COMPARISON OF LOWER LEG MORPHOLOGY AND STRETCH-SHORTENING CYCLE CAPABILITIES BETWEEN DANCERS AND VOLLEYBALL PLAYERS

A Thesis
by
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Abstract

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The stretch-shortening (SSC) cycle is the active storing elastic strain energy during the lengthening of the muscle-tendon unit that is subsequently utilized during the active shortening of the muscle-tendon unit known as elastic recoil. Athletes that habitually perform SSC actions, such as dancers and volleyball players, might possess preferable lower leg morphology, maximal strength and ballistic abilities that optimize performance. However, no known research has compared these physiological and biomechanical characteristic to SSC performance between aesthetic athletes and sport athletes. Healthy female dancers (n = 10; age = 19.7 ± 1.3 yrs; height = 163.9 ± 6.6 cm; body mass = 62.0 ± 10.3 kg), volleyball players (n = 10; age = 20.1 ± 1.5 yrs; height = 168.9 ± 4.5 cm; body mass = 63.0 ± 10.3 kg) and untrained individuals (n = 10; age = 19.5 ± 1.1 yrs; height = 166.0 ± 6.8 cm; body mass = 69.6 ± 14.5 kg) were recruited for this study. Subjects underwent a right and left lower leg scan using peripheral quantitative computed tomography (pQCT). Electromyography electrodes placed on both right and left medial gastrocnemii (MG) to record muscle pre-activity. Musculo-articular stiffness of the ankle complex was next measured using a free-oscillation technique.

Subjects then performed three maximal voluntary isometric plantarflexions (MVIP) on a custom-made inclined sled equipped with dual force plates at 20˚ for peak force measurements relative to body mass. Subjects lastly performed three countermovement hops (CMH) and three drop hops (DH) at 20cm (DH20), 30cm (DH30) and 40cm (DH40) on the sled. Dancers had significantly ($p \leq 0.05$) larger relative right and left lower leg muscle CSA and MVIP values in comparison to untrained controls. Dancers also had significantly greater relative concentric peak force, relative concentric peak power and hopped significantly higher than untrained controls during the CMH. Relative concentric impulse and hop height were significantly higher in dancers than untrained controls during all DH conditions. Pre-activity was significantly greater in the left MG of untrained controls when compared to dancers in all DH conditions. Volleyball players hopped significantly higher during all DH conditions when compared to untrained controls. Volleyball players also had significantly greater relative concentric impulse and relative concentric peak power than controls during DH30 and DH40. Untrained controls had significantly greater pre-activity of the left MG than did volleyball players during DH30. A significant relationship was observed between right and left lower leg muscle CSA with relative MVIP values. Significant relationships also existed between all hop heights with relative concentric peak force, impulse and peak power. This investigation provides evidence that dance may be a stimulus for muscular adaptations, relative strength levels and enhanced SSC capabilities. Training background also appears to positively influence DH performance in volleyball players. Further exploration of training in both these populations might aid to clarify muscle-tendon interaction and performance characteristics during SSC movements.

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Introduction

The multi-faceted components that comprise athleticism vary greatly across sports (Harries, Lubans, & Callister, 2012; Hrysomallis, 2011; Koutedakis, Owolabi, & Apostolos, 2008; Ziv & Lidor, 2010). However, biomechanical and physiological variables that determine elite performance are typically comparable between ballistic athletes (Lidor & Ziv, 2010; Rodrigues-Krause, Krause, & Reischak-Oliveira, 2015; Stojanovic, Ristic, McMaster, & Milanovic, 2016). Specifically, the stretch-shortening cycle (SSC) is a well-developed mechanism in trained, ballistic athletes (Kyrolainen & Komi, 1995). The stretch-shortening cycle (SSC) is characterized by the lengthening of the muscle-tendon unit during eccentric movement, which stores elastic energy that is utilized during immediate, succeeding concentric movement (Rice, et al., 2016). Muscle cross-sectional area (CSA), muscle strength, muscle activity, and musculo-articular stiffness of the medial gastrocnemius (MG) and Achilles' tendon each contribute to lower leg SSC performance (Bojsen-Moller, Magnusson, Rasmussen, Kjaer, & Aagaard, 2005; Butler & Dominy, 2015; Earp, Newton, Cormie, & Blazevich, 2014; Kubo et al., 2007; Nagano, Komura, & Fukashiro, 2004). Another aspect of interest when assessing and quantifying SSC capabilities is training background. When comparing different SSC athletes, it is vital that the modality and intensity of ballistic activity be considered (Fehling, Alekel, Clasey, Rector, & Stillman, 1995; Newton, Kraemer, & Hakkinen, 1999). For instance, the nature of dance choreography contrasts the reactive aspect of most team sports, such as volleyball (Wyon, Harris, Brown, & Clark, 2013). Furthermore, dancers are expected to achieve maximal height for every leap performed

(Wyon et al., 2013). Volleyball athletes, on the other hand, tailor each jump in response to the current play (Sheppard, Gabbett, & Stanganelli, 2009). While exhaustive research has been conducted on the SSC capabilities of many athletes, paucity in the literature remains on comparing jumping athletes that differ in technique and execution. This study aimed to determine the influence of different training backgrounds on muscle and tendon characteristics and SSC capabilities.

Past findings have established a strong relationship to occur between training and greater muscle CSA (Hakkinen et al., 1998; Hakkinen & Keskinen, 1989; Jakobsen et al., 2012; Stenroth et al., 2016; Widrick, Stelzer, Shoepe, & Garner, 2002). Additionally, muscle CSA has indicated to be directly proportional to maximal strength and jump height (Jakobsen et al., 2012). One can infer that an individuals with greater force generating capabilities would then also possess a larger muscle CSA (Komi, 1984). This has been speculated upon in various resistance training studies within a review by Wernbom and colleagues (Wernbom, Augustsson, & Thomee, 2007). An array of methods exists to measure muscle CSA such as limb circumference/skinfolds, CT scanning, MRI, and ultrasound (Jones, Bishop, Woods, & Green, 2008; Stenroth et al., 2016). A newer method, termed as the peripheral quantitative computed tomography (pQCT) scan, allows for the distinct measurement of volumetric density, as well as cross-sectional area of a peripheral body region without the imposition of other tissues overlaying it (Erlandson, Lorbergs, Mathur, & Cheung, 2016). To the best of our knowledge, no literature has utilized the pQCT when comparing medial gastrocnemius CSA of female athletes with untrained individuals.

Peak muscle force is a well-investigated variable, which has been utilized to quantify and predict performance (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Rice et al., 2016). High caliber athletes have been known to possess greater muscle strength than that of their untrained counterparts (Rabita, Couturier, & Lambertz, 2008; Stenroth et al., 2016). Various factors develop force generation capabilities such as training modality and muscle activity. Plyometric training, including sprinting, has shown to significantly increase maximal voluntary isometric contractions (MVIC) in comparison to endurance training (Grosset, Piscione, Lambertz, & Perot, 2009). Athletes frequently use SSC training parameters to maximize power and force output (Sheppard, Newton, & McGuigan, 2007). Evidence has also supported the concept that motor unit recruitment and maximal firing rate increase with dynamic strength training (Van Cutsem, Duchateau, & Hainaut, 1998). Past findings that have investigated the recruitment and firing nature of motor units have confirmed that ballistic contractions produce greater peak force than that of slow ramp contractions (Desmedt & Godaux, 1977). Therefore, rudimentary, biomechanical principles serve as a basis for the aforementioned concepts when considering force determinants of contractile properties (Close, 1972; Komi, 1984). According to the size principle, it might be assumed that jumping athletes would have a greater amount of muscle activity due to greater activation of motor units and occurrence of cross-bridge cycling (Andreassen & Arendt-Nielsen, 1987).

Higher maximal voluntary isometric contractions have also been shown correlate with greater muscle activity (Harley et al., 2002). By observing neuromuscular activity, we may be better equipped to understand the recruitment patterns of isolated muscles. Muscle activity, detected by EMG electrodes, is initiated within the motor cortex, which sends an electrical impulse down the spinal cord. The spinal cord then innervates individual muscle fibers via motor units. Muscle fibers cause a cascade of mechanical and chemical events to occur, which result in tetanic force, or muscle contraction. The term neural plasticity is used to articulate the trainability of motor unit innervation and nervous system sensitivity (Aagaard, 2003). Contractile rate of force development has shown to increase with strength training when recorded with EMG (Aagaard et al., 2002). This is due to not only greater motor neuron excitability, but also decreased neural inhibition (Aagaard, 2003). Arampatzts, Bruggemann, & Klapsing (2001) established drop jump mechanical power to be optimized by the level, rather than the duration, of muscle pre-activity (Arampatzis et al., 2001). This corroborates previous findings that reported greater pre-activity muscle activity to significantly influence greater DJ and countermovement performance (McBride, McCaulley, & Cormie, 2008). Moritani and colleagues found that muscle pre-activity was significantly greater in the MG than the soleus during maximal jumping (Moritani, Oddsson, & Thorstensson, 1991). Therefore, the current study chose to assess pre-activity of the MG. It is evident that neuromuscular activation greatly influences athletic performance, but the concrete mechanisms of dynamic performance in different athletes remain unknown.

When comparing power and endurance athletes, drop jump performance has resulted to be greater in power athletes due to quicker muscle pre-activity development, along with higher musculotendinous stiffness (Kyrolainen & Komi, 1995). The relationship between muscle and tendon interaction during dynamic activity is difficult to quantify in vivo, however, and remains ambiguous when establishing optimal stiffness and muscle activity levels (Arampatzis et al., 2001; Kubo et al., 2000; Taube, Leukel, & Gollhofer, 2012; Wilson, Wood, & Elliott, 1991). There is much debate on whether SSC capability is maximized by stiffer or more compliant muscle and tendon structures (Walshe & Wilson, 1997; Wilson, Murphy, & Pryor, 1994; Wilson et al., 1991). The plastic nature of muscle has been observed to modulate stiffness within the series elastic component (SEC) (Dyhre-Poulsen, Simonsen, & Voigt, 1991). The SEC of muscle, for clarification purposes, is located between actin and myosin filaments within cross-bridges (Komi, 1984). For this investigation, SEC stiffness will be synonymous with muscle stiffness. In preparation for impact, an observed decrease in stiffness has been suggested to optimize spring-like properties of muscle (Dyhre-Poulsen et al., 1991). This is concurrent with another study analyzing the bench press that determined optimal SEC stiffness to be more compliant (Wilson et al., 1991). When strictly examining tendon qualities, a stiffer Achilles' tendon is reported to elicit greater jump height (Kubo et al., 2007). Tendon properties are only able to reach fullest potential when proportional to the force generating capacity of the contractile component (CC) (Fukunaga, Kawakami, Kubo, & Kanehisa, 2002).

The vast majority of SSC research has demonstrated an isometric CC length to be most beneficial metabolically and mechanically (Fukunaga et al., 2002). Hopping training also causes the CC to operate at shorter lengths, while tendon forces have shown to increase (Hoffren-Mikkola, Ishikawa, Rantalainen, Avela, & Komi, 2015). Less work from the CC during SSC exercise has been observed as an adaptation of the tendon's trained ability to store more elastic strain energy and return in elastic recoil (Alexander, 2002). While metabolic energy is required for force development in the working muscles, metabolic efficiency is higher with greater tendon excursion (Alexander, 2002; Ettema, 1996). Tendons dissipate only 7% of energy as heat while approximately 93% is returned from the previous stretching into the shortening as elastic recoil (Alexander, 2002). Kurokawa, Fukunaga, & Fukashiro (2001) found that tendinous structures possess a peak shortening velocity 2.6 times as high as that of fascicles, indicating the tendon's exceptional ability to store mechanical energy given that energy dissipates as heat if recoil is prolonged (Kurokawa, et al., 2001). By modeling the triceps-surae complex as a spring, greater musculo-articular stiffness might serve as an advantage to dynamic performance (Pruyn, Watsford, & Murphy, 2014). It should be acknowledged that different methodologies and calculations may influence varying stiffness results in the literature (Hobara, Inoue, Kobayashi, & Ogata, 2014). The present study measured musculo-articular stiffness using a commonly used free oscillation method (Dumke, Pfaffenroth, McBride, & McCauley, 2010; Walshe, Wilson, & Murphy, 1996).

In order to properly assess SSC capabilities, researchers have analyzed biomechanical variables of several athletic movements. Multiple studies have used the countermovement jump in particular to analyze jumping ability, muscle-tendon stiffness, muscle activity, storage and utilization of elastic energy, the influence of potentiation, and the effect of different stretching conditions (Aboodarda et al., 2014; Arabatzi, Kellis, & Saez-Saez De Villarreal, 2010; Behm, Blazevich, Kay, & McHugh, 2016; Bobbert, 2001; Bobbert, Huijing, & van Ingen Schenau, 1987; Driss, Lambertz, Rouis, Jaafar, & Vandewalle, 2015; Harley et al., 2002; Kim, 2013; Kubo, Kawakami, & Fukunaga, 1999; McCurdy et al., 2010; Morrin & Redding, 2013; Stafilidis & Tilp, 2015; Taube et al., 2012; Walshe, Wilson, & Ettema, 1998). The SSC facilitates optimal execution of explosive movements and thus translates into greater performance. The most reliable predictor of jump height, however, has been determined to be relative vertical impulse during the propulsive, or concentric, phase (Kirby, McBride, Haines, & Dayne, 2011). Already touched upon, kinetic and kinematic measurements such as peak force, peak power, and vertical jump height have all been reported to increase with plyometric- and resistance- training (Arabatzi et al., 2010; Brown, Wells, Schade, Smith, & Fehling, 2007; Grosset et al., 2009; Malisoux, Francaux, Nielens, & Theisen, 2006).

Neural input is a component of augmented SSC performance. Nervous system adaptations occur through increased muscle spindle sensitivity, enhanced afferent feedback, and greater motor unit recruitment (Bergmann, Kramer, & Gruber, 2013; Taube et al., 2012). However, a substantial gap in the literature persists in regards to countermovement hopping. Like jumping, countermovement hopping should also reflect SSC capabilities and neural capabilities, but little research supports this claim. When hopping performance is maximal, the MG CC is significantly shorter in vivo (Lidstone et al., 2016). This means that the quasi-isometric nature of the CC during hopping should allow for the tendon to maximally store elastic strain energy (Fukunaga et al., 2002). Furthermore, a lengthened tendon during SSC activity should match greater return of elastic energy and result in greater force production (Kurokawa et al., 2001). The novelty of this study lies in the investigating of countermovement hops between different SSC athletes and untrained individuals. Although countermovement hopping literature is limited, a sizable amount of research has been conducted on drop hop performance.

When honing SSC skills, athletes commonly practice DJ's and drop hops in efforts to develop explosive performance (Malisoux et al., 2006). By restricting knee joint movement, contribution from the isolated ankle joint can be easily identified during hopping tasks. Drop hops might be indicative of an individual's ability to utilize stored elastic energy from different heights. Based on past findings, greater pre-activation and tendinous lengthening occurs at increased dropping heights (Ishikawa & Komi, 2004). A goal of the current study is to compare the SSC capabilities between athletes that vary in modality and intensity of ballistic training. By implementing different hopping tasks, the muscle and tendon characteristics assessed should be reflected by performance execution.

Theoretically, the influence of training background on muscle and tendon characteristics should be the greatest factor in the hypothesized differences. Although muscular strength has been recognized as advantageous to dance performance (Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005), our laboratory remains the only one to quantify plantarflexion strength between dancers and untrained individuals while volleyball players are not reported on in the literature. This investigation will also be the first to measure MG CSA with the pQCT. While jump height is an imperative element in dance, the aesthetic component results in a stylistic approach during SSC actions (Harley et al., 2002; McEldowney, Hopper, Etlin-Stein, & Redding, 2013). It has been suggested that lower CMJ height in dancers is interrelated with this concept (Harley et al., 2002). Dancers have shown significantly higher leg spring stiffness than that of basketball players during DJ performance, but no comparisons exist with volleyball players (Ambegaonkar et al., 2011). The aforementioned study alluded to the possibility that dancers possess higher ankle stiffness, which has been proposed to regulate leg stiffness more than knee stiffness (Farley & Morgenroth, 1999). It may be that the structure of particular explosive measurements, like the CMJ, also differs from most unilateral, dance SSC movements. However, limited knowledge exists on the hopping abilities of dancers in addition to a multitude of other biomechanical properties. Paucity in the literature also remains pertaining to hopping ability in female volleyball players.

Although various studies have been conducted on volleyball players, male athletes primarily dominate the literature. Furthermore, the studies that have analyzed volleyball players have mainly focused on sport-specific training parameters (Sheppard et al., 2007; Sheppard et al., 2009). Jumping is the highest trained movement pattern in volleyball (Ziv & Lidor, 2010). Conclusively, volleyball players have demonstrated higher jumping performance than have other athletes (Copic, Dopsaj, Ivanovic, Nesic, & Jaric, 2014; Jaric, Ugarkovic, & Kukolj, 2001). No known data has been collected on the muscle CSA, muscle activity, musculo-articular stiffness, or hopping performance of female volleyball players. Therefore, this investigation sought to bridge this gap.

The purpose of this study was to compare muscle CSA, muscle force, neuromuscular activity, musculo-articular stiffness and SSC capabilities during hopping tasks between female dancers, volleyball players, and untrained controls. The first hypothesis was that female dancers and volleyball players would have the similar relative CSA of the medial gastrocnemius and relative maximal voluntary isometric plantarflexion (MVIP) peak force to one another but larger when compared to untrained controls. The second hypothesis was that female dancers and volleyball players would have similar musculo-articular stiffness values but greater than untrained controls. The third hypothesis was that muscle pre-activity and SSC performance variables in all hopping conditions would be similar in dancers and volleyball players but greater than untrained controls.

Methods

Study Design

All subjects for the current study were females between the ages of 18-25. Dancers (*n*=10) and volleyball players (*n*=10) were required to have an eight- to ten-year minimum of dance or volleyball training and currently be training at a minimum of three times per week to ensure sufficient background. Untrained controls (*n*=10) could not have any endurance, strength training, volleyball or dance background, nor be involved in any organized sports or physical activity. All participants were healthy with no musculoskeletal injury, neuromuscular disease, lower limb injury within the past 6 months, or currently pregnant. The Appalachian State University Institutional Review Board approved this study prior to commencing date collection. Data collection consisted of one testing session for each subject, lasting no more than 75 minutes. Upon arrival, the subject signed an informed consent form and completed the ACSM health-screening questionnaire. The subject's height, weight, and lower leg anthropometrics were then measured. Subjects next underwent a series of muscle and tendon architectural measurements, a strength test, and hopping tasks. Participants received instructions that they should: 1) wear appropriate exercise clothes and shoes for testing; 2) be well nourished and hydrated prior to testing; 3) avoid alcohol within 12 hours of testing and caffeine and tobacco within three hours of testing; and 4) be rested and avoid significant exertion or exercise the day of testing.

Anthropometrics

Lower leg anthropometric measurements were taken from the right leg with an anthropometer (Lafayette Instrument Company, 01291, Lafayette, Indiana, USA). Lower leg length was defined as and measured from the lateral condyle to the lateral malleolus of the fibula. Achilles tendon to medial malleolus (AT-MM) length and Achilles tendon to lateral malleolus (AT-LM) length were then recorded. Subjects placed the right foot on a block with the shank directly over the ankle. Medial and lateral pictures were taken of the right foot 112 cm from the block with a Cannon camcorder (VIXIA HF G20, Melville, NY, USA). All of these measurements, in accordance with previously published methods (Pohl & Farr, 2010), were used exclusively for calculation of musculo-articular stiffness with a custom MATLab program (MathWorks, Natick, MA, USA) (Fukashiro, Noda, & Shibayama, 2001).

Muscle Volumetric Density and Cross-Sectional Area Measures

The peripheral quantitative computed tomography (pQCT) (Stratec Medizintechnik, Pforzheim, Germany) scans an area of a peripheral body region to measure volumetric density, as well as cross-sectional area (CSA) without the imposition of other tissues overlaying it. The subject placed the right lower leg into the device and sat motionless for 8-12 minutes while the scan was performed. Subjects repeated the same protocol with the left lower leg. Both scans started at the lateral malleolus and scanned at four different places as it moved upward towards the knee. The pQCT scanned at 4%, 14%, 38% and 66% of the tibia, with 0% representing the lateral malleolus. Medial gastrocnemius (MG) CSA was obtained at 66% of both legs and normalized to the total area (girth of the leg) given by the pQCT. The obtained value was used for comparison between groups.

Muscle Activity and Musculo-articular Stiffness

Wireless Delsys™ electromyography (EMG) sensors were then placed on the MG of both legs to measure electrical activity of the muscles (Delsys Trigno Wireless System, Natick, Massachusetts, USA). EMG electrodes (27x37x15 mm dimension with 4, 5x1mm contact points; gain = 909, bandwidth frequency = 20-450 Hz, common mode rejection ratio > 80 dB; 1000 samples/s) were attached to the skin over the muscle belly using Delsys™ adhesive sensor interfaces. Subjects wore EMG electrodes for the duration of testing from here. Active muscle and passive tendon stiffness was measured using a free-oscillation method according to previously validated methods (Fukashiro et al., 2001). The subjects sat on a bench with the forefeet resting on a wooden atop a force plate (Grainger, Lake Forest, IL, USA), while maintaining an ankle and knee angle of 90 degrees with an oscillating device resting on the thighs just proximal to the knee. Loads from 0-40 kg were added to oscillating device. One-minute rest periods were provided between increasing loads, with nine total trials completed. For each load, four slight perturbations were made to the oscillation device. The perturbations consisted of a medicine ball being dropped from an approximate height of 10-20 cm. Data was collected using a custom-designed LabVIEW (National Instruments, Version 8.2, Austin, Texas, USA) program with a sampling rate of 1000 Hz. Analog signals were converted from the force plate to digital signals (NI cDAQ-9172, National Instruments, Austin, TX, USA). Muscle activity was monitored for consistency throughout the free-oscillation method to ensure no large changes in muscle activity occurred. Musculo-articular stiffness was calculated using force plate oscillatory data using a custom-designed MATLab R2015b (MathWorks, Natick, MA, USA) program with previous equations from Rice et al. (2016) obtained from Fukashiro and colleagues (Fukashiro et al., 2001). Apparent stiffness (K) measures were converted to k values and used for comparison between groups.

Maximal Voluntary Isometric Plantarflexion

Maximal voluntary isometric plantarflexion (MVIP) force was measured following stiffness measurements. A custom-made sled at an inclination of 20˚ with dual force plates (Bertec, Columbus, OH, USA) was used for MVIP and hopping measurements. Subjects laid flat on the sled with a pad behind the knees and a strap just above the patella, which restricted joint movement. The purpose of this was to isolate the ankle joint for movement. Subjects were instructed to maintain rigidity and generate force at the ankle joint over a five second duration while maintaining each foot on a force plate. Subjects were all instructed to perform with maximal effort and encouraged verbally. Two-minute rest periods were provided between trials, with three trials completed. Subjects' trial with the highest peak force was used for further analysis. Peak force was defined as the maximal amount of force achieved during the MVIP. EMG readings from the right and left medial gastrocnemius were obtained during the MVIP. Raw EMG data was full-wave rectified, integrated, and averaged during the MVIP for later normalization of muscle activity during hopping.

Countermovement and Drop Hops

Lastly, subjects performed a series of hops, remaining in the same experimental set-up on the custom-sled. All subjects were instructed to rise onto the toes, hold for three seconds as an investigator counted and lastly flex the ankles rapidly to generate force into a countermovement hop. Subjects performed countermovement hops (CMH), using the ankle joint only to generate force. Two-minute rest periods were provided between trials, with three trials completed. The subjects then performed drop hops at three different heights from the custom-designed sled at 20cm (DH20), 30cm (DH30), and 40cm (DH40). Subjects were raised to each respective height by an investigator while another investigator then counted down, indicating when to release the sled. Two-minute rest periods were provided between trials, with three trials completed at each height. All subjects were familiarized with the hopping protocol and allotted a practice hop for each condition prior to actual data collection. Subjects' hop with the highest height was used for further analysis from each hopping condition. A potentiometer (Celesco, Chatsworth, CA, USA) attached to the top of the custom-made sled calculated displacement and provided hopping height measurements. The concentric phase was defined as starting at the beginning of the upward slope of the displacement-time curve from the maximal depth till the force-time curve reached 0 Newtons provided by the potentiometer and sum of both force plates (Bertec, Columbus, OH, USA) respectively. Peak force was determined as the maximal amount of force during the concentric phase and expressed relative to body mass. Impulse was defined as the product of force and time from the concentric phase and expressed relative to body mass. Forward dynamics were used to obtain a velocity-time curve. Power was obtained from the product of force and velocity. Peak power was determined as the maximal power transferred during the concentric phase and expressed relative to body mass. All values were then used for comparison. Pre-activity of both the left and right medial gastrocnemius were obtained from EMG readings of all drop hops selected for further analysis. The 100 ms prior to foot contact with force plates were defined as pre-activity (McBride et al., 2008). Values obtained were normalized to average iEMG values recorded from MVIP.

Statistical Analysis

SPSS version 12.0 (SPSS Inc., Chicago, IL, USA will be used to perform all statistical analyses where statistical significance was defined at an a priori value of $p \leq 0.05$. A multivariate analysis of variance was used to compare dancers, volleyball athletes, and sedentary subjects. A Bonferroni post hoc correction was used to determine differences in the variables between groups. The Pearson product correlation was used to determine relationships between the different variables investigated across all subjects.

The following scaling was utilized to determine strength of established correlations: trivial (0.0-0.1), weak (0.1-0.3), moderate (0.3-0.5), strong (0.5-0.7), very strong (0.7-0.9), or perfect (0.9-1.0).

Results

Collegiate dancers (*n*=10; age=19.7 ± 1.3 yrs; height=163.9 ± 6.6 cm; body mass=62.0 ± 10.3 kg), club volleyball players (*n*=10; age=20.1 ± 1.5 yrs; height=168.9 ± 4.5 cm; body mass=71.1 ± 10.6 kg), and untrained controls (*n*=10; age=19.5 ± 1.1 yrs; height=166.0 ± 6.8 cm; body mass=69.6 ± 14.5 kg) were tested for the current study. No significant ($p \leq 0.05$) differences existed between any groups for any of the anthropometric measures obtained. Dancers had significantly more years of background experience when compared to the Volleyball Players (D=17.0 ± 1.2 yrs; V: 10.0 ± 1.0 yrs). Dancers had significantly greater MG CSA relative to leg girth than untrained controls as shown in Table 1. Dancers also achieved significantly greater MVIP peak force relative to body mass than did controls (Table 1). Relative right and left MG CSA were significantly correlated (r = .62, r = .61) to relative MVIP peak force (Table 1).

Table 1

Relative Right (R) and Left (L) Medial Gastrocnemius (MG) Cross-Sectional Area (CSA) and Relative Maximal Voluntary Isometric Plantarflexion (MVIP) Peak Force (PF) (M ± SD)

Group	**R MG CSA (%)^**	**L MG CSA (%)^**	**Relative MVIP PF (N/Kg)**
Controls	0.61 ± 0.1	0.62 ± 0.1	20.5 ± 5.1
Dancers	0.69 ± 0.1*	0.68 ± 0.1*	27.7 ± 5.7*
Volleyball Players	0.65 ± 0.1	0.65 ± 0.1	26.1 ± 7.9

* Significantly greater ($p \leq 0.05$) than Controls.

^ Denotes a significant relationship ($p \leq 0.05$) with relative MVIP PF.

No significant differences existed between any groups for muscle stiffness (*k*m) or tendon stiffness (*k*t) presented in Table 2.

Table 2

Musculo-Articular Stiffness (M ± SD)

Group	***k*m (Nm^{-1}) N^{-1}**	***k*t (kN•m^{-1})**
Controls (*n*=7)	486.7 ± 235.1	342.5 ± 132.0
Dancers (*n*=7)	437.2 ± 57.0	449.3 ± 167.4
Volleyball Players (*n*=7)	535.2 ± 170.1	502.9 ± 144.9

Note. *k*m = Muscle stiffness; *k*t = tendon stiffness.

Dancers hopped significantly higher in comparison to controls in all hopping conditions (Figure 1). Volleyball players hopped significantly higher than controls in all drop hop conditions (Figure 1).

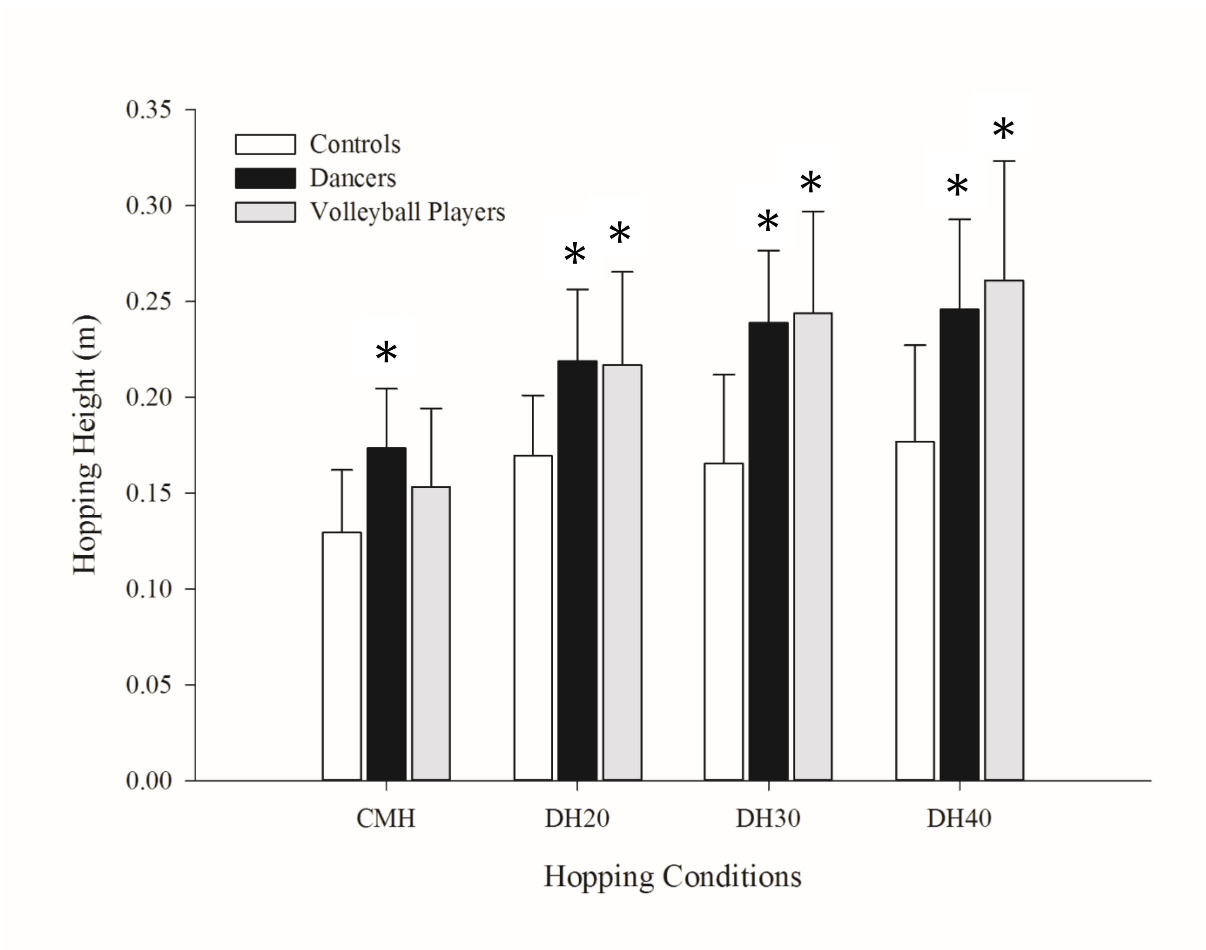

Figure 1. Conditional hopping heights between groups.
* Significantly greater ($p \leq 0.05$) than Controls.

Dancers had significantly higher relative concentric peak force and peak power than controls during the CMH (Table 3). Dancers also had significantly greater relative concentric impulse than controls during all drop hop conditions (Table 3). Volleyball players had significantly greater relative concentric impulse and relative peak power in comparison to controls during DH30 and DH40 shown in Table 3 as well. Controls had significantly greater pre-activity of the left MG than dancers of all drop hop conditions (Table 3). Controls also had significantly greater pre-activity of the left medial gastrocnemius compared to volleyball players during DH30.

Table 3

Biomechanical and Neuromuscular Variables Analyzed During Hopping (M ± SD)

Hop Type	Group	Rel Conc PF (N)	Rel Conc Imp (m/s)	Rel Conc PP (W)	R MG Pre-act. (mV)	L MG Pre-act. (mV)
CMH	Controls	12.9 ± 2.3	2.0 ± 0.2	7.0 ± 2.4	--	--
	Dancers	17.2 ± 2.8*	2.3 ± 0.3	10.7 ± 2.5*	--	--
	Volleyball Players	15.2 ± 2.7	2.1 ± 0.2	8.8 ± 3.1	--	--
DH20	Controls	21.3 ± 4.5	2.1 ± 0.2	11.2 ± 3.8	0.52 ± 0.45	0.67 ± 0.36^{+}
	Dancers	21.5 ± 3.6	2.5 ± 0.3*	14.0 ± 3.4	0.22 ± 0.15	0.23 ± 0.10
	Volleyball Players	23.1 ± 4.9	2.2 ± 0.2	14.9 ± 5.0	0.32 ± 0.32	0.53 ± 0.44
DH30	Controls	22.9 ± 4.8	2.1 ± 0.3	11.2 ± 3.9	0.76 ± 0.60	0.94 ± 0.53$^{+\#}$
	Dancers	24.6 ± 4.8	2.5 ± 0.3*	16.1 ± 4.0	0.53 ± 0.19	0.35 ± 0.21
	Volleyball Players	27.0 ± 5.2	2.4 ± 0.3*	17.4 ± 5.9*	0.36 ± 0.23	0.53 ± 0.26
DH40	Controls	24.5 ± 5.3	2.1 ± 0.4	11.7 ± 4.3	0.60 ± 0.40	0.98 ± 0.52^{+}
	Dancers	28.5 ± 4.7	2.6 ± 0.3*	16.7 ± 4.5	0.32 ± 0.15	0.35 ± 0.26
	Volleyball Players	29.2 ± 5.9	2.5 ± 0.3*	19.3 ± 6.4*	0.46 ± 0.20	0.69 ± 0.44

Note. Rel Conc PF = Relative concentric peak force; Rel Conc Imp = Relative concentric impulse; Rel Conc PP = Relative concentric peak power; R MG Pre-act. = Right medial gastrocnemius pre-activity; L MG Pre-activity = Left medial gastrocnemius pre-activity.

* Significantly greater ($p \leq 0.05$) than Controls.

$^{+}$ Significantly greater ($p \leq 0.05$) than Dancers.

$^{\#}$ Significantly greater ($p \leq 0.05$) than Volleyball Players.

Correlations were significant between relative concentric peak force with CMH (r = .86), DH20 (r = .70), DH30 (r = .68) and DH40 (r = .63) heights (Figure 2.A-D). Significant correlations also existed between relative concentric impulse with CMH (r = .56), DH20 (r = .67), DH30 (r = .79) and DH40 (r = .81) heights (Figure 3.A-D).

Lastly, significant correlations existed between relative concentric peak power with CMH (r = .95), DH20 (r = .90), DH30 (r = .88) and DH40 height (r = .88) (Figure 4.A-D).

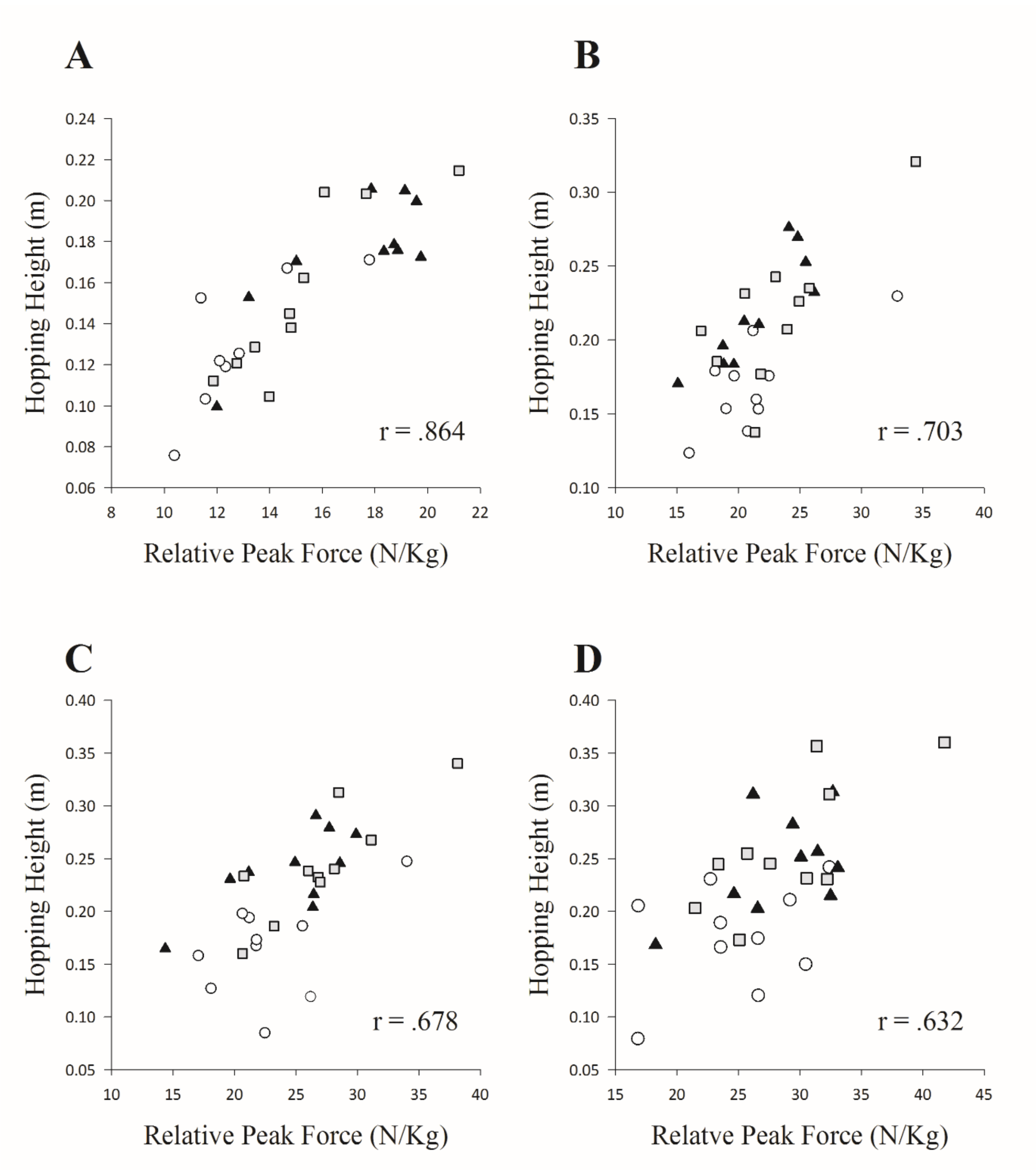

Figure 2. Significant relationships ($p \leq 0.05$) between hopping condition heights and relative concentric peak force. A) CMH; B) DH20; C) DH30; D) DH40. ○ = Controls; ▲ = Dancers; □ = Volleyball Players.

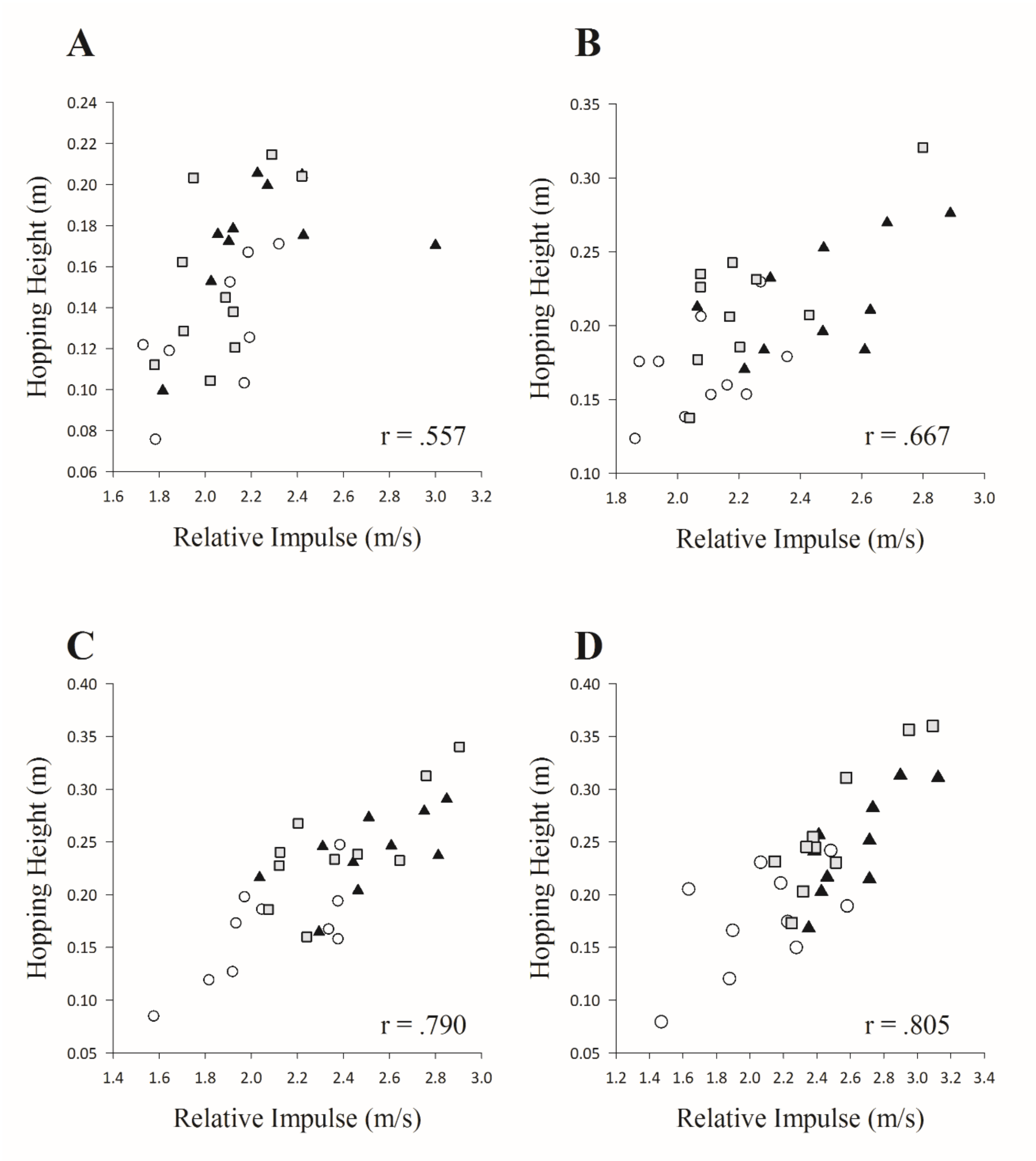

Figure 3. Significant relationships ($p \leq 0.05$) between hopping condition heights and relative concentric impulse. A) CMH; B) DH20; C) DH30; D) DH40. ○ = Controls; ▲ = Dancers; ▢ = Volleyball Players.

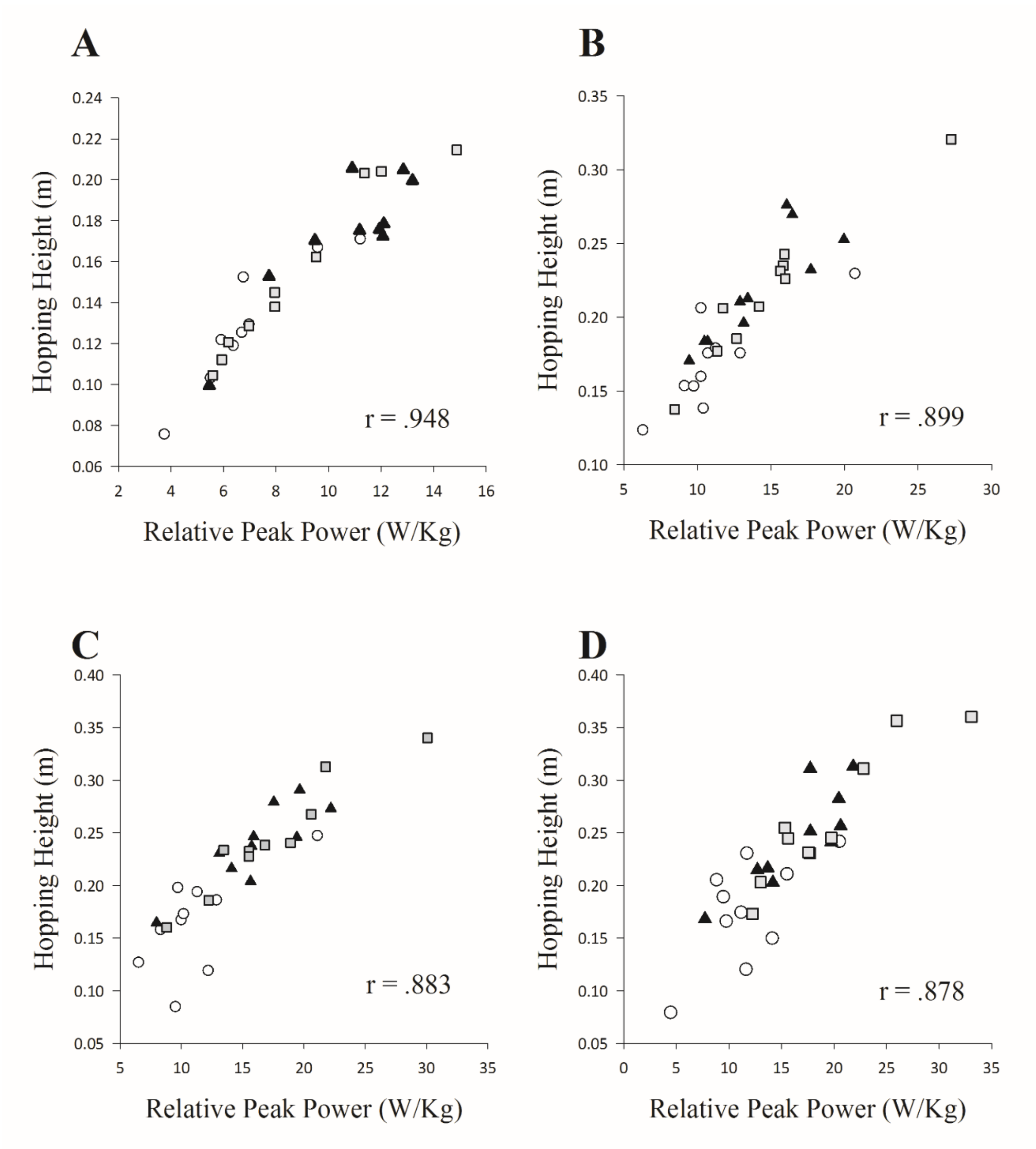

Figure 4. Significant relationships ($p \leq 0.05$) between hopping condition heights and relative concentric peak power. A) CMH; B) DH20; C) DH30; D) DH40. ○ = Controls; ▲ = Dancers; ▢ = Volleyball Players.

Discussion

The main findings of this investigation provide evidence that participation in dance and volleyball are similar stimuli for enhanced stretch-shortening cycle (SSC) performance in comparison to that of untrained individuals. Dance research has often remained in a more artistic and qualitative realm (Zajenkowski, Jankowski, & Kolata, 2015). An aim of the current study was to clarify discrepancies between different athletes that frequently use plyometric-training modalities but contrast one another in execution. Although dance and volleyball are quite dissimilar in performance, the stimulus due to participation in these activities appear to result in similar adaptations relating to SSC capabilities.

The muscle and tendon characteristics measured revealed that involvement in collegiate dance might result in larger relative medial gastrocnemius (MG) cross-sectional area (CSA) and maximal voluntary isometric plantarflexion (MVIP) peak force than untrained controls, which were significantly correlated to one another across all subjects. Intense, physical training involving high volumes of SSC action has resulted in reference to the dancer as a performing athlete (Koutedakis & Jamurtas, 2004; Liederbach et al., 2006). Muscle CSA has been universally associated with muscle force generation in athletic populations (Wernbom et al., 2007). The mechanisms by which muscle force production occur are extensively described by muscle contraction theories on the sarcomere-level, such as the cross-bridge theory with modern amendments (Herzog, Powers, Johnston, & Duvall, 2015). The interaction required between filamentous proteins actin and myosin to engage and produce force might involve the giant protein titin to regulate stiffness levels (Herzog, 2014). Recent evidence has suggested that mechanoreceptors located at the titin kinase domain detect contractile stress and cause an increase of ATP binding and autophosphorylation (Linke & Kruger, 2010). Although unresolved, it may be that this enzymatic activity results in muscle gene upregulation associated with hypertrophic responses (Lange et al., 2005). The importance of this concept relates back to the amount of both passive and active stretching the typical dancer experiences on a day-to-day basis (Wyon, Felton, & Galloway, 2009). Therefore, larger relative MG CSA may suggest well-trained patterns of muscle contraction and hypertrophy-induced training in response to dance (Aagaard et al., 2001). Future investigations might consider analyzing physiological muscle fiber CSA, which might better represent the number of available actin-myosin based cross-bridges for muscle contraction, recognized to be proportional to maximal force generation (Aagaard et al., 2001).

Our laboratory has previously established that dancers possess greater relative MVIP peak force than controls (Rice et al., 2016), and the yielded results of relative CSA from the current study warrant more profound investigation of MG characteristics, such as fiber type CSA and distribution. Although not measured in the current study, muscle fiber type has additionally been closely linked with strength levels (Wilson et al., 2012). A study by Dahlström and colleagues investigated fiber type of the vastus lateralis in dancers, finding that they are comparable to endurance athletes, dominated by a type I composition (Dahlstrom, Esbjornsson, Jansson, & Kaijser, 1987). An extraordinary proposal that eccentric exercise causes a shift of fast twitch muscle fibers to slow twitch muscle fibers via increased motor unit activation might explain the adaptation to such extreme sarcomeric lengthening experienced by dancers (Paschalis et al., 2012). However, different energy systems principally utilized are dependent upon the style of dance, and it has been proposed that some choreography results in reliance on glycolytic energy systems more than oxidative (Rodrigues-Krause et al., 2015). No data exists on fiber typing of the MG, which may differ given the greater ballistic focus of hopping, opposed to jumping, in most styles of dance. Contrasting to past findings, untrained controls had significantly greater pre-activity of the left MG only (Viitasalo, Salo, & Lahtinen, 1998). While electrode placement is a sensitive detail for muscle activity recordings, the observed significance may have been a protective mechanism due to increased afferent feedback for bracing during the DH conditions. Another possibility might be that dancers and volleyball players commonly use the left leg to jump or leap onto the right leg. A mechanism of metabolic conservation might therefore be adopted for greater efficiency during performance.

Previous researchers have found that semi-professional dancers did not achieve significantly higher countermovement jump heights than controls (Harley et al., 2002). Given the emphasis of hyper-plantarflexion and –dorsiflexion during most dance training, we proposed that stylistic adaptations might occur and influence SSC performance on a single-joint, rather than a multiple-joint, level (Russell, McEwan, Koutedakis, & Wyon, 2008). Our hypothesis that dancers would hop higher than controls was correct, and biomechanical variables analyzed supported performance as well. The greatest amount of exerted force (peak force), force generation over a period of time (impulse) and the product of the greatest force and velocity (peak power) serve as representations of athletic capabilities (Rice et al., 2016). Dancers achieved significantly greater relative peak force, concentric impulse and peak power during different hopping conditions than untrained controls. Relative impulse has been identified as the strongest predictor of jumping ability, which appeared to be consistently greater in dancers than controls during drop hop conditions (Kirby et al., 2011). The computation of relative concentric impulse, in fact, results in one's take-off velocity achieved with the following equation: $(F_{average}*\Delta t)/m = v_{final} - v_{initial}$, where $F_{average}$ is the average net force, Δt is the interval of time, m is the mass of the subject, v_{final} is the take-off velocity and $v_{initial}$ is the initial velocity (0 m/s) (Kirby et al., 2011). In SSC actions that involve flight time, take-off velocity may encompass one's ability to displace the center of mass maximally, which depends upon several of the aforementioned variables. Returning to the concept that greater efficiency is adopted during recurrent eccentric contraction exposure, optimal synchronization of motor units, tendon excursion, metabolic conservation and plantarflexion mechanics might support the SSC capabilities in the present investigation. Dance can thus be recognized as a stimulus for enhanced strength characteristics and dynamic performance of movements specific to hopping.

The data indicate that participation in club volleyball may serve as a stimulus for greater SSC performance than untrained controls as well. Interestingly, the untrained individuals and volleyball athletes did not differ significantly in relative MG CSA, muscle force generation, musculo-articular stiffness levels or CMH height. A Pearson correlation test revealed a near perfect relationship between body mass and total area of the lower leg at 66%. The absolute CSA means were higher in volleyball players, but we considered this negligible since the amount of muscle necessary to execute most athletic tasks requires the overcoming of whole body mass. The observed power for muscle and tendon (*k*t) stiffness were 0.131 and 0.376, respectively. Given the p-value for *k*t that was approaching significance, we propose that a larger sample size may have revealed greater musculo-articular stiffness levels in volleyball players. The modality of training and competing for volleyball players may suggest that lower hopping height conditions do not resemble sport-specific movements accurately (Coutts, 1982; Sheppard et al., 2008). In corroboration of this, kinematic measurements on volleyball and basketball players has shown greater flexion of the knees prior to performing a CMJ consequences greater vertical height (Gheller et al., 2015). The volleyball players did, however, achieve greater hop height during all DH conditions. At higher DH heights, volleyball players transferred significantly greater relative concentric peak power than did controls. Peak power is a fundamental constituent for elite jump performance in this population, which was demonstrated in the present work (Newton et al., 1999). Volleyball players are required to respond and sequence jumping movements to a wide variety of plays, which may necessitate power more than dance combinations due to the stringency of reaction-time (Sheppard et al., 2009). With such inconclusive results on certain measurements, it should be noted that the level of sport skill in this group was not homogeneous and player position was not inquired, which may have affected some of our outcomes. We acknowledge the small sample size as a limitation to the current investigation as well.

Lastly, the most intriguing aspect of the study is that dance and volleyball training serve as similar stimuli for enhanced SSC performance. The distinct movements authentic to dance create a challenge when seeking to compare frequently used performance patterns between dancers and sport athletes (Wyon et al., 2013). Therefore, the novel examination of ankle-specific SSC function in the present investigation allowed other contributing performance factors to be minimized or even eliminated. Although both athletic groups in the current study were only recreationally involved in their respective activities, we propose that implementation of a combined resistance- and plyometric-focused training program may influence performance characteristics to exceed that of their untrained counterparts to a greater degree (de Villarreal, Izquierdo, & Gonzalez-Badillo, 2011). Evidence has suggested that while plyometric training may benefit dynamic athletic performance, training at a load that maximizes mechanical power output most optimally enhances athletic tasks involved in many sports (Wilson, Newton, Murphy, & Humphries, 1993). The relationship between hopping height and relative concentric peak power was strongest across all trials in the current study. Therefore, employment of training protocols that may facilitate greater neural responses and transform movement synchronization might result in improved physiological and biomechanical variables with overall performance (Arabatzi et al., 2010; Kummel et al., 2016; Wilson et al., 2012). The benefits of supplementary training on both populations would potentially be manifold (Amorim et al., 2015; Stojanovic et al., 2016).

Conclusion

In conclusion, this investigation has shown that SSC capabilities about the ankle joint between different ballistic athletes and untrained individuals could be linked to associated physiological and biomechanical characteristics. The data indicate that involvement in dance might result in greater relative lower leg muscle CSA, muscle force, and stretch-shortening cycle performance than untrained individuals. Volleyball players did not possess quite as many differences in lower leg morphological characteristics as dancers did when compared with untrained controls. However, some aspects of greater SSC performance during drops hops was observed in volleyball players when compared to untrained controls. Further investigations might benefit from researching the muscle-tendon interaction and natural strategies utilized during sport-specific dynamic performance. Overall, dancers and volleyball players that are exposed to a high frequency of SSC actions have greater SSC capabilities, which may be reflective of their respective training backgrounds.

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Vita

Paige Elizabeth Rice was born in Burnsville, Minnesota. After graduating from Burnsville High School, Paige attended the University of Wisconsin-La Crosse and graduated as a double major with a B.S. in Exercise Sports Science and Spanish in 2014. Paige eventually went on to pursue her Masters of Science from Appalachian State University and graduated in May 2017. Paige plans to pursue a Ph.D. in Exercise Science with a focus on muscle-tendon function during stretch-shortening cycle movement at both the gross and molecular level. Paige's parents, Mary and Steve Rice, reside in Minnesota; and her sister, Hayley Rice, resides in Utah.