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# Relationships between Relative Strength, Power, and Speed among NCAA Division II Men's Lacrosse Athletes

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## Abstract

Lacrosse players are required to perform multiple sprints and changes of direction over the course of a game. These skills are reliant on the ability to rapidly produce lower-body force to be successful. Currently, little research examining the relationship between specific performance indicators and relative strength within this population exists. The purpose of this study was to investigate relationships between measures of lower-body strength and power to sprinting and change of direction speed (CODS) among male lacrosse players. Archived data for (n= 18) NCAA Division II male lacrosse athletes were used for this analysis. Lower-body strength was assessed using a one-repetition maximum back squat. Power was assessed using a countermovement jump (CMJ), squat jump (SJ), and standing long jump (SLJ). Sprint speed at 10 and 30 yds (i.e., 9.14 and 27.43 m) and CODS (i.e., T-Test (TT) and modified T-Test (MTT) were also assessed. Pearson's correlation was used to determine relationships between lower-body strength and power to sprint speed and CODS. Significant relationships ($r = -0.51$ - $-0.64$, $p \leq 0.05$) were discovered between all measures of power and CODS, as well as SLJ and sprint speed ($r = -0.51$; $p = 0.05$ and $-0.67$; $p \leq -0.01$, respectively). No significant relationships between relative strength and any measures of sprint speed or CODS were discovered. Although relative strength was not directly related to sprint speed or CODS performance, it may indirectly affect these measures based on its relationship to power, and power's relationship to sprint and CODS performance.

**Keywords:** Strength and conditioning, Performance optimization, Field sports, Maximum power, Linear speed, Agility

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## Introduction

Lacrosse is a sport characterized by intermittent high-intensity bouts of sprinting and rapid changes of direction (Calder, 2018). Previous research suggests these physical qualities are underpinned by both absolute lower-body strength and power, therefore, based on empirical and observational evidence it appears that in order to optimize performance in the game of lacrosse lower-body strength, power, and speed are essential (Collins et al., 2014; Delaney et al., 2015; Gutowski & Rosene, 2011; Kulakowski et al., 2020; Lockie et al., 2016; Miller, 2012; Sheppard et al., 2014; Styles et al., 2016). However, the relationships between these variables have not been fully explored within this sport.

Previous research has reported that linear sprint speed and change of direction speed (CODS) is related to the expression of absolute and relative lower-body strength and power among a variety of field and court-based athletes, such as soccer and volleyball (Andersen et al., 2018; Lockie et al., 2018; McFarland et al., 2016; Tramel et al., 2019). In fact, Andersen et al. (2018) found significant correlations between relative lower-body strength and power to linear and change of direction speed (CODS) among a group of Division II female soccer players. Similar findings have been reported by Lockie et al. (2018) and McFarland et al. (2016) in separate studies examining the relationships between components of linear speed, lower-body power, and CODS in diverse samples of collegiate soccer athletes (Lockie et al., 2018; McFarland et al., 2016). Both studies observed significant small-moderate relationships between lower-body power to linear and CODS ($r = -0.443$ to $-0.751$; $p < 0.05$, respectively). Additionally, Tramel et al. (2019) reported large, significant correlations between absolute and relative strength and measures of power as measured by a repeat jump test, as well as CODS as measured by the modified t-test (MTT) and 505-agility test (2019). Overall, these results indicate that regardless of sport, strength and conditioning professionals should emphasize the development of absolute and relative lower-body strength to improve measures of power, linear speed, and CODS in collegiate athletes.

While the relationships between lower-body strength and power to speed have been explored in other sports, few studies have investigated these correlations among lacrosse athletes. This is a notable observation due to the nature of the sport, the physical demands, and the qualities needed to excel (Collins et al., 2014; Delaney et al., 2015; Gutowski & Rosene, 2011; Kulakowski et al., 2020; Lockie et al., 2016; Miller, 2012; Sheppard et al., 2014; Sheppard & Young, 2006; Styles et al., 2016). A study conducted by Kulakowski et al. (2020) reported that measures of relative lower-body power (relative countermovement jump (CMJ) and squat jump (SJ)) were significantly related to linear speed and CODS in Division II female lacrosse athletes (Kulakowski et al., 2020). In addition to these findings the authors reported that only the CMJ ($r = -.506$, $p < 0.05$) and relative CMJ ($r = -.491$, $p = 0.05$) were related to 10m sprint speed. Standing long jump (SLJ) distance was significantly related to all CODS tests ($r = -.601$ - $-.684$, $p < 0.01$) and 30m speed ($r = -.528$, $p < 0.05$), while relative SLJ distance was significantly correlated with 5-0-5 speed ($r = -.642$, $p < 0.01$). Furthermore, the authors did not observe relationships between measures of absolute power and any sprint or CODS test ($r = -.101$ - $-.310$, $p > 0.05$). However, to the authors' knowledge, the relationships between lower-body strength and power measures to specific speed qualities has not been thoroughly addressed among male lacrosse players. This information may be of value when attempting to assess and improve upon athletic potential for athletes within this sport.

Additionally, previous research has suggested that individuals with greater relative strength produce greater external mechanical power during a vertical jump, jump higher, and sprint faster than those with less relative strength (Andersen et al., 2018; Kulakowski et al., 2020; McBride et al., 2009; Tramel et al., 2019). Based on previous research among female lacrosse players which has observed significant relationships between lower-body power and sprint and CODS ability, it would seem likely that relative strength and power may be essential for CODS performance ((Kulakowski et al., 2020; Sell et al., 2018; Tramel et al., 2019). To this end, research has revealed significant relationships between maximal lower-body strength, relative lower-body strength (RLBS), and CODS performance in elite-level female athletes (Polley et al., 2015; Sell et al., 2018; Suchomel et al., 2016). However, with respect to males, recent findings suggest that relationships between strength, power, and CODS performance are generally weak (McFarland et al., 2016).

Assessing relative strength rather than absolute strength of an individual is likely to be more important in certain sports, like lacrosse, where one must move their own body mass (e.g., sprinting, jumping, changing direction) (Sullivan & Feinn, 2012). Therefore, the purpose of this study was to determine if significant relationships exist between relative strength, lower-body power, linear speed, and CODS in Division II collegiate men's lacrosse athletes. This information could potentially be used by sports performance professionals to determine which lower-body strength and power assessments are most related to linear speed and CODS performance. Thus, the authors hypothesize that significant relationships will be observed between measures of relative muscular strength and lower-body power, and between lower-body power, linear speed, and CODS.

## Methods

### *Participants*

Anonymized archived data from 18 Division II collegiate men's lacrosse players (age: 19.2 ± 1.2 years; height: 181.3 ± 7.1 cm; body mass: 77.9 ± 10.4 kgs), who participated in normal pre-season testing, were analyzed for this study. All participants were required to be a member of the university's lacrosse team, injury free, and over 18 years of age, and fully participating in training at the time of testing to be included in this analysis. All participants had medical clearance for intercollegiate athletic participation, as well as read and signed consent forms to participate in athletics. The athletic department at the respective university also distributed written consent forms to the athletes at the start of the academic year to obtain permission to use any data collected from via normal testing and training procedures to potentially be used for research purposes. As such, the institutional ethics committee approved the use of pre-existing data for analysis. Each player also completed the university-mandated physical examination and read and signed the university consent and medical forms for participation in collegiate athletics.

### *Measurements and Procedures*

Data was collected in the pre-season over two days, with 48-hours between sessions. All anthropometric, power, and CODS assessments were performed on the first day, while strength and sprinting speed assessments were performed on the second day. The only data used were of those athletes that were able to complete all tests relevant to this study. Each session included a ten-minute standardized dynamic warm-up which included low aerobic intensity jogging, a sport-specific dynamic stretching protocol, and ended with participants performing assessment-specific exercises which included various bodyweight squats, lunges, and jumps. Participants were then provided full instruction on how to perform each test and were allowed up to two practice trials for each. The first session included anthropometric, lower-body power, and CODS measurements in the following order: height (Ht), body mass (BM), SJ, CMJ, and SLJ followed by the T-Test (TT) and MTT. The second testing session included absolute lower-body strength (LBS) and RLBS measurements which were assessed by a 1RM barbell back squat and linear sprint tests assessed at 10 and 30 yds. The following is a detailed description of each valid and reliable method utilized to assess participants within this investigation in the appropriate testing order.

### *Anthropometrics*

Height (cm) and body mass (kg) were measured on a doctor's beam scale (Cardinal; Detecto Scale Co, Webb City, MO, USA) (Andersen et al., 2018; Calder, 2018).

### *Lower-body power*

Vertical jump height for both the SJ and CMJ was measured using a jump mat (Just Jump, Probotics Inc., Huntsville, Al, USA) (Lockie et al., 2016; Miller, 2012). For both tests, athletes were instructed to stand in the center of the jump mat with their hands on their hips. For the SJ, athletes were instructed to squat until they achieved a 90-degree knee angle, pause for approximately 2 sec and while keeping the hands on the hips jump as high as possible, before landing back in the center of the mat in an athletic stance (i.e., head up, chest up, and a slight bend in the ankles, knees and hips) (Lockie et al., 2016). For the CMJ, athletes were also instructed to stand in the middle of the mat with hands on the hips, and when ready, jump as high as possible while minimizing the time between the eccentric and concentric muscle actions (Lockie et al., 2016). Each athlete performed SJ and CMJ in a randomized order and were given three attempts for each jump. The best attempt for each jump was recorded. The height jumped was then measured in inches and later converted to centimeters.

Standing long jump (SLJ): SLJ was used as an assessment of horizontal lower-body power and participants were allowed three attempts. Participants were instructed to stand at the starting line with their feet shoulder-width apart, bend at the knee and use an arm swing, and jump as far forward as possible in one motion. The distance jumped was then measured in inches and later converted to centimeters.

***Change-of-direction speed***

On the second day, the TT was used to measure each athlete's ability to perform multi-directional movements (i.e., forward sprint, backpedal, and side shuffles) (Figure 1). As described by Kulakowski et al. (2020), the TT required the participant to sprint forward 10 yds (9.14m) to a center cone and touch said cone with right hand, immediately shuffle to the left 5 yds (4.57m to touch a cone with their left hand and immediately shuffle to the right 10 yds (9.14m) to touch the third cone with their right hand. After the second shuffle, the athlete shuffled left towards the middle cone, touched the cone with their left hand and backpedaled to the same cone they started the test, covering a total of 40 yds (36.56m). Participants were instructed to not cross their feet while shuffling, touch all cones, and face forward for the entirety of the test. If the subject failed to do these actions the test was omitted and repeated after three minutes. The best of three trials were recorded and rounded to the nearest 0.10 sec.

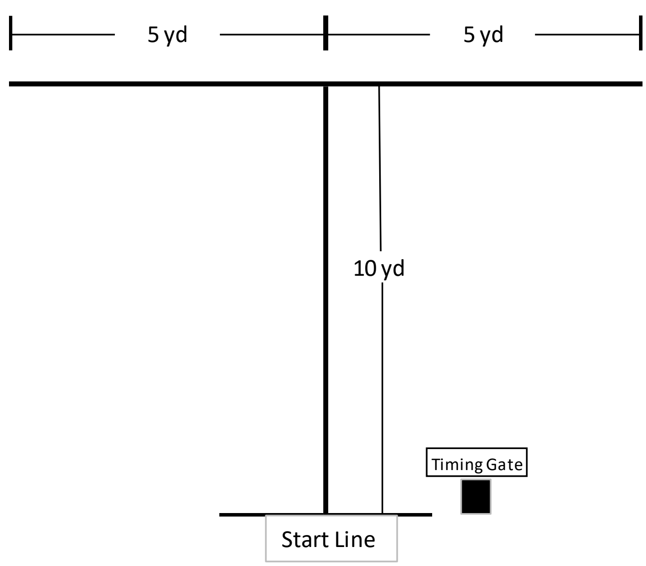


**Figure 1.** T-Test Layout. Adapted from Kulakowski et al. (2020).

Modified T-test: The MTT was performed in the same manner as the traditional T-test but required half of the distances be covered (Figure 2). This assessment requires the participant to sprint forward 5 yds (4.57m to a center cone and touch the cone with the right hand, immediately shuffle to the left 2.5 yds (2.28m) to touch a cone with the left hand and immediately shuffle to the right 5 yds (4.57m to touch the third cone with the right hand. After the second shuffle, the athlete shuffled left towards the middle cone, touched the cone with their left hand and backpedaled to the start cone, covering a total of 20 yds (18.28m). Participants were allowed two attempts for each assessment with the best score being recorded. Previous research suggests the MTT may be more advantageous compared to a TT as the shorter distances better mimics the COD requirements of most field-based sports (7, 26). The best of three trials were recorded and rounded to the nearest 0.10 sec.

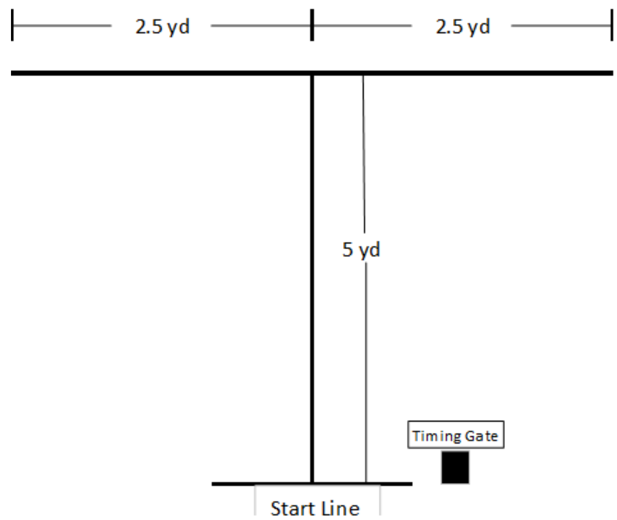


**Figure 2.** Modified T-Test Layout. Adapted from Kulakowski et al. (2020).

***Maximal Lower Body Strength***

First, maximal LBS was assessed via the 1RM barbell back squat test. For this assessment, weights were assigned based on participant's data from a previous 1RM barbell back squat test performed during an earlier strength development block. Before performing maximal back squat testing athletes were instructed in lifting protocol and warm-up. A dynamic warm-up was performed before any lifting occurred, led by strength and conditioning staff. The max protocol was as follows, for a lift to be counted as successful athletes had to reach a position where the quadriceps were parallel to the ground or lower, as judged by strength and conditioning staff. When warming-up, athletes with pervious maxes were to perform 5 reps at 50% 1RM, 3 reps 75% 1RM, 2 reps, ~85%-90% 1RM, then 1 rep until 1RM was found. This warm-up protocol is agreeable with current approaches within the field of lacrosse strength and conditioning (5). Athletes with no previous recorded 1RM were instructed to use the same warm-up protocol but to make estimations on weights that should be lifted based off previous resistance training cycles. Athletes were allowed 3 attempts to record a successful 1RM. LBS and RLBS measurements were assessed by a 1RM barbell back squat. Relative strength or RLBS was calculated for each athlete with the following equation (kilograms lifted)/(body mass (kg)).

***Linear Sprint Speed***

Split times for linear sprint speed were measured over a 10 yd (9.14m) and 30 yd (27.43 m) distance. The time required for participants to cover the first 10 yds and the total 30 yds was recorded to the nearest 0.10 sec using valid and reliable electronic timing system (TC-System, Brower Timing Systems, Draper, UT, USA) (Andersen et al., 2018). The best of three trials were recorded as the athlete's best score and used for analysis.

***Statistical analyses***

All statistical analyses were computed using PASW software version 24.0 (SPSS Inc, Chicago, IL, USA). Descriptive statistics (mean ± standard deviation (SD)) along with effect sizes were calculated for each variable. Pearson's correlation was used to find relationships between relative lower-body strength, power measurements, linear sprint speed, and CODS tests. Statistical significance was set at $p \leq 0.05$. The strengths of each correlation value were reported as follows: 0 to 0.30, or 0 to -0.30 was considered small; 0.31 to 0.49, or -0.31 to -0.49 was considered moderate; 0.50 to 0.69 or -0.50 to -0.69 was considered large; 0.70 to 0.89 or -0.70 to -0.89 was considered very large; and 0.90 to 1.0 or -0.90 to -1.0 a near perfect correlation (Sullivan & Feinn, 2012).

## Results

Descriptive data for all assessments are presented in Table 1.

**Table 1.** Descriptive Statistics for sample (n = 18).

| Variable | Minimum | Maximum | Mean ± SD | 95% CI | ES | CV |
|---|---|---|---|---|---|---|
| Age (yrs.) | 18 | 22 | 19.2 ± 1.2 | 18.6 to 19.8 | 0.996 | 6.3% |
| Ht (cm) | 165.1 | 193.0 | 181.3 ± 7.1 | 177.8 to 184.9 | 0.999 | 3.9% |
| BM (kg) | 61.2 | 106.6 | 77.9 ± 10.4 | 72.7 to 83.1 | 0.984 | 13.3% |
| BMI | 19.9 | 31.0 | 23.7 ± 2.9 | 22.3 to 25.1 | 0.986 | 12.1% |
| LBS (kg) | 81.7 | 174.6 | 113.1 ± 23.5 | 223.7 to 275.2 | 0.961 | 20.8% |
| RLBS (kg/BM) | 1.2 | 1.9 | 1.5 ± 0.2 | 1.4 to 1.6 | 0.982 | 13.9% |
| CMJ (cm) | 41.4 | 63.3 | 54.1 ± 5.1 | 20.4 to 22.2 | 0.992 | 9.2% |
| SJ (cm) | 41.7 | 61.5 | 51.3 ± 4.8 | 19.3 to 21.2 | 0.992 | 9.5% |
| SLJ (cm) | 196.9 | 271.8 | 243.1 ± 15.5 | 92.7 to 98.7 | 0.996 | 6.4% |
| TT (s) | 9.1 | 10.7 | 9.8 ± 0.5 | 9.6 to 10.1 | 0.98 | 5.1% |
| MTT (s) | 8.3 | 9.4 | 8.8 ± 0.3 | 8.7 to 8.9 | 0.998 | 3.3% |
| 10 yds (s) | 1.4 | 1.9 | 1.5 ± 0.1 | 1.4 to 1.6 | 0.995 | 7.1% |
| 30 yds (s) | 3.5 | 4.2 | 3.8 ± 0.2 | 3.8 to 3.9 | 0.998 | 4.0% |

All strength and power measurements in relation to COD and linear speeds are displayed in Table 2. No significant relationships between relative lower-body strength (RLBS) and any sprint or CODS tests were discovered ($p = 0.27 – 0.92$). However, significant moderate positive relationships were observed between RLBS and power as measured by the SJ ($p = 0.02$) (Figure 1.). Additionally, RLBS did not show significant relationships to any other measure of lower-body power ($p = 0.08 – 0.42$). Significant moderate negative correlations were discovered between all measures of lower-body power and CODS (TT) ($p = 0.01 – 0.03$). Additionally, significant moderate negative correlations were also observed between all measures of lower-body power and 27.43 m linear sprint speeds ($p = 0.00 – 0.03$). However, the only measure of power that correlated to 9.14 m linear sprint speed was the SLJ ($p = 0.02$). In short, these results show that RLBS is related to power, and power is related to linear sprint speed, which may influence CODS ability to a degree.

**Table 2.** Correlations between measures of strength and power to linear and change of direction speed.

| Variable | TT (s) | MTT (s) | 10 yd (s) | 30 yd (s) |
|---|---|---|---|---|
| LBS | -.094 | .145 | -.294 | -.243 |
| RLBS | -.273 | -.025 | -.203 | -.263 |
| CMJ (cm) | -.510* | -.318 | -.438 | -.514* |
| SJ | -.634** | -.260 | -.311 | -.556* |
| SLJ | -.636** | -.507* | -.536* | -.671** |

**Note**: * $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$

## Discussion

The purpose of the current study was to investigate the relationships between lower-body strength and measures of power, linear speed, and CODS among Division II men's lacrosse players. The primary findings of this research identified significant, large negative correlations between SLJ, linear sprint speed, and CODS. Significant, large negative correlations were also identified between CMJ and SJ height, and TT and 30 yd linear sprint speed. Significant, moderate positive correlations between RLBS and SJ. However, no significant correlation between LBS and any measure of power, linear speed, or CODS were identified. Therefore, the results of the current study suggest that emphasizing the development of RLBS, and vertical and horizontal power production may improve both sprint and CODS ability within this population. Additionally, these findings may be beneficial for strength and conditioning professionals working to determine which athletic qualities are most related to those which strongly influence success within the sport of lacrosse.

Previous studies have identified relationships between LBS, RLBS, and various measures of power (Andersen et al., 2018; Nimphius et al., 2010; Sullivan & Feinn, 2012). Though the results of the current study did not identify any correlations between LBS and any measurement of power, there were moderate positive correlations between RLBS and SJ. Although no direct relationships between RLBS and speed were observed within this study, the results suggest that emphasizing the development of RLBS within the collegiate male lacrosse population may result in improved concentric force production as assessed by the SJ and translates to increased power- and speed production. This is similar to an investigation conducted by Anderson et. al. (2018) which reported large to very large correlations between relative strength and vertical jump but no correlation with absolute strength suggesting that improved relative strength may help improve on-field performance more than development of absolute strength. Kulakowski et. al. (2020) also revealed a significant relationship between relative power measures (CMJ and SJ) and all CODS and sprint speeds above 10m and no relationships from absolute power measures. Previous research suggests that improvement in lower-body power may improve a lacrosse athlete's CODS ability and linear speed (Andersen et al., 2018; Lockie et al., 2018; McFarland et al., 2016; Sheppard et al., 2014; Sullivan & Feinn, 2012). Findings from the current study provide further evidence that CODS is significantly influenced by the ability to generate higher levels of force in a short amount of time with SJ and CMJ being significantly related to TT and CODS alone, and SLJ being related to both CODS test. Regarding men's lacrosse, this relationship may be due to the demands of performing quick sprints every few seconds while performing high intensity changes of direction from both a static and dynamic start. It also reveals that SJ is a quality that coaches may want to consider when tailoring to collegiate male lacrosse athletes.

The relationships between lower-body power and linear sprint speed have been well-reported (Kulakowski et al., 2020; NCAA 2015, Nimphius et al., 2010). The results of the current study identified significant large negative relationships between SLJ and linear sprint speeds over 10 and 30 yds. Additionally, significant large negative correlations between CMJ and SJ height and 30 yd sprints were also identified. These findings are similar to McFarland et al, (2016) who found moderate negative correlations between 10m and 30m sprints with CMJ and SJ among male college soccer athletes. Additionally, these results suggest that SLJ may be better to include in a testing battery as it is more closely related to other skills required to be successful in lacrosse and other field-based sports, specifically linear sprint speed, but that CMJ and/or SJ may be used as a predictor for 30 yd sprinting performance. Findings from the current study suggest that emphasizing RLBS development within collegiate male lacrosse populations has the potential to improve concentric power production, sprint ability, and likely contributes to the athletic success within the sport of lacrosse. The relationships between lower body power and CODS have also been the focus of multiple studies ((Delaney et al., 2015; Hammami et al., 2018; Keiner et al., 2014). The results of the current study revealed CMJ and SJ height had large negative correlations with TT but not MTT. Moderate negative relationships between SLJ and both measurements of CODS were also shown. These findings are similar to Kulakowski et al, (10) who reported moderate negative relationships between SBJ and CODS (5-0-5, TT, MTT) among Division II female lacrosse players.

Significant moderate negative relationships between all measures of power and 27.43 m linear sprint speed were identified within the current study. However, SLJ performance was the only measure of power that was significantly related to 9.14 m linear sprint speed and that relationship was moderately negative. Several of these findings are supported by research within the field which has examined lower-body power measures to sprint and CODS among female lacrosse athletes and soccer players ((Kulakowski et al., 2020; Lockie et al., 2016; McFarland et al., 2016). Within the prior studies, researchers aimed to determine the relationship between lower-body power measures to sprint and CODS and concluded that results from measures such as SJ, CMJ, and SLJ could reflect sprint and CODS ability. However, there was a singular nuanced finding within the current study which translates to the sport of lacrosse and can alter methods for assessing and developing lacrosse athletes. This finding revolves around the relationship between RLBS and power which at its most fundamental level can be translated as a relationship between power and CODS.

Although sport-specific actions in lacrosse and many other field-based sports are dynamic in nature, the result of our analysis provides further evidence of the importance of developing concentric strength. Furthermore, and contrary to popular belief, this study highlights the underpinnings that concentric and dynamic force production has on the ability to achieve higher maximum velocities as expressed by the 30 yd linear sprint speed. Significant moderate positive relationships were identified between 10 and 30 yd linear sprint performance and TT and MTT performance. This suggests that male lacrosse athletes can maintain or develop max velocity abilities by working on accelerative abilities. Sport coaches and strength coaches can benefit from this information to improve current approaches for developing athletes. Additionally, the relationship between TT and MTT suggests that athletes can develop and maintain CODS while working on quick change ability from varying distances. This is beneficial for sport coaches and strength coaches as MTT better mimics most field-based sports but to achieve change of direction ability a TT is just as beneficial. Furthermore, significant moderate relationships between 27.43 m linear sprint speed and TT performance were identified. This finding may be useful for positions in men's lacrosse that require the athlete to achieve maximal velocities while approaching to perform extended CODS more often than other positions.

This study has limitations that should be noted. Due to the relatively small sample size of participants in this study, it may be beneficial for future research to include larger sample sizes by coordinating and collaborating with other teams and universities. In addition to providing a more robust sample, this would also allow for a more heterogeneous dataset than the one utilized in the current study. A second limitation of the current study involves information regarding the sample itself. In the future, it may be beneficial to account for biological age, training age, role on team, and playing experience, and to examine their interactions and influence on measures of physical performance. Not only will this assist research groups with providing more context to support their findings, but it may also assist practitioners in the field with determining the best approaches for developing their respective teams. Finally, the large number of correlations performed may have caused some spurious correlations to occur. However, upon review it does appear that the data trends in a general direction and those correlations observed and reported do not simply appear to be random chance.

In conclusion, higher RLBS is related to greater SJ performance but was not found to be directly or significantly related to linear speed or CODS performance. However, it is possible that RLBS may indirectly affect these measures based on its relationship to power. Additionally, greater SLJ distance is related to enhanced CODS and linear sprint speed. Thus, these results suggest that strength and conditioning professionals should be aware of these relationships when working with collegiate Division II male lacrosse athletes. Additionally, the findings from this study also provides strength and conditioning professionals with valuable information to improve their current approaches for developing athletes and ensuring that they are within normal ranges for strength, power, linear speed, and CODS. Therefore, while focusing on lower-body power development is a key component in preparing male lacrosse athletes for their sport, strength and conditioning professionals should also aim to improve relative strength as well.

***Practical Implications***

Collectively, these findings can be utilized to further benefit the development of sport specific training approaches aimed at improving athletic performance within the sport of lacrosse. To be specific, sports performance professionals within the sport of lacrosse should emphasize the development of relative lower body strength, vertical and horizontal force production, and vertical power production capabilities. After these athletic qualities have been developed to an appreciable level, it is recommended that the training program aims to enhance the transfer of those general athletic qualities to those which are more specific to the sport of lacrosse.

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## References

Andersen, E., Lockie, R. G., & Dawes, J. J. (2018). Relationship of Absolute and Relative Lower-Body Strength to Predictors of Athletic Performance in Collegiate Women Soccer Players. *Sports*, *6*(4). https://doi.org/10.3390/sports6040106

Calder, A. R. (2018). Physical Profiling in Lacrosse: A Brief Review. *Sport Sciences for Health*, *14*(3), 475-483. https://doi.org/10.1007/s11332-018-0499-1

Collins, S. M., Silberlicht, M., Perzinski, C., Smith, S. P., & Davidson, P. W. (2014). The Relationship Between Body Composition and Preseason Performance Tests of Collegiate Male Lacrosse Players. *J Strength Cond Res*, *28*(9), 2673-2679. https://doi.org/10.1519/JSC.0000000000000454

Delaney, J. A., Scott, T. J., Ballard, D. A., Duthie, G. M., Hickmans, J. A., Lockie, R. G., & Dascombe, B. J. (2015). Contributing Factors to Change-of-Direction Ability in Professional Rugby League Players. *J Strength Cond Res*, *29*(10), 2688-2696. https://doi.org/10.1519/JSC.0000000000000960

Gutowski, A. E., & Rosene, J. M. (2011). Preseason Performance Testing Battery for Men's Lacrosse. *Strength & Conditioning Journal*, *33*(2), 16-22. https://doi.org/10.1519/SSC.0b013e318208cb04

Hammami, M., Negra, Y., Billaut, F., Hermassi, S., Shephard, R. J., & Chelly, M. S. (2018). Effects of Lower-Limb Strength Training on Agility, Repeated Sprinting with Changes of Direction, Leg Peak Power, and Neuromuscular Adaptations of Soccer Players. *J Strength Cond Res*, *32*(1), 37-47. https://doi.org/10.1519/JSC.0000000000001813

Hoffman, J. R. (2012). Athlete Testing and Program Evaluation. In *NSCA's guide to program design* (1 ed., pp. 23-50). Human Kinetics.

Jones, P., Bampouras, T. M., & Marrin, K. (2009). An Investigation into The Physical Determinants of Change of Direction Speed. *J Sports Med Phys Fitness*, *49*(1), 97-104. https://www.ncbi.nlm.nih.gov/pubmed/19188902

Keiner, M., Sander, A., Wirth, K., & Schmidtbleicher, D. (2014). Long-Term Strength Training Effects on Change-of-Direction Sprint Performance. *J Strength Cond Res*, *28*(1), 223-231. https://doi.org/10.1519/JSC.0b013e318295644b

Kulakowski, E., Lockie, R. G., Johnson, Q. R., Lindsay, K. G., & Dawes, J. J. (2020). Relationships of Lower-body Power Measures to Sprint and Change of Direction Speed among NCAA Division II Women's Lacrosse Players: An Exploratory Study. *Int J Exerc Sci*, *13*(6), 1667-1676. https://www.ncbi.nlm.nih.gov/pubmed/33414885

Lockie, R. G., Dawes, J. J., & Jones, M. T. (2018). Relationships between Linear Speed and Lower-Body Power with Change-of-Direction Speed in National Collegiate Athletic Association Divisions I and II Women Soccer Athletes. *Sports*, *6*(2). https://doi.org/10.3390/sports6020030

Lockie, R. G., Stage, A. A., Stokes, J. J., Orjalo, A. J., Davis, D. L., Giuliano, D. V., Moreno, M. R., Risso, F. G., Lazar, A., Birmingham-Babauta, S. A., & Tomita, T. M. (2016). Relationships and Predictive Capabilities of Jump Assessments to Soccer-Specific Field Test Performance in Division I Collegiate Players. *Sports*, *4*(4). https://doi.org/10.3390/sports4040056

Marcovic, G. (2007). Poor Relationship Between Strength and Power Qualities and Agility Performance. *J Sports Med Phys Fitness*, *47*(3), 276-283. https://www.ncbi.nlm.nih.gov/pubmed/17641593

McBride, J. M., Blow, D., Kirby, T. J., Haines, T. L., Dayne, A. M., & Triplett, N. T. (2009). Relationship Between Maximal Squat Strength and Five, Ten, And Forty Yard Sprint Times. *J Strength Cond Res*, *23*(6), 1633-1636. https://doi.org/10.1519/JSC.0b013e3181b2b8aa

McFarland, I. T., Dawes, J. J., Elder, C. L., & Lockie, R. G. (2016). Relationship of Two Vertical Jumping Tests to Sprint and Change of Direction Speed among Male and Female Collegiate Soccer Players. *Sports*, *4*(1). https://doi.org/10.3390/sports4010011

Miller, T. (2012). NSCA's Guide to Tests and Assessments. In *NSCA's Guide to Tests and Assessments* (pp. 1-14). Human Kinetics.

NCAA (2015). *2016 and 2017 NCAA women's lacrosse rules and interpretations*.

Nimphius, S., McGuigan, M. R., & Newton, R. U. (2010). Relationship Between Strength, Power, Speed, And Change of Direction Performance of Female Softball Players. *J Strength Cond Res*, *24*(4), 885-895. https://doi.org/10.1519/JSC.0b013e3181d4d41d

Nuzzo, J. L., Anning, J. H., & Scharfenberg, J. M. (2011). The Reliability of Three Devices Used for Measuring Vertical Jump Height. *J Strength Cond Res*, *25*(9), 2580-2590. https://doi.org/10.1519/JSC.0b013e3181fee650

Peterson, M. D., Alvar, B. A., & Rhea, M. R. (2006). The Contribution of Maximal Force Production to Explosive Movement Among Young Collegiate Athletes. *J Strength Cond Res*, *20*(4), 867-873. https://doi.org/10.1519/R-18695.1

Polley, C. S., Cormack, S. J., Gabbett, T. J., & Polglaze, T. (2015). Activity Profile of High-Level Australian Lacrosse Players. *J Strength Cond Res*, *29*(1), 126-136. https://doi.org/10.1519/JSC.0000000000000599

Sell, K. M., Prendergast, J. M., Ghigiarelli, J. J., Gonzalez, A. M., Biscardi, L. M., Jajtner, A. R., & Rothstein, A. S. (2018). Comparison of Physical Fitness Parameters for Starters vs. Nonstarters in an NCAA Division I Men's Lacrosse Team. *J Strength Cond Res*, *32*(11), 3160-3168. https://doi.org/10.1519/JSC.0000000000002830

Sheppard, J. M., Dawes, J. J., Jeffreys, I., Spiteri, T., & Nimphius, S. (2014). Broadening The View of Agility: A Scientific Review Of The Literature. *Journal of Australian Strength and Conditioning*, *22*(3), 6-25.

Sheppard, J. M., & Young, W. B. (2006). Agility Literature Review: Classifications, Training and Testing. *J Sports Sci*, *24*(9), 919-932. https://doi.org/10.1080/02640410500457109

Spiteri, T., Nimphius, S., Hart, N. H., Specos, C., Sheppard, J. M., & Newton, R. U. (2014). Contribution of Strength Characteristics to Change of Direction and Agility Performance in Female Basketball Athletes. *J Strength Cond Res*, *28*(9), 2415-2423. https://doi.org/10.1519/JSC.0000000000000547

Steinhagen, M. R., Meyers, M. C., Erickson, H. H., Noble, L., & Richardson, M. T. (1998). Physiological Profile of College Club-Sport Lacrosse Athletes. *The Journal of Strength and Conditioning Research*, *12*(4), 226-231.

Styles, W. J., Matthews, M. J., & Comfort, P. (2016). Effects of Strength Training on Squat and Sprint Performance in Soccer Players. *J Strength Cond Res*, *30*(6), 1534-1539. https://doi.org/10.1519/JSC.0000000000001243

Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The Importance of Muscular Strength in Athletic Performance. *Sports Medicine*, *46*(10), 1419-1449. https://doi.org/10.1007/s40279-016-0486-0

Sullivan, G. M., & Feinn, R. (2012). Using Effect Size-or Why the P Value Is Not Enough. *J Grad Med Educ*, *4*(3), 279-282. https://doi.org/10.4300/JGME-D-12-00156.1

Tramel, W., Lockie, R. G., Lindsay, K. G., & Dawes, J. J. (2019). Associations between Absolute and Relative Lower Body Strength to Measures of Power and Change of Direction Speed in Division II Female Volleyball Players. *Sports*, *7*(7). https://doi.org/10.3390/sports7070160