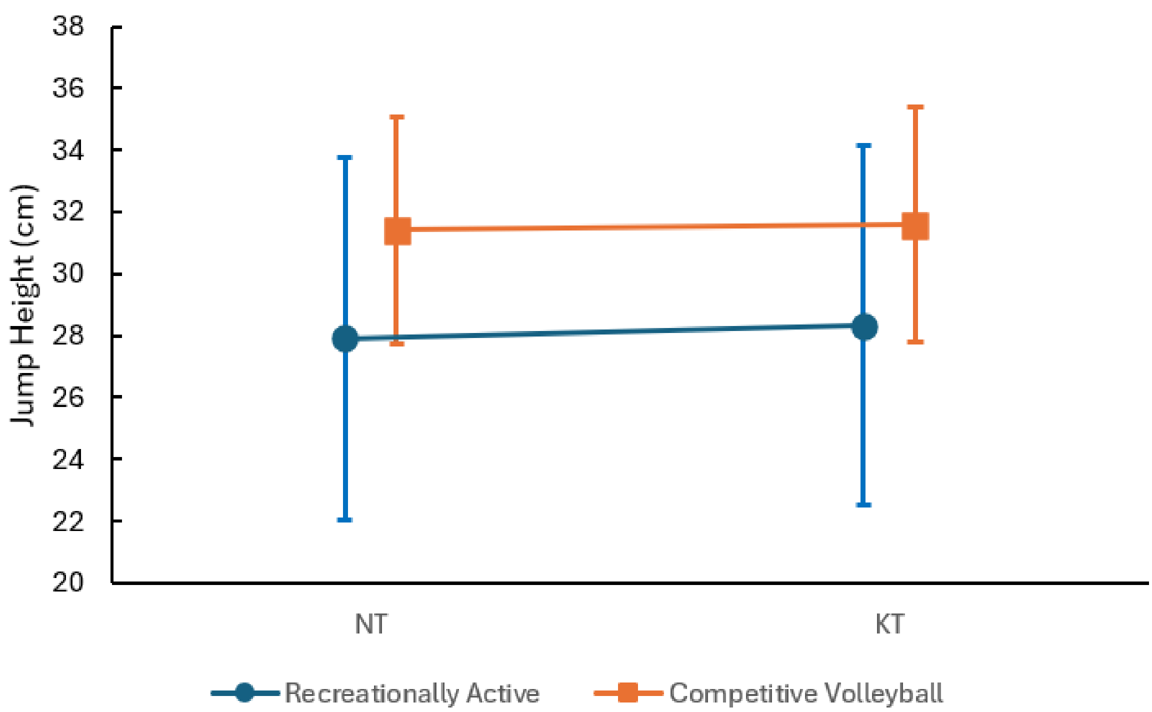
Performance Measures

Jump Height

The 2 × 2 mixed-measures ANOVA for jump height revealed no significant interaction between group and taping condition, $F(1, 22) = 0.29$, $p = .60$, $\eta^2 = .01$. There were also no significant main effects of group, $F(1, 22) = 2.87$, $p = .10$, $\eta^2 = .12$, or taping condition, $F(1, 22) = 1.43$, $p = .25$, $\eta^2 = .06$. Figure 6 illustrates jump height across groups and taping conditions.

Figure 6

Countermovement Jump Height Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



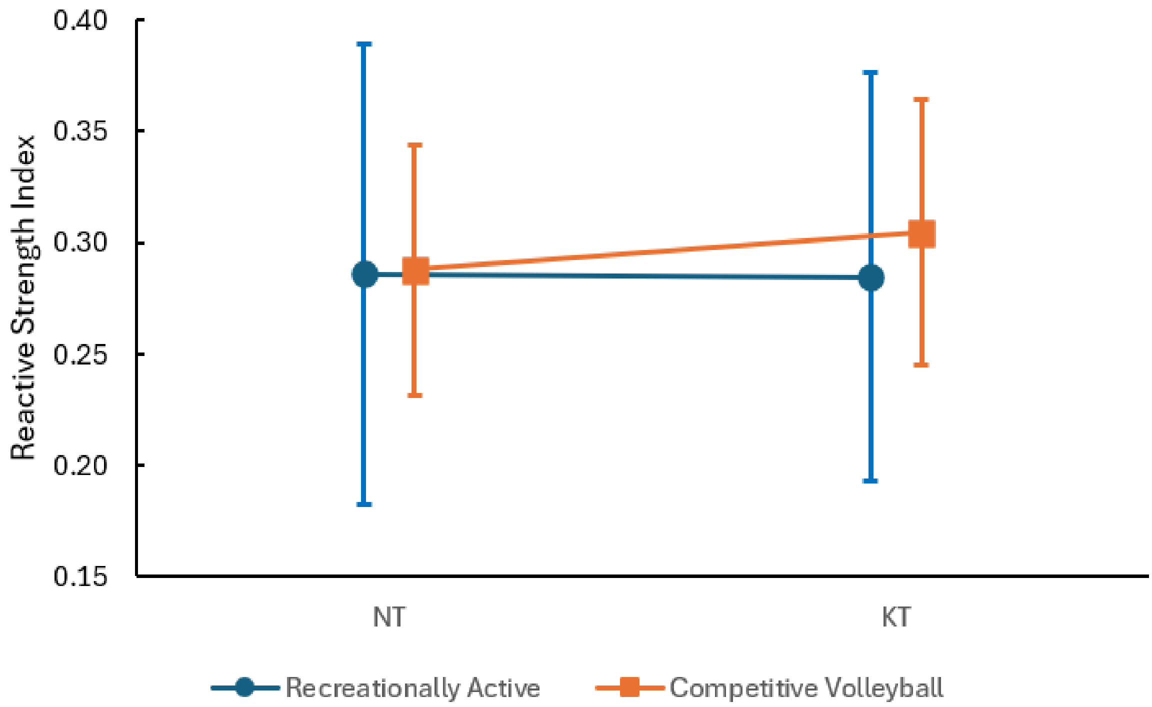
Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

Reactive Strength Index

The 2 × 2 mixed-measures ANOVA for RSI revealed no significant interaction between group and taping condition, $F(1, 22) = 2.74$, $p = .11$, $\eta^2 = .11$. There were also no significant main effects of group, $F(1, 22) = 0.12$, $p = .73$, $\eta^2 = .01$, or taping condition, $F(1, 22) = 1.50$, $p = .23$, $\eta^2 = .06$. Figure 7 illustrates RSI across groups and taping conditions.

Figure 7

Reactive Strength Index Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

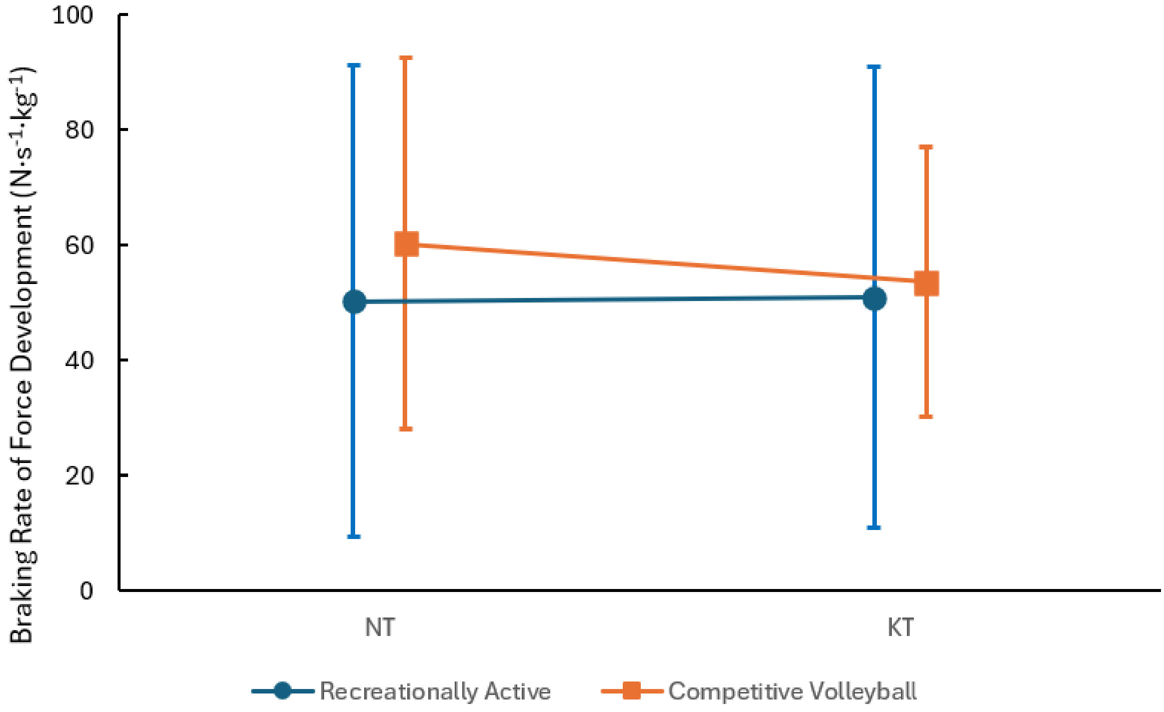
Kinetic Measures

Braking Rate of Force Development

The 2 × 2 mixed-measures ANOVA for braking RFD revealed no significant interaction between group and taping condition, $F(1, 22) = 2.03$, $p = .17$, $\eta^2 = .08$. There were also no significant main effects of group, $F(1, 22) = 0.21$, $p = .65$, $\eta^2 = .01$, or taping condition, $F(1, 22) = 1.35$, $p = .26$, $\eta^2 = .06$. Figure 8 illustrates braking RFD across groups and taping conditions.

Figure 8

Braking Rate of Force Development Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



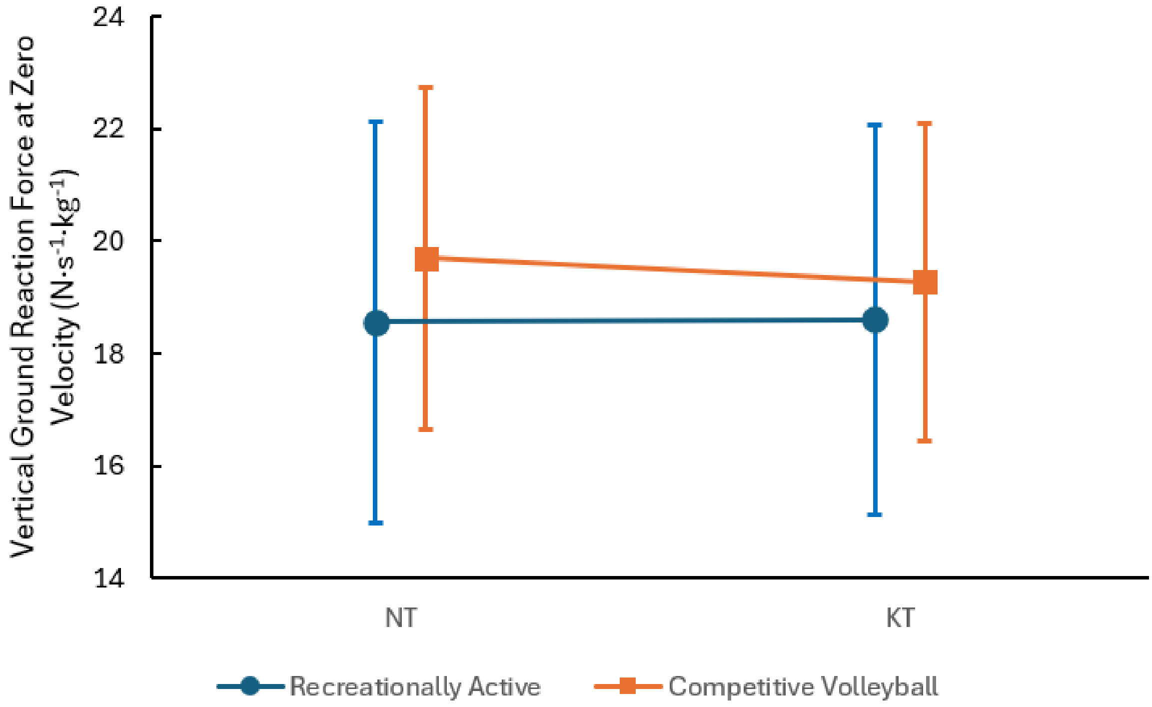
Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

Vertical Ground Reaction Force at Zero Velocity

The 2 × 2 mixed-measures ANOVA for vGRF at zero velocity revealed no significant interaction between group and taping condition, $F(1, 22) = 1.21$, $p = .28$, $\eta^2 = .05$. There were also no significant main effects of group, $F(1, 22) = 0.47$, $p = .50$, $\eta^2 = .02$, or taping condition, $F(1, 22) = 0.74$, $p = .40$, $\eta^2 = .03$. Figure 9 illustrates vGRF at zero velocity across groups and taping conditions.

Figure 9

Vertical Ground Reaction Force at Zero Velocity Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



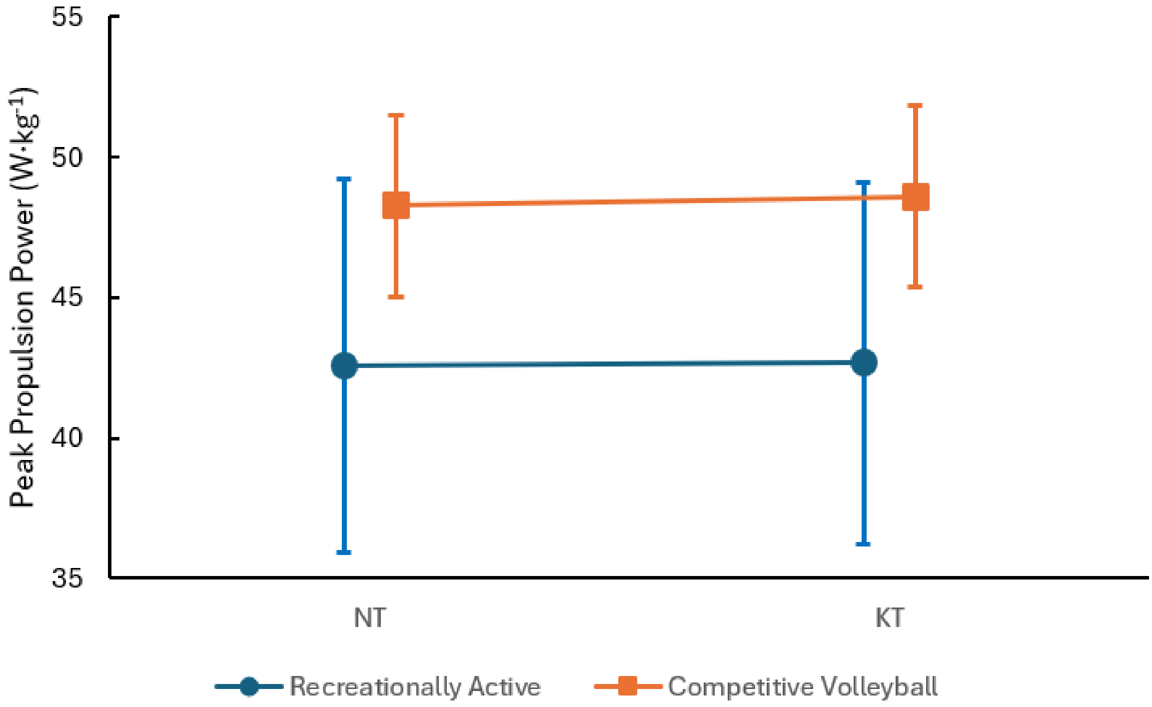
Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

Peak Power

The 2 × 2 mixed-measures ANOVA for peak power revealed no significant interaction between group and taping condition, $F(1, 22) = 0.17$, $p = .69$, $\eta^2 = .01$. There was a significant main effect of group, $F(1, 22) = 7.76$, $p < .05$, $\eta^2 = .26$, indicating that, regardless of taping condition, the competitive volleyball group produced significantly greater peak power than the recreationally active group. There was no significant main effect of taping condition, $F(1, 22) = 0.42$, $p = .52$, $\eta^2 = .02$. Figure 10 illustrates peak power across groups and taping conditions.

Figure 10

Peak Power Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

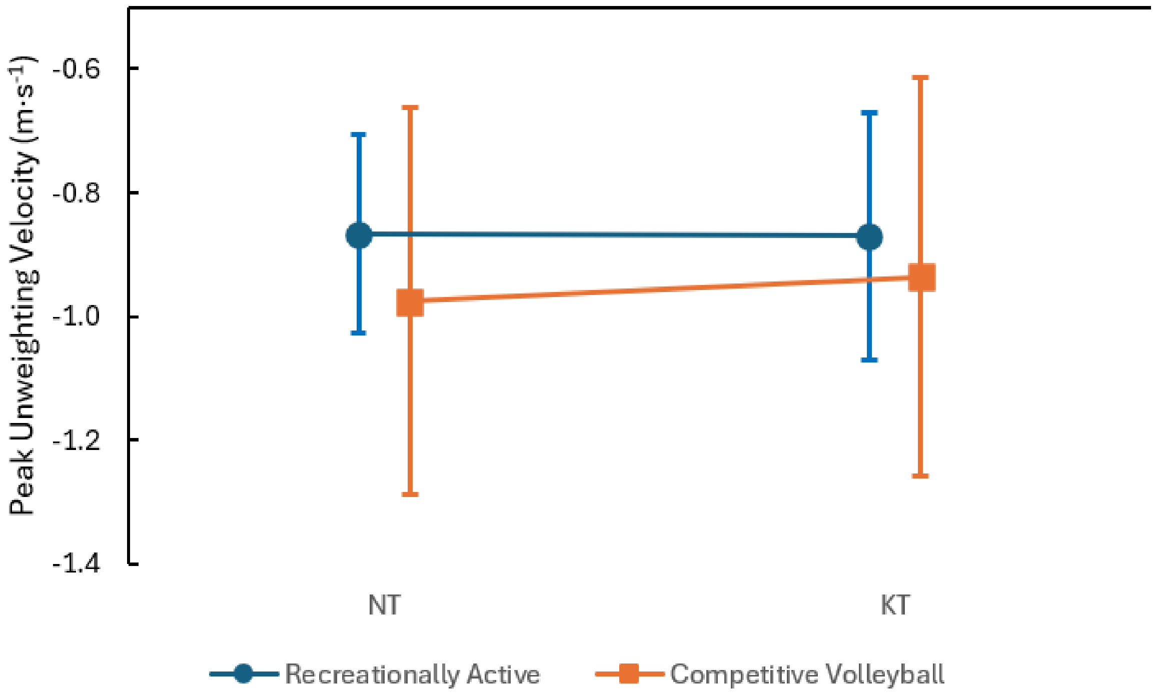
Kinematic Measures

Peak Unweighting Velocity

The 2 × 2 mixed-measures ANOVA for peak unweighting velocity revealed no significant interaction between group and taping condition, $F(1, 22) = 1.15$, $p = .30$, $\eta^2 = .05$. There were also no significant main effects for group, $F(1, 22) = 0.70$, $p = .412$, $\eta^2 = .03$, or taping condition, $F(1, 22) = 0.89$, $p = .36$, $\eta^2 = .04$. Figure 11 illustrates peak unweighting velocity across groups and taping conditions.

Figure 11

Peak Unweighting Velocity Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



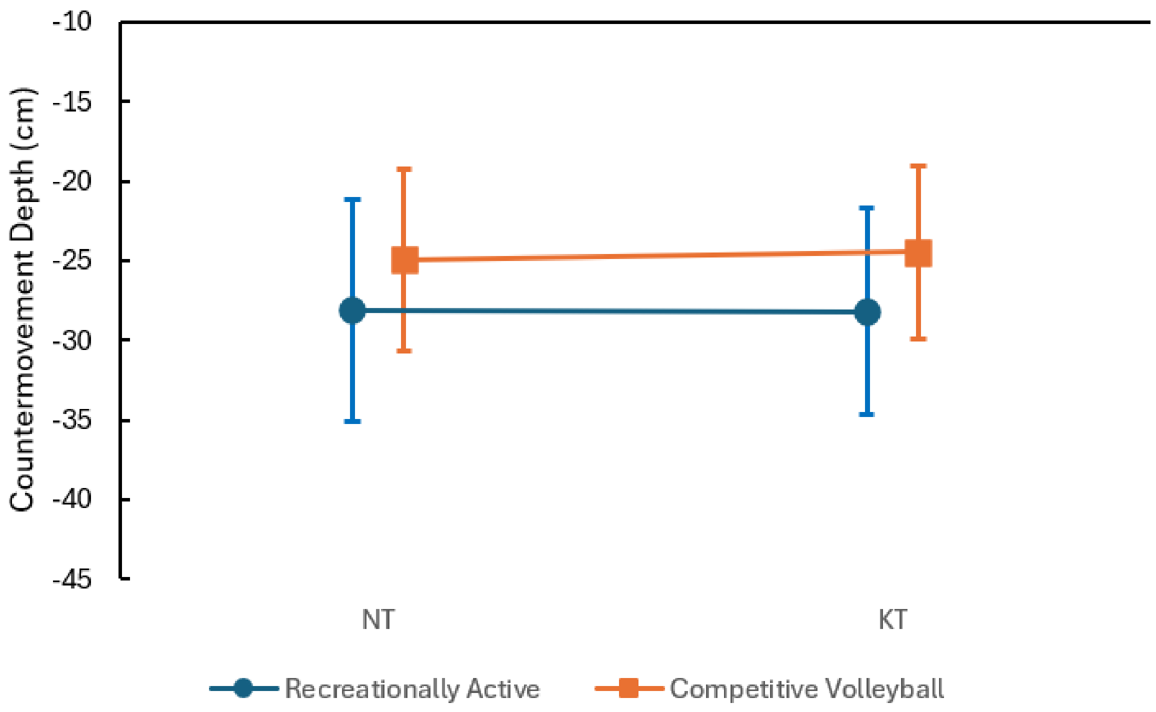
Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations. Negative values indicate downward centre-of-mass velocity during the unweighting phase, with more negative values representing a greater magnitude of downward velocity.

Countermovement Depth

The 2 × 2 mixed-measures ANOVA for countermovement depth revealed no significant interaction between group and taping condition, $F(1, 22) = 0.43$, $p = .52$, $\eta^2 = .02$. There were also no significant main effects of group, $F(1, 22) = 1.89$, $p = .18$, $\eta^2 = .08$, or taping condition, $F(1, 22) = 0.21$, $p = .65$, $\eta^2 = .01$. Figure 12 illustrates countermovement depth across groups and taping conditions.

Figure 12

Countermovement Depth Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations. Negative values indicate downward displacement of the center of mass relative to the standing position, with more negative values representing a greater countermovement depth.

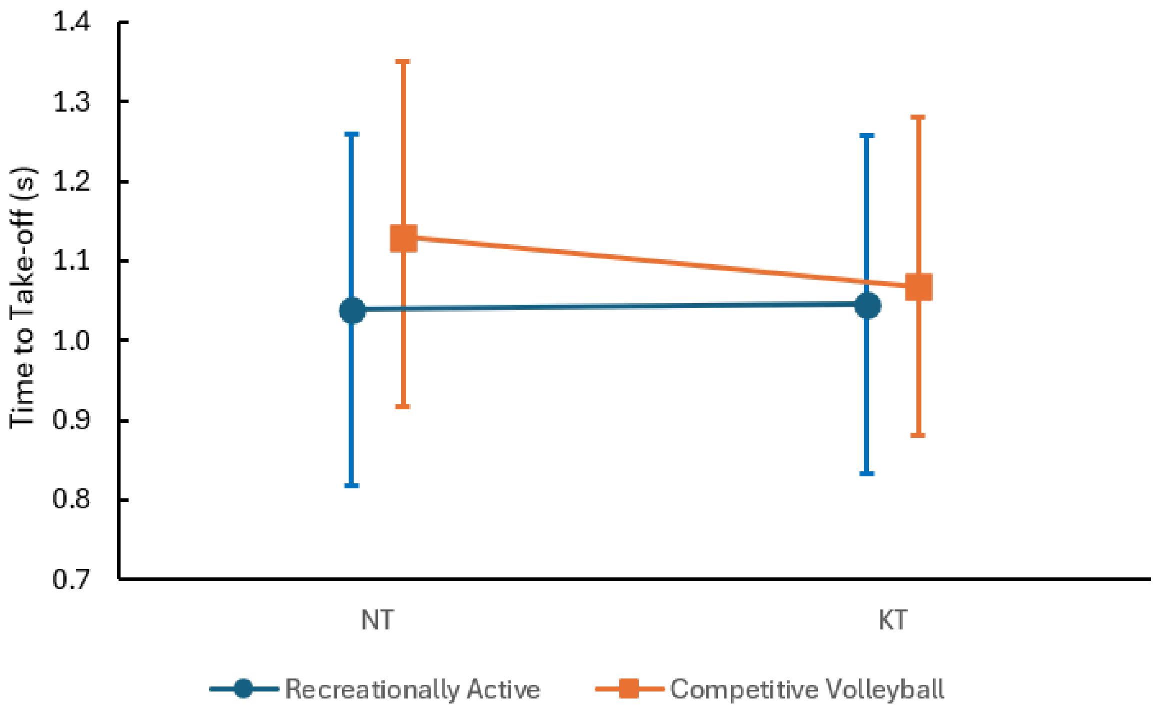
Temporal Measures

Time to Take-off

The 2 × 2 mixed-measures ANOVA for time to take-off revealed no significant interaction between group and taping condition, $F(1, 22) = 4.24$, $p = .054$, $\eta^2 = .16$. There were also no significant main effects for group, $F(1, 22) = 0.45$, $p = .50$, $\eta^2 = .02$, or taping condition, $F(1, 22) = 2.78$, $p = .11$, $\eta^2 = .11$. Figure 13 illustrates time to take-off across groups and taping conditions.

Figure 13

Countermovement Jump Time to Take-off Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



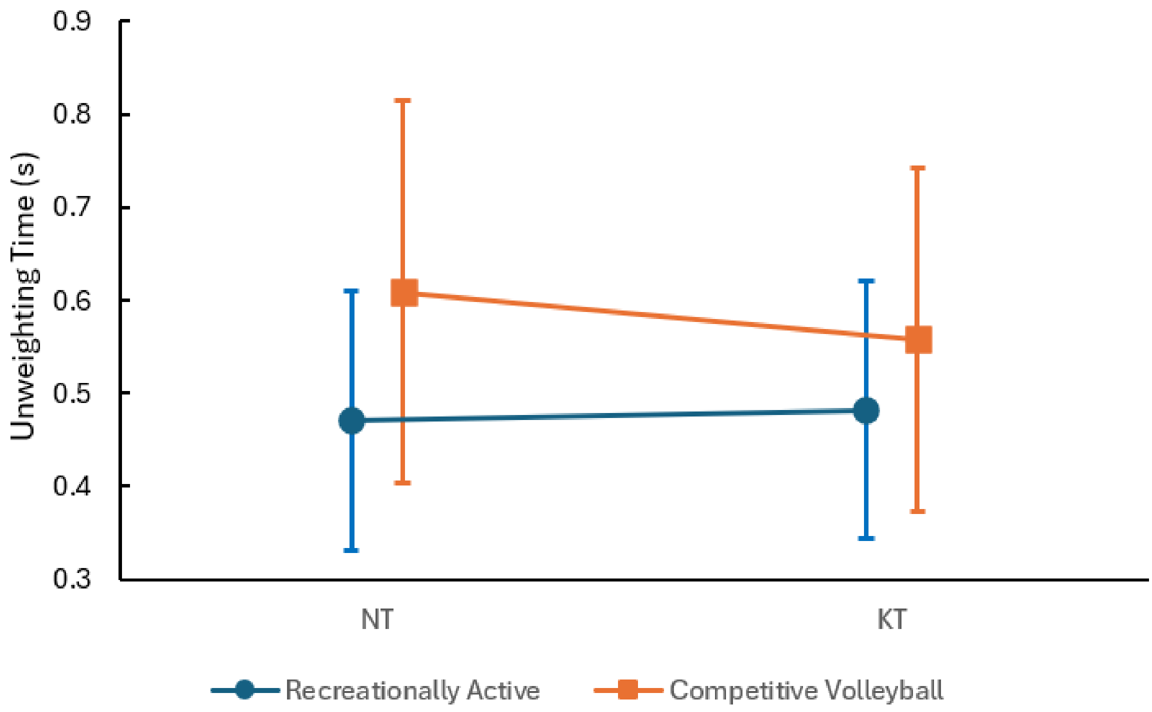
Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

Unweighting Time

The 2 × 2 mixed-measures ANOVA for unweighting time revealed a significant interaction between group and taping condition, $F(1, 22) = 7.41$, $p < .05$, $\eta^2 = .25$. Follow-up comparisons revealed no significant difference between taping conditions in the recreationally active group, $t(11) = 0.64$, $p = .54$, $d = .18$. However, unweighting time was significantly shorter in the KT condition than in the NT condition for the competitive volleyball group, $t(11) = 2.97$, $p < .05$, $d = .86$. Figure 14 illustrates the interaction between group and taping condition for unweighting time.

Figure 14

Unweighting Time Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



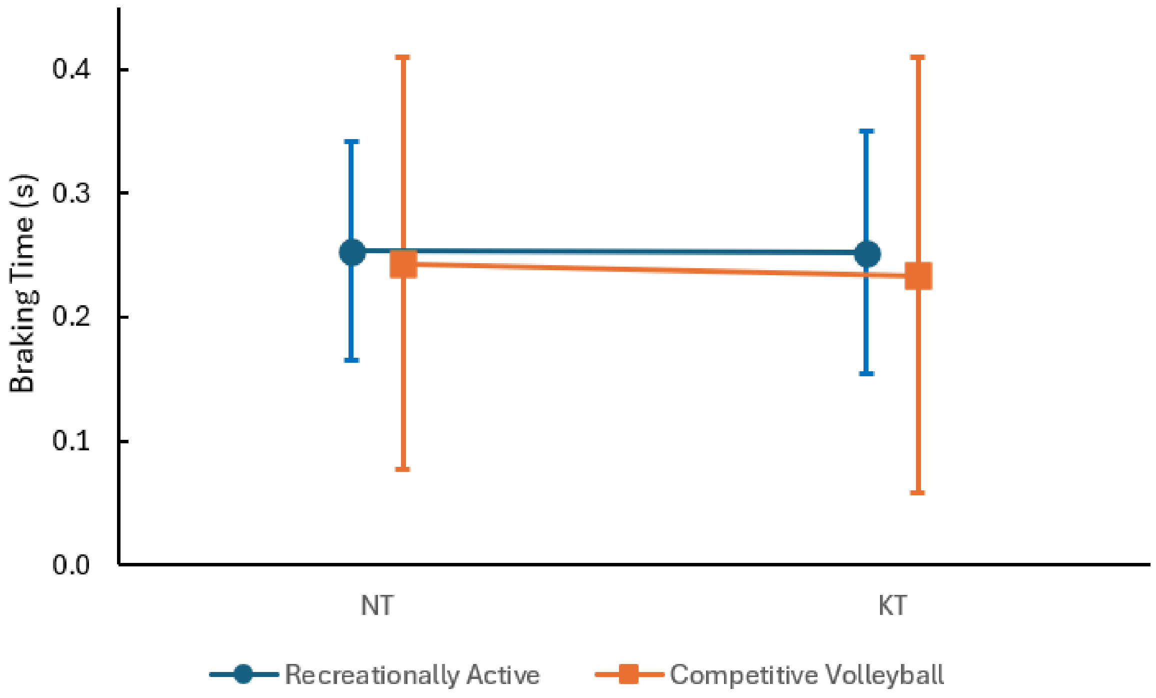
Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

Braking Time

The 2 × 2 mixed-measures ANOVA for braking time revealed no significant interaction between group and taping condition, $F(1, 22) = 0.07$, $p = .79$, $\eta^2 = .01$. There were also no significant main effects for group, $F(1, 22) = 0.05$, $p = .82$, $\eta^2 = .01$, or taping condition, $F(1, 22) = 0.39$, $p = .54$, $\eta^2 = .02$. Figure 15 illustrates braking time across groups and taping conditions.

Figure 15

Braking Time Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



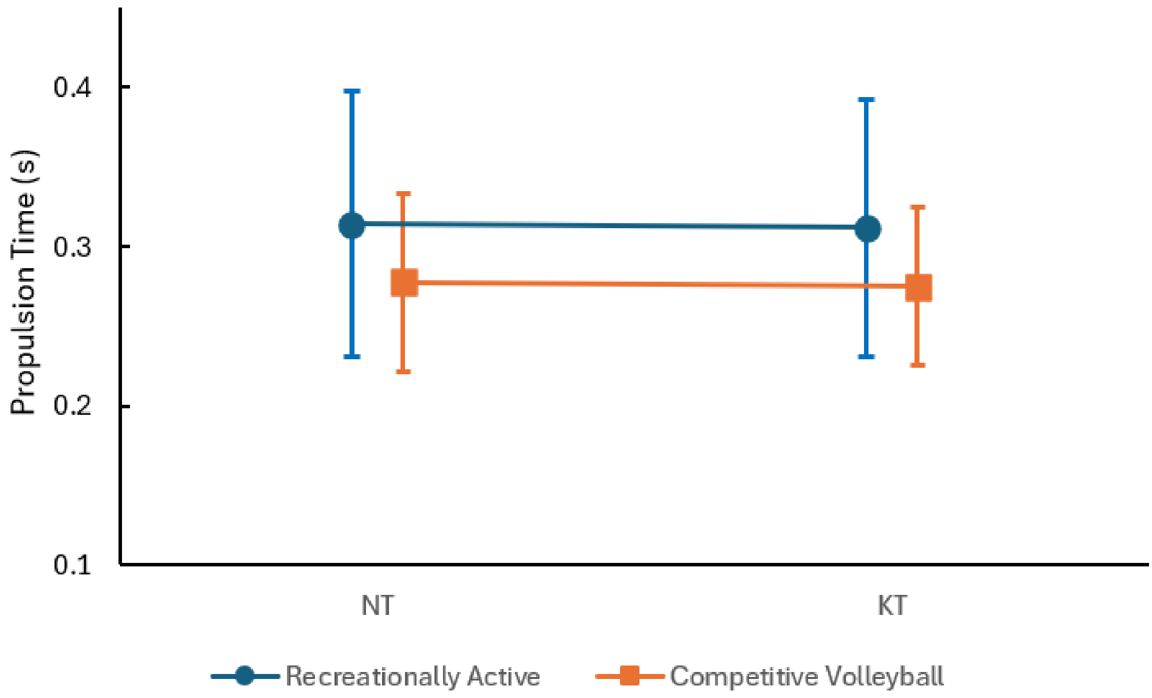
Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

Propulsion Time

The 2 × 2 mixed-measures ANOVA for propulsion time revealed no significant interaction between group and taping condition, $F(1, 22) = 0.05$, $p = .82$, $\eta^2 = .01$. There were also no significant main effects for group, $F(1, 22) = 1.67$, $p = .21$, $\eta^2 = .07$, or taping condition, $F(1, 22) = 0.82$, $p = .37$, $\eta^2 = .04$. Figure 16 illustrates propulsion time across groups and taping conditions.

Figure 16

Propulsion Time Between Taping Conditions in Recreationally Active and Competitive Volleyball Athletes



Note. Values represent group means for recreationally active and competitive volleyball athletes in the no-tape (NT) and kinesiology-taped (KT) conditions. Error bars represent standard deviations.

Discussion

The purpose of this project was to determine whether KT influenced power, performance, and SSC factors during a CMJ task. Peak power was the only measure that differed significantly between the recreationally active and competitive volleyball groups. No significant effects of KT were identified except for unweighting phase time in the competitive volleyball group, where taping resulted in a shorter phase duration. The findings did not support the general hypotheses that competitive volleyball athletes would demonstrate greater lower-extremity performance than the recreationally active group or that KT would improve vertical power and lower-extremity performance in the recreationally active group. These results are discussed below with respect to the limited differences between the competitive volleyball and recreationally active groups, the limited effects of the current KT application, practical implications, and future directions of this work.

The Effectiveness of Quadriceps Kinesiology Tape Application on Countermovement Jump Performance

To date, this is the first study to examine the effects of KT applied to the superficial quadriceps on CMJ performance and the underlying factors of the stretch-shortening cycle between female jumpers with a recreationally active or a competitive volleyball background. No statistically significant interaction or main effect for taping was found in jump height or RSI scores. When considering the impulse-momentum relationship during the vertical jump, jump height is determined by the take-off velocity which is influenced by net vertical impulse produced in the propulsion phase (Hall, 2019; Linthorne, 2001). Thus, the lack of significant differences in jump height suggests that KT did not meaningfully affect the force-time characteristics required to increase take-off velocity. Similarly, the fact that no significant differences were seen in RSI scores suggests that KT did not improve jump performance relative to the time to complete the task. Although jump height is also dependent on force being applied over time, RSI provides additional information by expressing the achieved jump height relative to time to take-off and can therefore distinguish changes in performance that occur through either greater vertical displacement, shorter movement time, or a combination of both (McMahon, Jones, et al., 2018). These results are consistent with a growing body of research which has found no differences in vertical jump performance following KT application. For example, Nunes et al. (2013) found no differences between KT tape and placebo tape applied to the lateral borders of the gastrocnemius during a single-legged CMJ. Similarly, Boozari and colleagues (2018) reported no changes in jump height following gastrocnemius taping in both fatigued and non-fatigued conditions. Moreover, Strutzenberger et al. (2015) found no effect on jump height during a CMJ or drop jump when taping the gluteal muscles.

Nevertheless, some researchers have reported limited or context-specific improvements to vertical jump performance with KT application. MacDowall et al.'s (2015) investigation of healthy varsity athletes found that KT applied to the gastrocnemius and soleus resulted in an increased single-legged squat jump height of 2.4 cm. It must be noted that these researchers did not find significant differences between taping conditions during the other three vertical jump tasks (bilateral squat jump, single-legged CMJ, bilateral CMJ), although they noted a trend toward minor improvements in jump height following KT application (MacDowall et al., 2015). Similarly, Mostert-Wentzel (2012) found that bilateral gluteus maximus KT application resulted in significant increases in jump heights (by 1.4 cm to 2.3 cm) in varsity male athletes. However, significant increases in jump height were also reported in the placebo taped (2 horizontal KT strips applied to gluteus maximus without tension) group (Mostert-Wentzel, 2012). The increase in jump height seen in both the experimental and placebo groups may reflect non-specific effects of taping, such as participant expectation or altered perception of support, rather than a direct physiological effect of KT. While this interpretation should be made cautiously, Lam et al. (2023) supports the possibility that belief in elastic tape may influence perceived performance without changes in muscle activity. Additionally, both investigations used a Vertec to assess vertical jump height (MacDowall et al., 2015; Mostert-Wentzel, 2012). Although the Vertec is commonly used in field settings, it may provide less precise jump-height estimates than laboratory-based methods because jump height is determined from the highest vane displaced during a jump (Leard et al., 2007; Nuzzo et al., 2011). In comparison, the present study used a force platform and calculated jump height using the impulse-momentum relationship, providing a more direct assessment of take-off velocity than field-based tools such as the Vertec (Bui et al., 2014). Therefore, previous reports of improved jump height following KT application appear to be limited and should be interpreted cautiously due to task-specific findings, placebo-group improvements, and differences in jump-height measurement methods. In contrast, the present study found no significant improvement in jump height or RSI, suggesting that bilateral KT applied to the superficial quadriceps with 25% stretch did not provide a meaningful functional enhancement to CMJ performance and should not be considered by recreational or competitive athletes seeking a competitive advantage.

As with jump height and RSI, KT application did not significantly affect peak propulsion power. This finding further supports the interpretation that KT did not meaningfully alter the force-time characteristics required to improve CMJ performance. Furthermore, the outcome is consistent with previous literature suggesting that evidence is limited for KT improving athletic-based performance outcomes in healthy and active individuals (Drouin et al., 2013). For instance, Cheung and colleagues (2015) examined healthy volleyball players and found that KT did not result in greater peak jump power when compared to the no-taped or placebo trials. Likewise, Alabbad and Muaidi's (2021) single-blind randomized controlled trial in weightlifters found no significant influence of estimated peak power following KT application to various muscles (gluteus maximus, rectus femoris, and gastrocnemius) during a single-legged CMJ. It should be acknowledged that these investigations assessed power using estimation equations or jump mats, which may provide less direct assessments of power than calculations derived from a force platform (Alabbad & Muaidi, 2021; Cheung et al., 2015). Boozari and colleagues (2018) extend these results in fatigued and non-fatigued conditions during single-legged CMJ while using the more robust method to determine power. The researchers demonstrated that gastrocnemius application of KT had no effect on peak power regardless of the fatigued condition (Boozari et al., 2018). Therefore, the present findings add to previous literature suggesting that an acute quadriceps KT application does not meaningfully enhance peak power regardless of muscles taped, CMJ protocol, or methods to calculate power output.

The lack of statistically significant differences was also seen for the kinetic variables examined in the present study. There were no significant differences between the no tape and KT conditions in braking RFD or vGRF at zero velocity in either the recreationally active or the competitive volleyball group. These results are consistent with the findings of Boozari et al. (2018), who reported that gastrocnemius KT had no effect on RFD and peak propulsion force regardless of fatigued condition in healthy non-athletic females. In contrast, Vithoulka et al. (2010) reported significantly greater peak eccentric quadriceps torque following KT applied to the rectus femoris, vastus lateralis, and vastus medialis in healthy young females. Although their taping location and sample were more comparable to the present study, eccentric torque was assessed during an isolated isokinetic task and therefore does not directly represent the rapid development of force during the braking phase of a multi-joint CMJ.

Nevertheless, some researchers have established a significant effect of KT on kinetic measures during a CMJ. For example, Huang et al. (2011) found a statistically significant increase in peak vGRF following KT application. However, the magnitude of the change they reported was small, increasing from 2.28 to 2.31 times body weight. Although statistically significant, this small change in peak force did not appear to translate into a meaningful improvement in jump height. Furthermore, the reported force measure was not defined relative to a specific biomechanical event on the force-time curve and therefore does not indicate whether vGRF at zero velocity was altered (Huang et al., 2011). Thus, the findings of Huang et al. (2011) demonstrate that a statistically significant change in an isolated kinetic variable does not necessarily correspond with an improvement in CMJ performance. Mendez-Rebolledo et al. (2018) also reported significant increases in CMJ peak propulsion vGRF with KT application, but this effect was not observed during the squat jump. The researchers speculated that KT may enhance the stretch component of the CMJ which could be a possible reason the squat jump was not affected (Mendez-Rebolledo et al., 2018). However, methodological differences should be considered when comparing these results with the present study. Mendez-Rebolledo et al. (2018) applied tape to several muscle groups (1. Longissimus; 2. Gluteus maximus; 3. Biceps femoris; 4. Rectus femoris; 5. Gastrocnemius), whereas the present study applied KT only to the superficial quadriceps. Additionally, significant enhancements in peak propulsion vGRF were reported only 72-hours after application, whereas the present study examined the acute effects of KT. Therefore, their results may not transfer directly to the acute quadriceps KT application used in the present study.

The 25% stretch used during KT application represents one methodological factor that should be considered when interpreting the absence of significant effects in the present study. This magnitude of stretch was selected because previous investigations using approximately 20–25% stretch across the rectus femoris, vastus lateralis, and vastus medialis reported increases in quadriceps peak torque during controlled isokinetic tasks (Choi & Lee, 2018, 2019). However, because both studies measured torque before taping and subsequently reassessed torque after KT application, repeated testing or familiarization effects should not be excluded as contributors to their findings (Choi & Lee, 2018, 2019). Therefore, the present application was intended to reproduce previously investigated quadriceps taping procedures while standardizing the relative elongation applied across participants and limiting familiarization effects. Importantly, the mechanical stimulus produced by KT varies considerably with the amount of tape elongation. Using the same RT-2 RockTape employed in the present study, Cheatham and Baker (2021) reported elongation forces of approximately 2.27 N at 25%, 6.51 N at 50%, and 30.13 N at 75%, with tape stress also increasing as elongation increased. Thus, the 25% application used in the present study produced substantially less mechanical tension than would be expected at greater elongations and may partially explain why KT had minimal effects when applied to the superficial quadriceps.

Despite the effects previously reported with similar quadriceps applications using lower magnitudes of stretch during isolated tasks, KT did not significantly alter peak unweighting velocity, countermovement depth, braking RFD, vGRF at zero velocity, or braking and propulsion phase times in the present study. The absence of changes across these phase-specific variables suggests that the 25% quadriceps application did not meaningfully alter the mechanical strategy used to perform the CMJ. Although greater tape elongation would have increased the mechanical tension applied to the underlying tissues, it cannot be determined from the present findings whether a greater stretch would have produced a different CMJ response. The absence of changes in unweighting velocity also indicates that the 25% application did not negatively alter the preparatory downward movement, while the lack of subsequent changes in braking RFD and vGRF at zero velocity indicates that it did not enhance braking-phase force production. Future research comparing different KT elongations while directly assessing muscle activity and CMJ force-time characteristics may help determine whether tape tension influences the response to quadriceps KT during dynamic jumping.

Unweighting phase time was the only variable in the current study that demonstrated a significant interaction effect. In the competitive volleyball group, mean unweighting phase time decreased from 0.61 s in the no-tape condition to 0.56 s in the KT condition, representing a reduction of 0.05 s, or approximately 8.2%. Although the difference was considered statistically significant, the reduction in unweighting time appears to have limited relevance to the overall execution of the CMJ as it was not accompanied with enhanced kinetic output in subsequent phases (braking RFD, vGRF at zero velocity, and peak power) or translate to increased CMJ performance (jump height and RSI). Furthermore, because multiple dependent variables were examined independently, the possibility of a Type I error should also be considered when interpreting this isolated significant interaction.

The importance of interpreting unweighting time alongside other CMJ characteristics is demonstrated by McMahon, Jones, et al. (2018). They found that athletes in the higher RSI group completed the unweighting, braking, and propulsion phases in less time than athletes with lower RSI (McMahon, Jones, et al., 2018). However, the shorter unweighting phase in the high RSI group was accompanied by greater peak unweighting velocity (McMahon, Jones, et al., 2018). The faster downwards unweighting movement required a greater braking impulse to return COM velocity to zero which was associated with increased force production at the transition into propulsion (McMahon, Jones, et al., 2018). Conversely, the competitive volleyball group in the present study completed the unweighting phase more quickly with KT without a corresponding increase in peak unweighting velocity, braking RFD, vGRF at zero velocity, or peak propulsion power. Therefore, the KT-related reduction in unweighting time appears to represent a small alteration in movement timing rather than an enhancement of the broader force-time strategy associated with improved SSC performance.

Comparison of Countermovement Jump Performance Between Competitive Volleyball and Recreationally Active Groups

The competitive volleyball players jumped approximately 3 cm (12.0%) higher than the recreationally active women, yet this mean difference did not reach statistical significance. Similarly, measures of reactive strength were nearly identical between the two groups. Therefore, although the competitive volleyball athletes demonstrated a descriptively greater jump height, the present findings did not provide statistical evidence of a difference in overall CMJ performance between the two populations. A potential source of limited between group differences may be attributable to the low sample size, which may have reduced statistical power to establish significant effects.

One factor that may have contributed to the insignificant group difference was the performance level of the participants recruited into each group. The recreationally active inclusion criteria required regular participation in physical activity but did not restrict participants according to previous resistance-training or recreational sport experience. Consequently, some participants may have entered the study with considerable exposure to activities that support jumping performance. This interpretation is consistent with when comparing the results to previous studies, where the recreationally active jumpers demonstrated greater jump heights (a 15.7% to 27.2% increase) and RSI scores (a 0% to 26% increase) than those reported in comparable samples (Harry et al., 2021; Krzyszkowski et al., 2021; Rojano-Ortega et al., 2022). In contrast, the jump height and RSI values observed in the competitive volleyball group were generally within ranges previously reported in collegiate and professional female volleyball athletes (Cabarkapa et al., 2023, 2024; Donahue et al., 2023). Thus, the limited statistical separation between groups may have reflected relatively better CMJ performance within the recreationally active sample rather than unusually poor performance by the competitive volleyball athletes. Future studies aiming to examine whether KT effects differ according to jumping ability may benefit from including a more distinct comparison group, such as sedentary or minimally active participants.

It is essential to highlight that differences in methodology such as the use of arm-swing and verbal cueing limit comparisons between the present findings and previous literature. Donahue and colleagues (2023) used similar CMJ protocol to the present study (i.e., allowing arm swing and verbally informing the participants to "jump as high as possible"), reporting values approximately 6.8% greater for jump height and 11.8% greater for RSI than those observed in the competitive volleyball group of the current study. However, other investigations involving female competitive volleyball players or recreationally active jumpers have prevented arm swing and used verbal cues emphasizing explosive performance (Cabarkapa et al., 2023, 2024; Harry et al., 2021; Krzyszkowski et al., 2021). These methodological differences are important because arm swing has been shown to increase vertical jump height and take-off velocity, including in volleyball players (Feltner et al., 2004; Vaverka et al., 2016). In contrast, verbal cues emphasizing explosiveness may influence temporal and force-time characteristics of the CMJ (Kershner et al., 2019; Krzyszkowski et al., 2021). Therefore, allowing arm swing while cueing participants to jump as high as possible may have encouraged a strategy that prioritized jump height rather than rapid completion of the movement. The distinction is relevant because RSI is influenced by both jump height and time to take-off. Hence, longer movement times can reduce RSI scores even when jump height is maintained or increased (Kipp et al., 2016; Suchomel et al., 2015). Consequently, methodological differences in arm swing and verbal cueing should be considered when comparing the present jump height and RSI findings with previous literature. Furthermore, it may be prudent to standardize cueing instructions toward the specific performance outcome of interest when examining SSC function, such as maximal jump height or explosive force production.

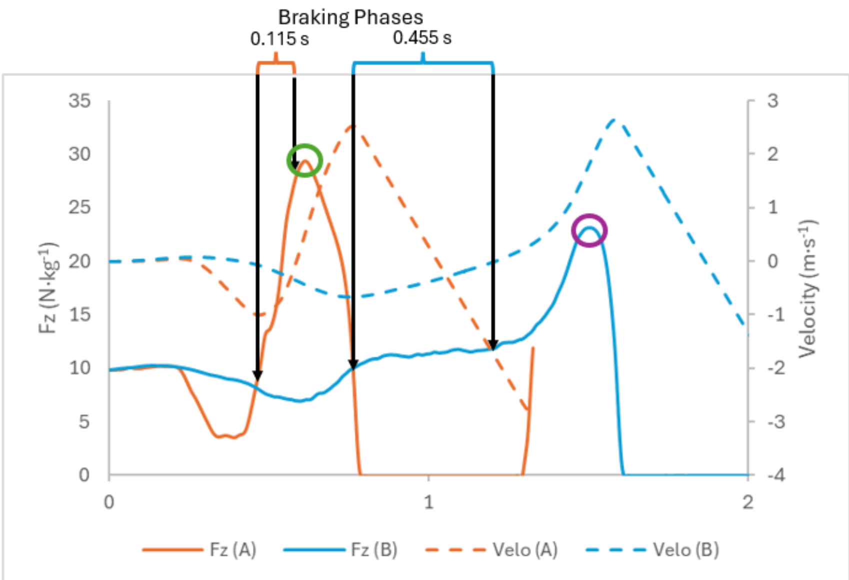
Analysis of the underlying mechanical variables provides additional context regarding the limited between-group differences in jump height and RSI. Peak propulsion power was the only measure that demonstrated a statistically significant group effect, with the competitive volleyball athletes producing more power than the recreationally active group. The findings are consistent with the previous literature showing that training background can influence CMJ power production. For example, Cormie et al. (2009) reported greater relative peak power in experienced jumpers than non-jumpers, with power training increasing measured peak power in the non-jumpers in the longitudinal component of their investigation. Peak power has also been strongly associated with CMJ height, although average propulsion power demonstrates a similarly strong relationship with performance (McLellan et al., 2011). Furthermore, Marković et al. (2014) suggested that peak power may be particularly useful for describing jumping ability after accounting for body mass and countermovement strategy. Thus, the athletes in the competitive volleyball group ability to demonstrate greater peak propulsive power likely reflect a better capacity to produce high force-velocity mechanical output during the later portion of propulsion than those considered recreationally active.

However, greater peak propulsion power did not correspond with a significant advantage in jump height or RSI for the competitive volleyball group. It is essential to consider this lack of significance in performance measures because peak power represents the largest instantaneous product of force and velocity between the low position of the countermovement to take-off and does not describe how it is produced or maintained throughout the phase (Cormie et al., 2009; McHugh et al., 2020). Cormie and colleagues (2009) address the limitations when analysing gross measures such as peak power, suggesting that they provide no insight into the precise timing or behaviours of the mechanical strategy used across the full movement of the CMJ. In training studies where improvements in jump performance accompanied greater propulsion power, changes have also been observed throughout the force, velocity, and power-time profiles, including characteristics within the preceding unweighting and braking phases (Cormie et al., 2009, 2010). Similarly, (McMahon, Jones, et al., 2018) found that athletes who jumped higher with greater RSI scores demonstrated significantly increased force, velocity, and power across a substantial portion of the entire CMJ. In the present study, the groups did not differ significantly in peak unweighting velocity, countermovement depth, braking RFD, vGRF at zero velocity, or phase-specific time. Thus, the competitive volleyball athletes demonstrated a greater peak propulsion power without evidence of corresponding differences in the broader CMJ strategy measured in the present study. Because average propulsion power, propulsion impulse, and the complete power-time curve were not assessed, it cannot be determined whether the volleyball group maintained greater mechanical output throughout propulsion or whether the between-group difference was limited primarily to the peak value.

Beyond the group level comparisons, Figure 17 illustrates the individual variability in CMJ force-time strategies observed within the present sample. The selected recreationally active participant (orange) demonstrated a peak downward COM velocity of approximately 1.0 $m \cdot s^{-1}$ followed by a short braking phase (0.11 s), high vGRF at zero velocity (27.9 $N \cdot kg^{-1}$), and high braking RFD (157.6 $N \cdot s^{-1} \cdot kg^{-1}$). In contrast, the selected competitive volleyball participant (blue) demonstrated a lower peak downward COM velocity (0.66 $m \cdot s^{-1}$), a longer braking phase (0.45 s), lower vGRF at zero velocity (11.9 $N \cdot kg^{-1}$), and lower braking RFD (4.5 $N \cdot s^{-1} \cdot kg^{-1}$), with peak force occurring later during the upward portion of the movement. Despite these contrasting profiles, the competitive volleyball participant achieved a greater jump height (32.7 cm vs. 30.0 cm) and peak propulsion power (50.3 $W \cdot kg^{-1}$ vs. 47.1 $W \cdot kg^{-1}$). The comparison highlights that superior jump outcomes may occur when force is applied effectively over time, even if the force-time profile does not display the rapid and forceful braking-phase characteristics typically associated with SSC efficiency (McHugh et al., 2020). Garhammer and Gregor (1992) similarly emphasized that vertical jump performance depends not only on the magnitude of force, but also the duration of high force application in propulsion. Therefore, Figure 17 suggests that some competitive volleyball athletes may achieve superior jump outcomes despite displaying force-time characteristics that are less dependent on rapid force development in the braking phase and are broadly consistent with the idea that these athletes may be relatively time-dependent jumpers (Laffaye et al., 2014). Furthermore, it illustrates the variability may have obscured group mean values and should be considered. Inferences on added variability are consistent with the absence of significant between-group differences in unweighting velocity, braking RFD, vGRF at zero velocity, countermovement depth, and phase-specific time in the present study. It should be noted that since Figure 17 represents two individual participants, these profiles should be viewed as descriptive examples rather than evidence of a characteristic jumping strategy within either group.

Figure 17

Representative Countermovement Jump Force- and Velocity-Time Profiles



Note. Representative force (solid) and COM velocity (dashed) profiles from one recreationally active participant (orange) and one competitive volleyball participant (blue) demonstrating contrasting unweighting and braking strategies. Black arrows identify the beginning and end of the braking phase for each participant, and circles indicate the occurrence of peak vGRF.

Practical Application

Based on the results of the present investigation, acute bilateral KT applied to the superficial quadriceps with 25% stretch was not found to improve jump height, RSI, peak propulsion power, braking RFD, vGRF at zero velocity, countermovement depth, or most phase-specific temporal variables in healthy females that are recreationally active or competitive volleyball athletes. Although unweighting phase time decreased in the competitive volleyball group with KT, this change appeared to have limited relevance to overall CMJ execution because it was not accompanied by improvements in subsequent kinetic or kinematic variables, jump height, or RSI. Therefore, this quadriceps KT application protocol should not be considered as a strategy to provide acute enhancement of CMJ performance or SSC function in similar populations. However, it should be noted that this KT protocol did not appear to impair vertical jump performance or underlying SSC factors. Lam et al. (2023) research suggests that perceived performance benefits may occur without changes to functional performance in individuals wearing KT. Accordingly, athletes who choose to use KT for perceived comfort, support, or confidence may continue to wear the tape during practice or competition without reductions in functional performance. These conclusions are specific to the bilateral application to rectus femoris, vastus lateralis, and vastus medialis using 25% stretch during acute test settings as used in the present investigation.

Limitations

Several limitations of the present study should be acknowledged. First, the sample was limited to healthy females who were either recreationally active or competitive volleyball athletes. Although these groups were selected to represent different training backgrounds, the recreationally active group appeared to perform at a higher level than expected based on previously reported jump height and RSI values in recreational female samples (Harry et al., 2021; Krzyszkowski et al., 2021; Rojano-Ortega et al., 2022). This may have reduced the separation between groups and limited the ability to detect between-group differences in CMJ performance or KT responsiveness. The recreationally active group also included participants with varied activity backgrounds, such as hockey and dance, which may have increased within-group variability in jumping ability and SSC-related characteristics. Similarly, the competitive volleyball group included athletes regardless of playing position, which may have introduced variability in jumping demands and training history (Skazalski et al., 2018). Therefore, the present findings should be generalized cautiously and are most applicable to healthy active females with recreational or competitive volleyball backgrounds rather than to sedentary individuals, elite jumpers, or athletes from other sports.

A second limitation relates to sample size and timing of data collection. The a priori power analysis indicated that 34 participants were required to detect the anticipated interaction effect, whereas the final sample consisted of 24 participants, with 12 participants in each group. Consequently, the study was underpowered relative to the original sample size estimate. Although similar sample sizes have been used in previous CMJ and KT investigations (Donahue et al., 2023; Krzyszkowski et al., 2021), the current sample size representation may have reduced the ability to detect small Group x Taping Condition interactions or between-group differences. Furthermore, this limitation is particularly relevant when interpreting insignificant findings and means that the absence of statistical significance should not be considered evidence that small effects were definitively absent. Data collection for the competitive volleyball group also occurred during the five weeks following the final game of the varsity season and near the university examination period. Although previous research suggests that jump height and many force-time metrics may remain relatively stable across a competitive season in female collegiate volleyball athletes (Cabarkapa et al., 2023), individual differences in training status, academic demands, and post-season priorities may have influenced performance during testing. As a result, the performance observed during testing may not necessarily represent each athlete's typical in-season physical abilities.

An additional statistical limitation relates to the number of dependent variables examined in the present study. Separate ANOVAs were conducted for each performance, kinetic, kinematic, and temporal variable using an alpha level of .05 without adjustment for multiple comparisons. Conducting multiple statistical tests increases the possibility of a Type I error, and this should be considered when interpreting isolated significant findings. This consideration is particularly relevant to the Group × Taping Condition interaction observed for unweighting time, as it was the only significant KT-related effect among the measured CMJ outcomes. Thus, greater emphasis should be placed on the overall pattern within the findings. More specifically, the findings which demonstrated no KT-related improvements in jump height, RSI, or the measured kinetic and kinematic variables, rather than interpreting the unweighting-time interaction independently.

Several limitations should also be considered regarding the KT design. The present research involved a KT protocol as follows: acute bilateral application of standard RockTape to the superficial quadriceps muscles (rectus femoris, vastus lateralis, and vastus medialis), with 25% stretch from resting. Cheatham and Baker (2021) reported that the mechanical properties of RockTape changed across elongation lengths increasing from 25% to 75% elongation. Additionally, previous research has shown that elastic therapeutic tapes from different manufacturers can differ in mechanical properties, including elongation, stiffness, stress, and adherence characteristics (Boonkerd & Limroongreungrat, 2016; Matheus et al., 2017). Therefore, the results should not be generalized to other application durations, KT brands, magnitudes of stretch, or muscle groups. In addition, the study compared KT with a no-tape condition rather than a sham or placebo-tape condition. Consequently, the design was not intended to distinguish tape-specific mechanical effects from perceptual or expectancy responses associated with wearing KT.

Finally, limitations associated with CMJ measurement and data processing should be considered. Participants were permitted to use a self-selected countermovement depth and arm swing, which preserved their preferred jumping strategy but may also have increased between-participant variability in CMJ mechanics. In addition, jump height was calculated from COM velocity at take-off and therefore represented the vertical rise of the COM from take-off to the apex of the jump. The calculation did not account for the difference between COM position during initial standing and COM position at take-off. Because take-off posture can influence this displacement, omission of this component may have affected the absolute jump-height estimates leading to errors in jump height and RSI measurements (Chiu & Dæhlin, 2019). Although the same calculation was applied consistently across all participants and conditions, this limitation should be considered when interpreting the reported jump-height values and when comparing them with studies that incorporate the differences between standing and take-off COM displacement.

Assumptions Made

Various assumptions were made when conducting the present study. First, it was assumed that KT was applied consistently and that the KT application produced a similar relative tape stretch across participants. To improve consistency, participants were placed in the same position when measuring the leg and applying the tape. The position involved participants lying supine on a table with their legs hanging off the edge and their knees flexed to approximately 90°. Participant-specific measurements were used to determine the required strip length for the rectus femoris, vastus lateralis, and vastus medialis. The leg measurements were used to calculate the length of each KT strip so that the tape could be applied with 25%

stretch from its resting length. During application, each strip was applied along the predetermined anatomical landmarks with approximately 25% stretch through the working portion of the tape and unstretched anchors. Although these procedures standardized the application, actual tape tension at the skin was not measured directly. It was therefore assumed that applying the tape according to the same relative elongation and anatomical procedures resulted in comparable tape tension across participants.

Additionally, it was assumed that the KT used throughout the study demonstrated sufficiently similar mechanical and adhesive properties. Two mega rolls of RT2 standard RockTape were used throughout the study to reduce variability that may occur between different tape brands (Boonkerd & Limroongreungrat, 2016; Matheus et al., 2017). Although Cheatham and Baker (2021) reported that standard RockTape mechanical properties changed across various elongations of stretch, the researchers reported low variance in the mechanical properties at 25% stretch. Because the same tape product and target elongation were used throughout the present study, it was assumed that any between-strip variation in mechanical properties was sufficiently small that it did not systematically influence comparisons between participants or conditions.

Several assumptions were also made regarding CMJ performance during data collection. First, it was assumed that all participants gave maximal effort during each recorded CMJ trial. Participants were provided with standardized instructions and were asked to jump as high as possible to encourage maximal effort. Furthermore, the Vertec jump device was also used as an overhead target to motivate participants during the task (Laffaye et al., 2014). Secondly, it was also assumed that fatigue did not systematically influence performance across trials or taping conditions. Participants received one minute of rest between CMJ trials and a standardized five-minute interval between conditions to reduce the potential influence of fatigue (Trossman & Li, 1989). Furthermore, the order of the no-tape and KT conditions was randomized and counterbalanced within each group to reduce systematic order and learning effects. Although these procedures were implemented to standardize testing, individual variation in motivation, familiarization, recovery, and trial-to-trial performance could not be eliminated completely.

Finally, it was assumed that force-platform measurements were sufficiently consistent across testing sessions to permit comparison between participants and conditions. Various steps were implemented to reduce potential random sources of noise. For starters, all electronic equipment was powered on for at least 20 minutes before testing to reduce potential thermal and instrumental noise (Beckham et al., 2014). Additionally, the force platform was calibrated immediately before data collection to ensure that conversion calculations were appropriate for the testing environment (Beckham et al., 2014). These procedures were intended to reduce systematic measurement variation across sessions. Nevertheless, because biomechanical measurements inherently contain some degree of measurement error, it was assumed that any remaining instrumentation error was small and did not systematically favour either taping condition or participant group.

Future Considerations

The present study was the first to examine the effect of acute bilateral KT application to the superficial quadriceps on CMJ performance and underlying SSC factors in female jumpers who are either recreationally active or competitive volleyball athletes. Although few significant effects of KT were identified, several methodological questions remain. One priority for future research is to examine whether the magnitude of tape stretch influences the response to quadriceps KT during dynamic jumping. The present protocol used 25% stretch, whereas the mechanical tension produced by RockTape increases substantially at greater elongations (Cheatham & Baker, 2021). Previous research has also demonstrated that stretched KT can produce local tissue deformation and changes in passive muscle properties

(Lopes et al., 2022; Pamuk & Yucesoy, 2015); however, these findings do not establish how different tape tensions influence actively contracting muscle during a CMJ. Future studies should therefore directly compare multiple standardized stretch magnitudes while assessing CMJ force-time characteristics alongside measures of muscle activity, such as EMG. Such approaches would help identify whether tape tension produces measurable neuromuscular or mechanical changes during jumping rather than inferring these mechanisms from force-platform outcomes alone.

Future research should also further examine CMJ mechanics in female volleyball athletes using larger samples and comparison groups with more clearly distinct jumping and training backgrounds. Peak propulsion power was the only variable to differ significantly between groups, with greater values in the competitive volleyball athletes despite no significant differences in the other measured CMJ variables. Because peak power represents only the greatest instantaneous product of force and velocity, it does not indicate whether greater mechanical output was maintained throughout propulsion. Future investigations should therefore examine complete force, velocity, and power-time profiles in addition to peak values to determine whether greater peak propulsion power reflects broader differences in propulsion-phase mechanics or an isolated peak within an otherwise similar CMJ strategy.

The timing of force development around the transition from braking to propulsion warrants further investigation. McHugh et al. (2020) demonstrated that the relationship between peak force and the braking-to-propulsion transition can provide information about the shape of the CMJ force-time profile. Although the present study measured vGRF at zero COM velocity, the timing of peak force relative to this event was not quantified. Similarly, Cabarkapa et al. (2023, 2024) reported peak eccentric and concentric force characteristics in female volleyball athletes, but these peak values alone do not establish when maximum force occurred relative to the phase transition. Future studies using temporal-phase or continuous force-time analyses could therefore determine whether distinct phase-specific patterns of force development exist within female volleyball populations.

Finally, future CMJ investigations should account for methodological considerations identified in the present study. Larger samples would improve statistical power for detecting group x condition interactions. Distinguishing between player position, training history, and jumping exposure may reduce unexplained within-group variability. Additionally, jump-height calculations derived from take-off velocity should account for the displacement of the COM between the initial standing position and take-off when total vertical COM displacement is of interest (Chiu & Dæhlin, 2019). Together, these methodological refinements would allow future studies to more precisely determine whether quadriceps KT influences CMJ mechanics and to characterize the force-time strategies used by female volleyball athletes.

Conclusion

The purpose of this study was to investigate the effect of acute bilateral KT application to the superficial quadriceps with 25% stretch on CMJ performance and phase-specific kinetic, kinematic, and temporal variables in females that were recreationally active and competitive volleyball athletes. It was found that KT did not significantly improve jump height, RSI, peak propulsion power, braking RFD, vGRF at zero velocity, unweighting velocity, countermovement depth, braking phase time, or propulsion phase time. Consequently, these findings provide no evidence that the quadriceps KT protocol used in the present study acutely enhanced CMJ performance or the measured force-time characteristics of the movement in either group.

Unweighting phase time was the only variable that demonstrated a significant KT-related interaction effect. In the competitive volleyball group, mean unweighting time decreased from 0.61 s in the no-tape condition to 0.56 s with KT, representing a reduction of approximately 0.05 s. However, this temporal change was not accompanied by a greater peak unweighting velocity, enhanced braking RFD or vGRF at zero velocity, greater peak propulsion power, or improvements in jump height or RSI. Therefore, the reduction in unweighting time appears to have had limited relevance to the overall execution of the CMJ and is better interpreted as an isolated alteration in movement timing than as an enhancement of the broader force-time strategy.

Between-group comparisons showed that the competitive volleyball group produced greater peak propulsion power than the recreationally active group; however, this did not translate into significantly greater jump height or RSI. No significant between-group differences were observed in the measured unweighting or braking phase variables. Therefore, the competitive volleyball group demonstrated a greater capacity to reach a high instantaneous mechanical power during propulsion without evidence of corresponding differences in overall CMJ performance or the preceding unweighting and braking characteristics measured in the present study.

In conclusion, the findings do not support acute bilateral KT applied to the superficial quadriceps with 25% stretch as a strategy for improving CMJ performance in healthy recreationally active females or competitive female volleyball athletes. These conclusions are specific to the tape application, stretch magnitude, application duration, and populations examined. Further research using larger samples, different KT stretch magnitudes and application durations, and direct neuromuscular measures may clarify whether alternative quadriceps KT protocols influence CMJ mechanics.

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Appendices

Appendix A: Recruitment Poster

Learn the Benefits of Kinesiology Tape on Jump Performance

This study looks to examine the benefits of kinesiotape when applied to the muscles of the thigh on force production and movement coordination in females.

Are you eligible?

- Healthy active female (ages 18 to 27)
- Identify with one of the following statements:
    1. Varsity volleyball athlete (current or previous 5 years)
    2. Recreationally active (previous 6 months)
- No recent injuries preventing physical activity (6 months)

Participant involvement

- Single session (up to 1 hour)
- Warm-up and cool-down
- Perform maximum effort vertical jumps with and without kinesiology tape

Lakehead UNIVERSITY

Benefits to you

- Learn proper technique when applying and removing kinesiology tape
- Discover how kinesiology tape may influence your jumping ability

Want to learn more?

Contact the student researcher at:

1 (807) 630-9350

bbosinge@lakeheadu.ca

Approved by Lakehead University Research Ethics Board

Appendix B: Recruitment Email Script to Varsity Volleyball Coach

Dear Coach Nichol,

My name is Brandon Bosinger, a current MSc student in the Kinesiology program here at Lakehead University. I am reaching out because the athletes on your team are perfect candidates to participate in my research study.

My research is looking to investigate the effects of applying kinesiology tape to the knee extensors on vertical jump behaviours, including segmental coordination, force production, and performance outcome. Participating in this study will provide an excellent opportunity for your athletes to learn about their current jumping ability and the role kinesiology tape may play in improving jump height.

I am attaching an information form that provides detailed information about this research study and its involved participation that you may look over and provide to the athletes. If the athletes volunteer to participate in my research, I plan to work with you and your athletes to create a testing timeline that will not interfere with training or school responsibilities. If you have any questions, please get in touch with me at bbosinge@lakeheadu.ca or (807) 630-9350.

If you would like a summary of the results at the conclusion of the study, let me know via email.

Thank you for your assistance in the progression of my research.

Brandon

Appendix C: Information Letter

Dear Potential Participant,

Thank you for expressing an interest in the research study titled "The Effects of Kinesiology Tape on Countermovement Jump Performance in Recreationally Active and Competitive Female Volleyball Players." The study is being conducted by Brandon Bosinger, a graduate student of the Masters of Science (MSc) in the School of Kinesiology at Lakehead University. This research project will be conducted under the supervision of Dr. Derek Kivi, Associate Professor in the School of Kinesiology.

Purpose

The purpose of this study is to examine the effects of kinesiology tape when applied to the knee extensor muscles of the thigh on the performance, forces, motion, and timing of the vertical jump between females that are recreationally active and varsity volleyball athletes.

What is Requested as a Participant?

You are being asked to voluntarily participate in this study because you are a healthy female between the ages of 18 and 27 years with one of the following statements being true for you: (1) You are a current member of the Lakehead University women varsity volleyball team or have previous varsity volleyball experience (past 5 years) and currently participate in recreational sport and/or regular jump training; or (2) You regularly perform physical activity (i.e., sporting activities, resistance training, etc.) at least twice per week over the last 6 months and have no professional or varsity levelled sporting experience.

To be an eligible participant, you must have not experienced a lower-extremity (i.e., hips, knees, or ankles) injury in the past three months that prevented you from regular physical activity or participating in your sport. Furthermore, eligibility to participate in this study requires no health conditions that contraindicate kinesiology tape use, such as allergies to the tape, current injury to the skin (i.e., open wound, infection, rash) on the thigh, and other severe health conditions (i.e., cancer, kidney disease, or circulatory diseases).

If you agree to participate in this study, you will be asked to come to room SB-1028 in the C.J. Sanders Fieldhouse at Lakehead University for a single session lasting approximately 60 minutes. During the testing session, you will perform multiple trials of the vertical jump test with and without kinesiology tape applied to the quadriceps region of both legs. The taping condition order that you will perform vertical jump testing will be determined randomly. You will be asked to wear loose fitted athletic shorts to allow the application of kinesiology tape to the quadriceps and mounting of the electrogoniometer devises at the hip, knee, and ankle. For the remainder of your attire, you will be asked to wear what you would typically wear while playing volleyball (if a volleyball athlete) or engaging in training, most notably the shoes.

What Will Testing Involve? What Information Will Be Collected?

If you agree to participate and fully understand what the study involves, you will be asked to sign a consent form. This form is written documentation that you have read this information letter and understand your rights as a volunteering participant. Additionally, you will complete a Get Active Questionnaire (GAQ) and information/demographic form before data collection. The GAQ form will verify that you are healthy and free from any medical conditions which may prevent your safe participation in this study. The information/demographic form will collect background information about yourself. Lastly, the student researcher will need to take six application site measurements (three each leg). As kinesiology tape will be applied to the skin with a pre-determined stretch, these six measurements will be used to calculate the appropriate length at which each piece of tape will be cut. The testing session may continue after all forms are completed and leg measurements are made.

A warm-up will be implemented before data collection begins. The warm-up will be performed in the following order, 5-minutes of stationary biking at a comfortable pace, a series of dynamic movements, and three guided sub-maximal vertical jumps. The student researcher will then present the taping condition order (and apply if kinesiology taped condition is first) and mount the three electrogoniometers to the hip, knee, and ankle of your dominant leg. The electrogoniometers will be used to collect joint motion data during the vertical jump trials. Applying the kinesiology tape will include cleaning the thigh area and trimming excess hair if necessary to limit discomfort during tape removal. Three pieces of kinesiology tape will be applied to both legs (six total) targeting the superficial quadriceps muscles known as rectus femoris, vastus lateralis, and vastus medialis. You will perform three vertical jumps for both the no-tape and kinesiology taped conditions, for a total of six vertical jumps. You will be provided a 1-minute rest period between trials; however, you may take a longer rest period if necessary. A 5-minutes rest period will be provided between taping conditions. If you are to perform the kinesiology taped trials second, you will be taped immediately following the completion of the non-taped jump trials.

Each vertical jump trial will be performed on a force platform to collect/calculate various data (i.e., force, time, velocity, displacement, power). Additionally, a vertec jump apparatus will be aligned with the force platform on the side of your dominant hand. For each jump trial, you will be asked to "jump and reach as high as possible to move the highest possible vein [on the vertec] while landing safely back onto the force platform." The student researcher will also ask you to start by standing upright on the force platform motionless for a few seconds before asking you to jump to start each trial while they begin collected force data. Force data collected during this period of motionlessness will be used for calculating variable of interest. If the student researcher detects too much motion occurs during this period you may be asked to repeat a jump trial so the calculations will more accurately represent true values, with a maximum of eight jumps being performed in total during the testing. Following the completion of all jump trials for both taping conditions, a cool-down will be implemented involving 5-minutes of low-intensity cycle and lower body static stretches.

What Risks Come with Participating in This Study?

Participation in this study involves performing maximal effort countermovement jumps, which comes with inherent risk of physical harm. These potential risks for physical harm include fatigue, muscle soreness, and musculoskeletal injury (i.e., muscle strain, ligament sprain, bone fracture). To minimize the risks of physical harm, you will be young and healthy individuals that compete in varsity volleyball (current or previously) and/or regularly incorporate physical activity/training in your weekly routine. You will also be screened for any contraindications to physical exercise utilizing the GAQ form. All participants will perform a warm-up involving a moderate aerobic exercise that utilizes the lower-extremity musculature (i.e., stationary bike), which will be followed by dynamic movements and submaximal countermovement jumps to prepare the lower-extremity for maximum effort dynamic movement involved with testing. In the instance an injury occurs with testing, you will no longer be permitted to continue with testing.

Potential risks associated with kinesiology tape application include an adverse skin reaction and discomfort during tape removal. Additionally, there are health conditions (that you will be screened for) that present contraindicated use of kinesiology tape. The student researcher that is applying the tape has trained and received their RockTape functional movement training basic and advanced kinesiology tape certifications, where they developed the knowledge to apply and remove the tape appropriately. You will be asked to notify the student researcher immediately if you feel any discomfort, where testing will stop, and the tape will be immediately removed. The student researcher will also implement precautionary taping guidelines that involves trimming away excess hair necessary and cleaning the area with alcohol wipes to limit skin irritation.

How Does Participating in This Study Benefit You?

If you have never used kinesiology tape previously, you will be provided the opportunity to learn the proper techniques used when applying and removing the tape. Also, you may benefit from this study by being provided the opportunity to discover information on your jumping ability and how it might be altered with the application of kinesiology tape. Lastly, as various components of the stretch-shortening cycle will be analyzed in this study, the information can guide future training if your goal is to improve performance.

What Are your Rights as a Participant?

As a potential participant, you maintain the following rights throughout this study:

I. You are under no obligation to participate and are free to withdraw at any time
II. Your decision to participate will not affect your academic, athletic, and/or employment status
III. You will be given, in a timely manner throughout the course of the research project, information that is relevant to your decision to continue or withdraw from participation
IV. You will be given information on the participant right to request withdrawal of data

How to Receive a Copy of the Research Results?

If you wish to receive a copy of your individual and/or the overall results of the study, please check the appropriate box(s) on the consent form and provide an email address where the results can be sent.

Is it Okay to Withdraw from This Study?

Yes, you can withdraw from this study at any time without penalty. Your involvement in this study is completely voluntary and any pre-existing interest in participating can change without accountability. You will be encouraged to ask the student researcher any questions regarding the nature of this study assist in your decision to participate on your own accord.

How Will Confidentiality Be Maintained?

Any information as a participant will remain completely confidential. You will be assigned a unique identification number (ID) that only the student researcher will have access to. Your name will not be attached to any data (your ID number will) or included with publishing the results. All data collected during testing will be safely stored on a password protected computer. Only the student researcher will know the password and only the student researcher and research supervisor will see the individual data.

How Will the Results of the Study Be Published?

A presentation of the results will be made during the 2024/25 academic year to fellow graduate students and faculty in the School of Kinesiology at Lakehead University. The results of the study will also be submitted to a peer-reviewed journal for publication and/or at a sports science conference. No information will be attached to you as a participant throughout any presentation of data with this study, keeping your identity completely confidential.

Where Will Your Data Be Stored?

Following the completion of this study, the data will be stored in the School of Kinesiology at Lakehead University with Dr. Derek Kivi for seven years. All electronic data will be securely stored on a password protected computer, with hard copies of the consent forms, GAQs, and information/demographic forms locked in Dr. Derek Kivi's office. Only the student researcher and the research supervisor involved in this study may access the results.

Researcher Contact Information

If you have any questions and/or are interested in participating in this study, feel free to contact the student researcher, Brandon Bosinger, using the contact information listed below. You may also contact the research supervisor, Dr. Derek Kivi.

Research Ethics Board Review and Approval

This study has been approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team please contact Sue Wright at the Research Ethics Board at 807-343-8010 ext. 8283 or research@lakeheadu.ca.

Your participation would be greatly appreciated. Thank you for your consideration.

Sincerely,

Brandon Bosinger
Student researcher
bbosinge@lakeheadu.ca

Dr. Derek Kivi
Research supervisor
dkivi@lakeheadu.ca

Appendix D: Get Active Questionnaire

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

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

THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

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 E: Additional Information/Demographic Form

Participant ID # (to be filled in by student researcher): ____________________________

Age: __________ Height (cm): ________ Mass (kg): ________

Participant questionnaire

Question	Answer
Which of the following best describes your athletic experience? 1) Current member of varsity volleyball team 2) Physically active with previous varsity volleyball experience (include when you were last a member of a team [years]) 3) Physically active with no varsity athletic experience	
Have you been physically active for the past 6 months? (Yes or no)	
If yes to previous question, how frequently are you physically active (#/week)?	
Have you sustained an injury to your hips, knees, ankles, or feet? If yes, what injury?	
If yes to previous question, how recent was your latest injury?	
How long have you been training since your most recent injury?	
Do you have any known allergies to kinesiology tape? (Yes, no, or unknown)	
Have you been diagnosed or are being treated for any of the following health conditions: Cancer, kidney disease, congestive heart failure, deep vein thrombosis, or skin infections (on the front thigh)? (Yes or no)	

Appendix F: Grouped Inclusion/Exclusion Criteria

Competitive Volleyball Group:

- Current or previous members (past 5 years) of a varsity volleyball team
- Currently perform regular jump training (minimum twice weekly)

Recreationally Active Group:

- Perform physical activity (i.e., resistance training, sporting activities, etc.) at least twice a week in the previous 6 months
- Have no professional or varsity sporting experience

General Exclusion Criteria (see Appendix E for asked questions):

- Are considered unsafe to participate based on GAQ response
- Sustained a lower-extremity injury in past 3 months preventing participating in training, practices, or games
- Have any neurological or musculoskeletal conditions which inhibit their ability to perform maximal effort vertical jumps
- Express any contraindications to KT use, such as allergies to the tape, open skin wounds, infections, irritations at the application site, and other severe health conditions such as cancer, kidney disease, or circulatory diseases

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Appendix G: Informed Consent Form

I Understand and Consent to the Following:

- ✓ I have read and understood the information contained in the Information Letter
- ✓ I have responded truthfully to any screening measures, even if it limits my ability to participate in this study
- ✓ I agree to participate
- ✓ That I am a volunteer and can withdraw from this study at any moment
- ✓ I understand the risks and benefits with the study
- ✓ The data will be securely stored at Lakehead University for a minimum of 7 years following completion of the research project
- ✓ The research findings will be made available upon request
- ✓ My information will remain confidential in any publication and presentations of the research findings
- ✓ Any previous questions/concerns have been addressed

By consenting to participate, I have not waived any rights to legal recourse in the event of research-related harm.

Name (printed): ____

____ ______________________

Signature of Participant Date

Would you like to receive a copy of your individual results and/or a summary of the overall results of the study:

☐ Individual results Email: ____

☐ Summary of results

☐ Neither

____ ______________________

Signature of Student Researcher Date

____ ______________________

Signature of Research Supervisor Date

Appendix H: Quadriceps Measurements

General Information

The muscle measurements were used for calculating the length that each piece of KT based on applying a 25% stretch length increase and anchors. As the anchors for each muscle used standardized lengths, only the areas where KT was applied with a stretch needed to be measured for calculations. Rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) were the three quadriceps muscles measured for both legs. Figure H1 highlights the landmarks used during the measurement process involved with KT.

Rectus Femoris

Each participant was positioned laying supine, keeping the hips extended and the knees bent to 90 degrees. RF was measured between 13 cm below ASIS (start) to the superior border of the patella bone (end) where the KT was applied with stretched (see Figure H2).

Vastus Lateralis

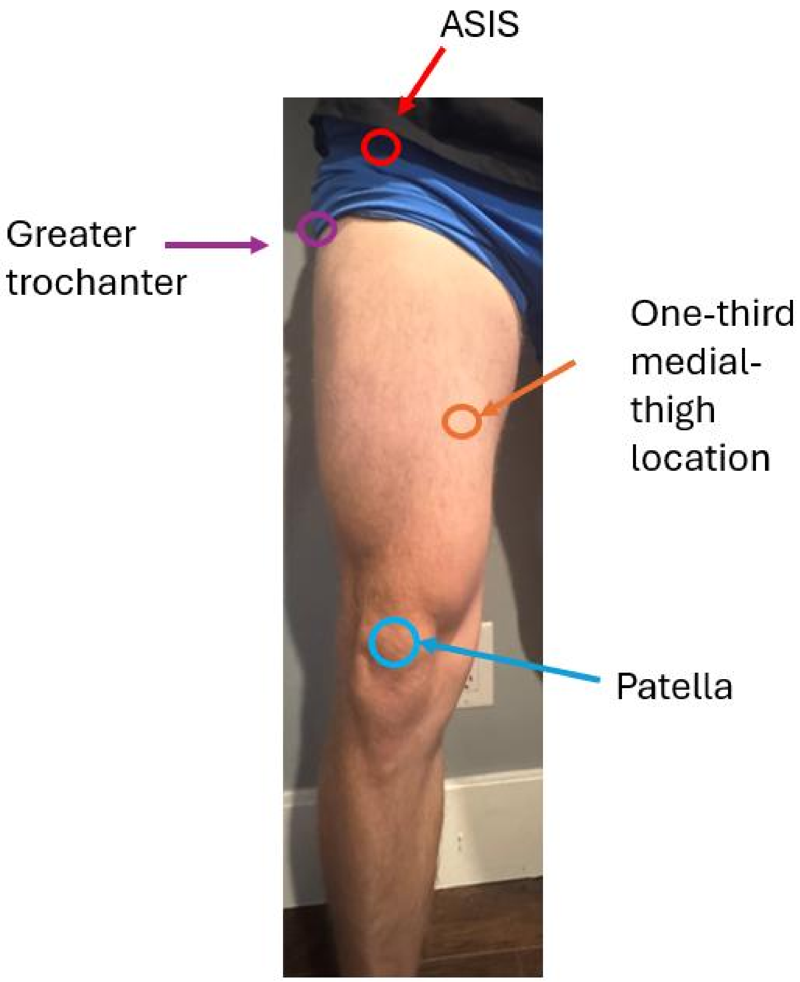
Each participant was positioned laying supine, keeping the hips extended and the knees bent to 90 degrees. VL was measured between 3 cm below the greater trochanter (start) to the lateral border of the patella (end) where the KT was applied with stretch (see Figure H2).

Vastus Medialis

Each participant was positioned laying supine, keeping the hips extended and the knees bent to 90 degrees. VM was measured between the middle 1/3rd of the medial thigh (start) to the medial border of the patella (end) where the KT was applied with stretch (see Figure H2).

Figure H1

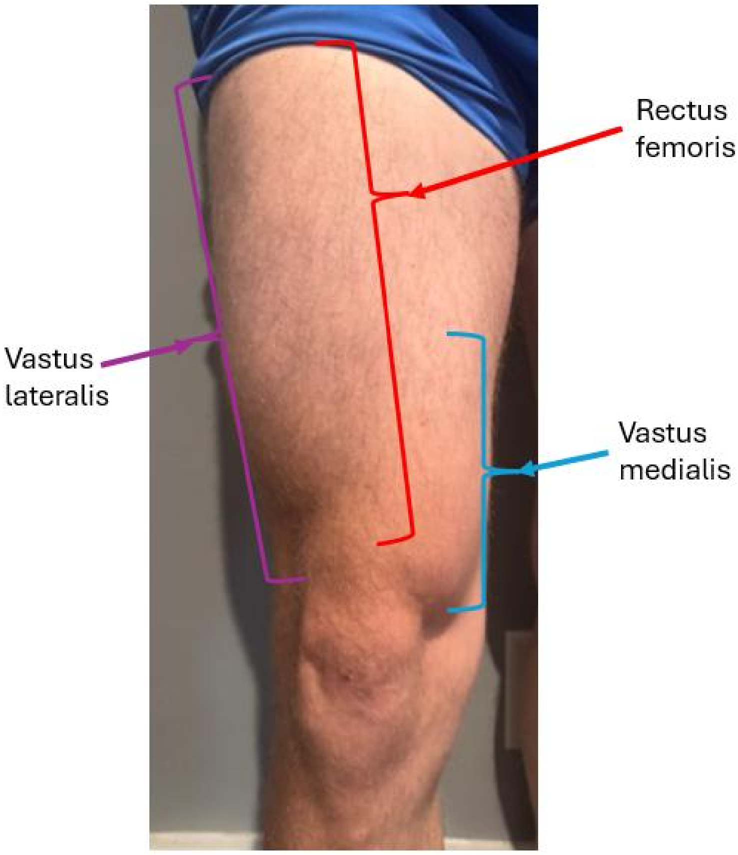
Anatomical Landmarks Used to Identify the One-Third Medial-Thigh Measurement Location



Note. Photograph illustrating the approximate surface locations of the anterior superior iliac spine (ASIS), greater trochanter, patella, and one-third medial-thigh measurement location used for measurement-site identification. Colored circles and arrows indicate the approximate surface locations of each landmark and measurement point.

Figure H2

Approximate Surface Locations of the Superficial Quadriceps Muscle Measurement Regions



Note. Photograph illustrating the approximate surface regions corresponding to the rectus femoris, vastus lateralis, and vastus medialis used for muscle measurement identification. Colored brackets and arrows indicate the approximate surface locations of each muscle and are intended to illustrate the measurement regions rather than precise anatomical muscle boundaries.

Appendix I: Data Measurement Sheet

Participant ID number: ____________

Equation I1

Kinesiology Tape Length

$$KT_{cm} = ML_{cm} - (ML_{cm} * 0.25) + Ap_{cm} + Ad_{cm}$$

Note. Kinesiology tape = KT, muscle length = ML, Ap = proximal anchor, Ad = distal anchor

Quadriceps Measurements

Leg	Muscle	Muscle Length (cm)	Tape Length (cm)
	Rectus femoris		
Right	Vastus lateralis		
	Vastus medialis		
	Rectus femoris		
Left	Vastus lateralis		
	Vastus medialis		

Vertec Standing Reach Height (cm): ____________

Dominant Hand: **Left** **Right**

Dominant Leg: **Left** **Right**

Appendix J: Dependent Variable Equations

Table J1

Equations Used to Calculate Dependent Variables

Variable (Notation)	Equation
Performance Measures	
Jump height (m)	$= \frac{Velocity\ _{TO}^{2}}{g * 2}$
RSI	$= \frac{Jump\ height}{t_{\ total\ time\ to\ takeoff}}$
Kinetic Measures	
Braking RFD ($N \cdot kg^{-1} \cdot s^{-1}$)	$= (\frac{F_{2} - F_{1}}{t_{2} - t_{1}})/kg$
Force at Zero Velocity ($N \cdot kg^{-1}$)	$= \frac{F}{kg}$
Peak Power ($W \cdot kg^{-1}$)	$= \frac{P}{kg}$

Appendix K: Data Means and Standard Deviations

Table K1

Countermovement Jump Performance Outcomes Between Group and Taping Condition

Performance variable	Recreationally active		Competitive volleyball	
	NT	KT	NT	KT
Jump height (cm)	27.9 ± 5.8	28.3 ± 5.8	31.4 ± 3.7	31.6 ± 3.8
RSI (ratio)	0.29 ± 0.10	0.28 ± 0.09	0.29 ± 0.06	0.30 ± 0.06

Note. There were no significant interaction or main group and taping effects in the performance measures.

Table K2

Countermovement Jump Kinetic Outcomes Between Group and Taping Condition

Kinetic variable	Recreationally active		Competitive volleyball	
	NT	KT	NT	KT
Braking RFD ($N \cdot s^{-1} \cdot kg^{-1}$)	50.3 ± 40.96	51.0 ± 39.9	60.3 ± 32.2	53.6 ± 23.5
vGRF at zero velocity ($N \cdot kg^{-1}$)	18.6 ± 3.6	18.6 ± 3.5	19.7 ± 3.0	19.3 ± 2.8
Peak power ($W \cdot kg^{-1}$)	42.6 ± 6.6	42.7 ± 6.4	48.2 ± 3.2	48.6 ± 3.2

Note. A significant main effect of group was found in peak power. Group means and standard deviations regardless of taping condition were as follows: Recreationally active (M = 42.62 $W \cdot kg^{-1}$, SD = 6.54); Competitive Volleyball (M = 48.42 $W \cdot kg^{-1}$, SD = 3.24). There were no significant interaction or main group and taping effects in the remaining kinetic measures.

Table K3

Countermovement Jump Kinematic Outcomes Between Group and Taping Condition

Kinematic variable	Recreationally active		Competitive volleyball	
	NT	KT	NT	KT
Peak unweighting velocity ($m \cdot s^{-1}$)	-0.87 ± 0.16	-0.87 ± 0.20	-0.98 ± 0.31	-0.94 ± 0.32
Countermovement depth (cm)	-28.1 ± 7.0	-28.1 ± 6.5	-24.9 ± 5.7	-24.5 ± 5.4

Note. There were no significant interaction or main group and taping effects in the kinematic measures.

Table K4

Countermovement Jump Temporal Outcomes Between Group and Taping Condition

Temporal variable	Recreationally active		Competitive volleyball	
	NT	KT	NT	KT
Total time (s)	1.04 ± 0.22	1.05 ± 0.21	1.13 ± 0.21	1.07 ± 0.19
Unweighting time (s)	0.47 ± 0.14	0.48 ± 0.14	0.61 ± 0.21	*0.56 ± 0.18
Braking time (s)	0.25 ± 0.09	0.25 ± 0.10	0.24 ± 0.17	0.23 ± 0.18
Propulsion time (s)	0.31 ± 0.08	0.31 ± 0.08	0.28 ± 0.06	0.28 ± 0.05

Note. A significant interaction effect occurred in unweighting time, with significant decreases occurring with KT in the competitive volleyball group (*). There were no significant interaction or main group and taping effects in the remaining temporal measures.