# The Associations Between Lateral Jumps and 180° Change of Direction Performance: Considering for the Effect of Sex and Maturation

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**ABSTRACT**

Change of direction (COD) abilities are essential for field- and court-based sport athletes and often are critical determining factors of success. With rising competitiveness in sports, there is an increased emphasis on youth athletic development to gain performance advantages. As such, assessing and monitoring COD abilities in youth athletes regularly and efficiently is critical to coaches. Previous researchers have demonstrated significant associations between jump and COD performance enabling coaches practical and reliable methods of assessing leg muscle qualities. Predominantly, jumps used to assess leg power have been conducted vertically and horizontally, but rarely in the lateral direction. Additionally, these assessments are often applied to mixed populations uniformly, without considering the confounding effect of sex or maturation, despite known differences in physical development.

The overarching research question of this thesis was "Can single-leg lateral jumps be used as a predictor of 180° COD performance among youth male and female athletes pre-, circa-, and post-peak height velocity (PHV)?". The first aim was to review and critique the current literature that has investigated the relationships between lateral jumps and COD performance. The second aim was to determine between-session reliability of two lateral jump tasks and a 180° COD task. The third aim was to quantify the relationship between the lateral jump tasks and the 180-degree COD task.

First, a literature review was conducted systematically to identify relevant articles. Eleven experimental studies were found and reviewed. The main conclusions drawn from these articles were: (1) moderate to strong relationships ($r>0.55$) were observed between lateral jump and COD assessments, suggesting both tasks share some similar neuromuscular qualities that contribute to lateral performance; and (2) there is a paucity of research investigating the relationship between lateral jump performance variables and COD performance, while considering how this relationship may be affected by sex and maturation.

Next, a three-week repeated measures study design was used to determine between-session variability of single-leg lateral countermovement jumps, single-leg lateral reactive jumps and 180° COD. Coefficients of variation (CV) and intraclass correlation co-efficient (ICC) were used to quantify variability over three occasions separated by seven days. The main findings were: (1) the two lateral jumps and 180° COD assessments demonstrated acceptable variability (CV = 3.2-5.5%; ICC = 0.84-0.90) in kinematic variables; and, (2) only the single-leg lateral reactive jump assessments were found to have acceptable reliability (CV = 7.1-13.8%; ICC = 0.70-0.89) in kinetic variables.

Lastly, a cross-sectional study was implemented to quantify the associations between vertical, horizontal, and lateral jump variables, with 180° COD performance across 73 youth athletes of different sexes and maturation stages. Additionally, kinematic and kinetic performance variables of all assessments were used to create stepwise linear regression models that predict 180° COD performance by subgroup. The main findings were: (1) linear sprinting was the most effective predictor of 180° COD performance across all subgroups; and, (2) the best jump predictors of 180° COD performance was the horizontal jump in males, the vertical jump in females, the vertical jump and lateral reactive jump in pre-PHV and circa-PHV participants, and the horizontal jump, and lateral reactive jump in post-PHV participants.

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**ATTESTATION OF AUTHORSHIP**

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another (except where explicitly defined in the acknowledgments), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Matoko Carlson Noudéhou

**CO-AUTHORED WORKS**

| Chapter publication reference | | Author % |
|---|---|---|
| Chapter 2: | Noudehou, MC, Neville, J, Bourgeois, FA, Cahill, M, Oliver, JL and Cronin, J. A Review of The Relationship Between Lateral Jumps and Change of Direction: An Analysis of The Effect of Sex and Maturation. *(Currently pending review in the Journal of Strength and Conditioning Research)* | MCN: 80%<br>JN: 5%<br>FAB: 5%<br>JC: 5%<br>JLO: 3%<br>MC: 2% |
| Chapter 3: | Noudehou, MC, Neville, J, Bourgeois, FA, Deiwald, S, Cahill, M, and Cronin, J. Variability of Lateral Jump and Change of Direction Kinematics and Kinetics in Youth Athletes *(Currently pending review in the International Journal of Sports Science and Coaching)* | MCN: 80%<br>JN: 5%<br>FAB: 5%<br>SD: 5%<br>JC: 3%<br>MC: 2% |
| Chapter 4: | Noudehou, MC, Neville, J, Bourgeois, FA, Deiwald, S, Cahill, M, and Cronin, J. The Predictive Associations Between Multi-Directional Jump Variables and Change of Direction Performance in Males and Females of Different Maturation Stages *(Currently pending review in Pediatric Exercise Science)* | MCN: 80%<br>JN: 5%<br>FAB: 5%<br>JC: 5%<br>SD: 3%<br>MC: 2% |

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**PUBLICATION ARISING FROM THE THESIS**

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**Noudéhou MC,** Neville, J, Bourgeois, FA, Diewald S, Cahill, M, and Cronin, J. Variability of Lateral Jump and Change of Direction Kinematics and Kinetics in Youth Athletes. *(Currently pending review in the International Journal of Sports Science and Coaching, submitted April 16th, 2021).*

**Noudéhou MC,** Neville, J, Bourgeois, FA, Diewald S, Cahill, M, and Cronin, J. The Predictive Associations Between Multi-Directional Jump Variables and Change of Direction Performance in Males and Females of Different Maturation Stages. *(Currently pending review in Pediatric Exercise Science, submitted May 3, 2021).*

**ETHICS APPROVAL**

Ethical approval for the thesis was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 17 December 2019.

Ethics Application: AUTEC: 19/444 The relationship between single left lateral jump ability and performance in single leg lateral change of direction tasks in youth athletes.

# CHAPTER 1 - INTRODUCTION

## Background

In field- and court-based sports, athletes experience repeated planned and unplanned changes in sprint direction to gain competitive advantages over opponents. Change of direction (COD) can be defined as a movement where no immediate reaction to a stimulus is required, thus the direction change is pre-planned (3). Thus, the ability to change direction repeatedly and proficiently can be considered a determining factor of success in team sports. Agility, also a determining factor of team sports success, is defined as a movement in response to stimuli, thus the change in sprint direction is unplanned (3). Because agility performance is dependent on an athlete's ability to process given stimuli in addition to the physical and technical determinants of COD performance, it is more difficult to assess and as such will be outside the scope of this research.

Change of direction performance is often dictated by straight sprinting speed, technique and leg muscle qualities with the latter including strength, power and reactive strength (45). These leg muscle qualities may also be determining performance metrics of certain jump assessments (3). Brughelli et al. have argued that categorising jump assessments into these classifications may be overly complicated. Instead, they propose to consider all jumps as measures of leg power and classify jumps based on direction of force application, or if the movement was performed unilaterally or bilaterally (3). Jump assessments should be designed to mimic the directions of force application required by COD tasks. Additionally, the influence of the stretch shortening cycle (SSC) required by an assessment should be considered. Fast SSC involve short contraction times (<0.25 seconds) and little angular displacement in the hip knee and ankle joints, while slow SSC involves long contraction times and large angular displacement in the joints (16). Therefore, jump assessments can be used to govern the type of SSC required by evaluating rapid eccentric stretching capabilities and the contribution of elastic energy (fast SCC) or longer eccentric phases that allow for greater force development (slow SSC) (16).

Maturation and sex will affect how youth athletes develop the necessary leg muscle qualities required by COD performance. Despite initial differences between sexes, both male and female pre-PHV athletes develop strength, speed and power at similar rates (24). Male post-PHV athletes improve in all components of performance except flexibility, while females on average reach adolescence two years earlier than males and experience increases in fat mass, joint laxity, differential rates of neuromuscular strength development, and an increase in reliance on quadriceps-dominant landing strategies (24). Due to the difference in rates of neuromuscular development between males and females and differences in lean muscle mass ratio, sex will affect the development the muscle qualities required in multidirectional jumps and sprints, potentially impacting the relationship between jump and COD performance. This suggests that not only does sex play an important role, but maturation differences may also confound these performance relationships. Due to increased neuroplasticity, pre-PHV athletes develop strength through improvements of the neuromuscular system and can attain limited power development through neural adaptations. Meanwhile, male post-PHV athletes undergo rapid muscle mass gains and increased rate of strength and power development due to increased androgen concentrations (24).

Due to the complexities of sex and maturation there is a need to develop a greater understanding of the shared characteristics between 180° COD and lateral jump ability. This thesis focuses on the leg muscles qualities of male and female youth athletes and investigates the effects of pre-, circa-, and post-PHV on leg muscle qualities. Specifically, lateral leg power tasks among youth athletes were examined to determine their use as predictors of performance in a single-effort lateral (i.e. 180°COD) task.

**Research Questions**

The thesis looked to answer the overarching question "Can single-leg lateral jumps be used as a predictor of 180° COD performance among male and female youth athletes pre-, circa-, and post-PHV?". First, the current literature that has investigated the relationships between lateral jumps and COD performance was reviewed. Second, the between-session variability of two lateral jump tasks and a 180° COD task was quantified, and finally the relationship between the lateral jump tasks and the 180-degree COD task were examined.

Three investigations were conducted to specifically:

1. Analyse the current research regarding the relationship between lateral jump performance measures and 180° COD performance, while evaluating if these relationships were influenced by differences due to sex and maturation [Literature Review].
2. Determine the reliability of kinetic and kinematic measures for lateral jumps and a 180° COD assessment across participants of different maturation statuses and sexes [Study 1].
3. Determine the association between kinetic and kinematic measures for lateral jump and 180° COD assessments across participants of different maturation status and sex [Study 2].

**Research Approach**

To assess 180° COD performance, a modified 505 COD assessment was chosen. This limited the influence of straight-line sprinting with a shortened 9.14m sprint approach. Additionally, this assessment included a single 180° change in sprint direction that required predominantly medio-lateral force production while limiting the influence of aerobic capacity compared to assessments that involve multiple changes in direction (1, 47). Time of completion(s) was used to measure COD performance.

Considering the increased need to improve athletic abilities in youth populations combined with the clear differences in physical development between sexes and maturation groups, it was imperative that coaches implemented predictive assessments specific to their athletes. The use of predictive assessments will inform on an individual athlete's future performance and illuminate deficiencies that need to be addressed.

To investigate the effect of sex and maturation on the kinematic and kinetic performance variables obtained by the chosen assessments, a mixed youth population of males and females across maturation stages was recruited to compare associations between subgroups. Differences in strength development could affect jump, sprint and COD strategies used by different sexes and maturation groups, and subsequently influence which jumps best predict 180° COD ability within each group. To determine which type of jump assessments are specific to different sexes and maturation groups, a single-leg lateral CMJ (LJ) and a single-leg reactive lateral jump (LRJ) were used to investigate leg muscle qualities in the medio-lateral direction. Specifically, these assessments were chosen to investigate slow and fast SSC muscle qualities in lateral jump performance. The LRJ assessment was performed from two different approach jump distances relative to participant leg lengths. Additionally, vertical and horizontal CMJ jumps, and linear sprints were included in the investigation to compare the predictive ability of multi-directional jumps. A combination of jump distance and jump kinetic performance metrics were used to define jump performance.

**Thesis Structure**

This thesis is composed of three interlinked chapters that directly address each research question, as illustrated in Figure 1.1. The thesis is framed by a literature review (Chapter 2) investigating the shared characteristics and relationship between lateral jump and COD abilities. Specifically, this review explored the effect of sex and maturation on these lateral performance characteristics. Chapter 3 is an acute study that investigated the reliability of performance metrics collected from two lateral jumps and a 180° COD assessment. The final chapter (Chapter 4) is a cross-sectional study that determined the strength of statistical associations between single-leg lateral jumps and 180° COD performance metrics across male and female athletes of different maturation stages.

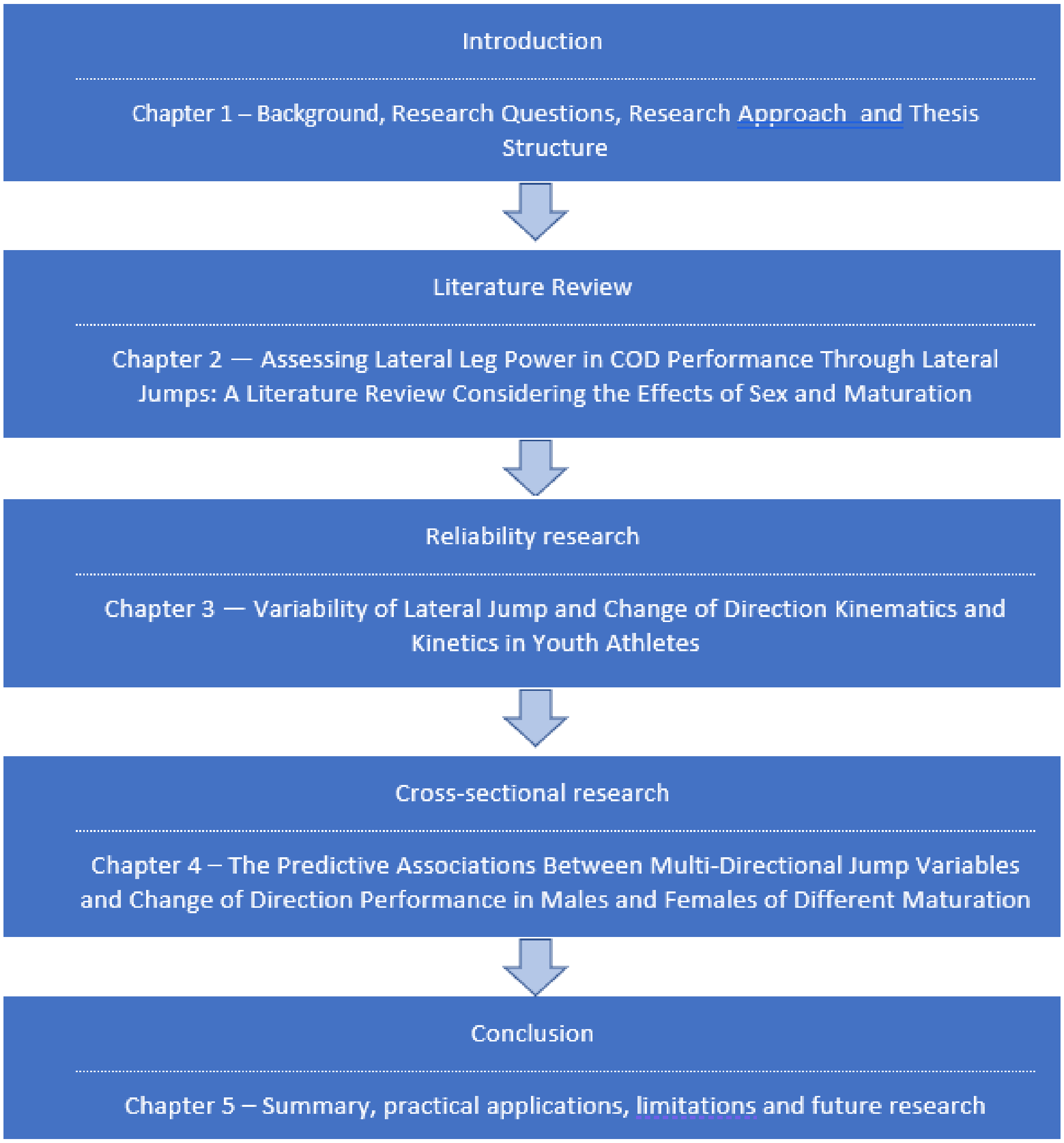


**Figure 1.1.** Thesis flowchart.

# CHAPTER 2 - ASSESSING LATERAL LEG POWER IN COD PERFORMANCE THROUGH LATERAL JUMPS: A LITERATURE REVIEW CONSIDERING THE EFFECTS OF SEX AND MATURATION.

*This chapter is currently pending review in Journal of Strength and Conditioning Research.*

Reference:

Noudehou, MC, Neville, J, Bourgeois, FA, Cahill, M, Oliver, JL and Cronin, J. Assessing Lateral Leg Power in COD Performance Through Lateral Jumps: A Literature Review Considering The Effects Of Sex And Maturation. *Journal of Strength and Conditioning Research* (Submitted 3/22/2021).

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Noudehou M, 80%; Neville J, 5%; Bourgeois FA, 5%; Cronin JB, 5%; Oliver JL, 3%, Cahill MJ, 2%.

**INTRODUCTION**

In sports the ability to change direction repeatedly and proficiently can be considered a determining factor of success in field- and court-based sports. When evaluating COD abilities, coaches use many COD tasks including: 10yd Shuttle, L-Run, Zigzag test, Slalom Run, Box test, 505, Illinois Agility Test, T-Test (3). When comparing these common COD assessments, it is evident that the bioenergetic demands, primary direction of applied forces, angle of the COD, number of CODs, distance covered between CODs and duration of these tasks vary greatly (1, 12, 42). These possible variations in a COD task should be considered when developing and comparing assessments. Regardless of the variation in COD tasks, understanding the determinants of COD in the context of specific populations is of great interest to practitioners.

Key determinants of performance in COD tasks are multifaceted and encompass both technical and physical factors. The technical factors of COD performance consist of foot placement, adjustment of stride, and body posture while the physical factors of COD performance consist of straight-line sprinting speed and leg muscle qualities (45), with the latter including strength, power and reactive strength (47). Brughelli et al. (3) argued that the classification of leg muscle qualities into strength, power and reactive strength may be overly complicated. Preferably, jumps would be classified in terms of the direction of net force application (i.e. vertical (Fz), anterior-posterior (Fy), and medio-lateral (Fx)) and whether the movement involves unilateral or bilateral force production. These leg power capabilities have mostly been investigated in the vertical and horizontal directions. Therefore, the focus of this systematic search and critical review is on the lateral leg muscle qualities of strength, reactive strength and power examined through jumps.

Plyometric tasks are a reliable and practical option for practitioners seeking to assess leg muscle qualities. Single-leg jumps performed vertically ($r = -0.033$ to $-0.452$), horizontally ($r = -0.306$ to $-0.569$) and laterally ($r = -0.318$ to $-0.721$) have demonstrated varied strengths of statistical association with COD performance (26). Therefore, it would be valuable for practitioners to know which specific leg power qualities contribute to both multi-directional plyometrics and COD performance. It has been proposed that single-leg lateral plyometric training could potentially be beneficial to lateral COD performance (45). Yet, there is little understanding of how lateral expressions of force are related to lateral COD capability. Having a better understanding of this relationship will assist coaches in determining whether training lateral leg power qualities is needed in addition to traditional vertical and horizontal training.

A secondary interest was investigating whether the lateral leg power qualities that affect COD performance are similar across sexes and maturation stages. The technical aspect of COD performance may be affected by maturational differences in development that cause rapid limb growth and affect limb coordination (24). Similarly, differences between males and females in rates of neuromuscular development, muscle mass gains and power development would have a direct effect on COD capabilities (24). Understanding these effects would provide better guidance for programming lateral power development given gender and maturational differences.

Given the aforementioned, the focus of this review was to elucidate the importance of lateral leg power qualities in lateral COD performance. A secondary interest was to determine whether sex and maturation affect lateral leg power and COD ability.

## METHODS

### Subjects

This review included studies with male and female participants ranging in age from 9 to 34 years of age of various performance levels from recreational to professional, playing team sports such as American football, Australian rules football, netball, soccer and volleyball.

### Experimental Approach to the Problem

A methodical approach was used to conduct this review of the literature to control for quality. The electronic search was conducted in May 2020 through an academic library comprised of EBSCO, Google Scholar, OVID, ScienceDirect, SCOPUS and SPORTDiscus databases. The keywords "505 agility test **OR** change of direction **OR** COD" **AND** "lateral jump **OR** lateral reactive jump" **AND** **"**unilateral jumps **OR** unilateral plyometrics" **AND** "peak height velocity" **AND** "kinematics **OR** kinetics" were used to begin the search.

**Procedures**

Articles were included if they met two of the three criteria: (1) they included lateral jump assessments; (2) provided kinetic data; and (3) provided maturation or sex comparisons. The following articles (*n* = 4) satisfied criteria (1) and (2): (2, 20, 21, 32). The following articles (*n* = 6) satisfied criteria (1) and (3): (2, 6, 18, 23, 29, 30). The following article (*n* = 1) satisfied criteria (2) and (3): (27) (Fig. 2.1).

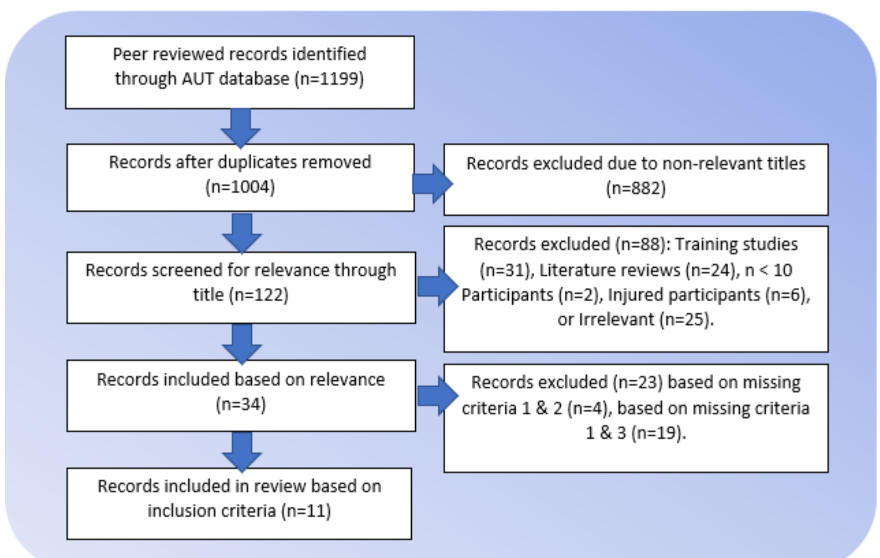


**Figure 2.1.** Search methods and results of studies through steps of the literature review. (Search complete 14 May 2020 at 10am EST).

Though the aim of this review was to summarise research examining the relationships between lateral jump and COD performance in youth athletes, articles that used adult participants were included, if they met two of the three criteria to better understand lateral performance relationships.

The statistical strength of correlation between two quantitative variables was determined via Pearson's guidelines which suggest that r values of 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, and 0.8-1.0 demonstrate very weak, weak, moderate, strong and very strong relationships, respectively (14). The magnitude of difference between sexes was calculated using the Hedges *g* method. Standardised differences of 0-0.2, 0.21-0.5, and 0.51 or greater were considered small, moderate and large differences, respectively (19).

**RESULTS**

Initially, all articles retrieved from the search (*n* = 1199) were peer-reviewed and not limited to any specific publication years or languages. Duplicates of records were removed, and articles were screened by title to determine their relevance. Titles that mentioned youth performance in jumping, agility or change of direction; or the effect of sex on performance; or the effect of maturation (i.e. PHV) on performance; or multi-directional jump performance, training or assessment; or agility performance of change of direction performance were included (n = 128). Articles were screened for relevance by abstract and included (*n* = 35) (Table 2.1) or excluded if they were training studies, literature reviews, were based on finding from 10 or fewer participants, or involved injured participants.

**Table 2.1. Summary of studies included in literature review. * =** COD complex involving 31 m and 5 direction changes. M = male, F = female, PHV = peak height velocity, COD = change of direction, SL = single-leg, VJ = vertical jump, HJ = horizontal jump, LJ = lateral jump, RVSH = repeated vertical single-leg hop, RVJ = reactive vertical jump, RHJ = reactive horizontal jump, RLJ = reactive lateral jump, IAT = Illinois agility test.

| Study | n = | Sport/Group | Sex | Age (years) | Jump Assessments | COD Assessments |
|---|---|---|---|---|---|---|
| Brock et al. (2) | 14 | American Football | M | 20.1 ± 1.4 | 90 land-cut (RLJ) | 180° COD |
| Ceroni et al. (5) | 117 | Recreational | M | 13.7 ± 1.9 | SL VJ | - |
| | 106 | Recreational | F | 13.3 ± 1.9 | | |
| Condello et al. (6) | 14 | College Soccer | M | 19.6 ± 1.5 | - | 60° COD |
| | 12 | College Soccer | F | 21.0 ± 2.7 | | |
| Harrison et al. (18) | 60 | High School | M | 15.5 ± 1.1 | RVSH | - |
| | 49 | High School | F | 15.6 ± 1.1 | | |
| Henry et al. (20) | 31 | Australian Rules Football | M | 29.0 ± 5.0 | SL RVJ, SL RHJ, SL RLJ | 60° Reactive Agility |
| Hewit et al. (21) | 19 | Netball | F | 19.5 ± 1.1 | SL VJ, SL HJ, SL LJ | - |
| Lawson et al. (23) | 12 | Volleyball | M | 22.4 ± 1.9 | Step-close VJ, No-step VJ | - |
| | 12 | Volleyball | F | 21.3 ± 1.8 | | |
| Lockie et al. (27) | 21 | College Club Athlete | M | 23.4 ± 2.4 | VJ, HJ, LJ | 505, IAT |
| | 22 | College Club Athlete | F | 22.9 ± 2.3 | | |
| Meylan et al. (29) | 11 | Post PHV | M & F | 14.5 ± 1.3 | VJ, HJ | - |
| | 12 | Circa PHV | M & F | 12.7 ± 1.1 | | |
| | 19 | Pre PHV | M & F | 10.9 ± 1.2 | | |
| Meylan et al. (30) | 68 | Youth | M | 11.0 ± 1.1 | VJ, HJ | COD Task* |
| | 45 | Youth | F | 11.3 ± 0.9 | | |
| Meylan et al. (32) | 30 | Team Sport | M | 21.9 ± 3.8 | SL VJ, SL HJ, SL LJ | - |

**Summary of Assessments.**

This review found multiple COD tests that were used to assess performance. Of the 11 studies, 5 measured COD completion time and only 2 (2, 6) of the 11 studies reported GRF performance measures involving the COD step/s. Change of direction assessments reported in this review included 505 (27), 180° COD (2), 60° COD (6), Illinois Agility Test (27), a Zigzag COD complex (30), and reactive agility tests (20). This array of COD assessments varied in total distance (9 m to 60 m), the number of changes in direction (1 to 7), and varied in angle of these changes in direction (45° to 180°) (Table 2.2).

Lateral jump assessments used by researchers (*n* = 5) in this literature review included single-leg countermovement jumps (i.e. jumps initiated from a stationary position) (21, 27, 32), and single-leg reactive jumps (i.e. jumps that were preceded by a drop or a prior jump) (2, 20) (Table 2.3).

**Table 2.2. Mean and standard deviation of COD kinetic and performance variables.** IAT = Illinois agility test, GCT = ground contact time, VGRF = vertical ground reaction forces, LGRF = lateral ground reaction forces.

| | | **Male** (mean ± SD) | **Female** (mean ± SD) |
|---|---|---|---|
| Lockie et al. (27) | 505R (s) | 2.53 ± 0.16 | 2.94 ± 0.26 |
| | 505L (s) | 2.54 ± 0.19 | 2.90 ± 0.25 |
| | IAT (s) | 16.78 ± 0.99 | 19.02 ± 1.49 |
| Condello et al. (6) | 60° COD GCT (s) | 0.23 ± 0.03 | 0.24 ± 0.03 |
| | **VGRF** | | |
| | Mean Force (N/kg) | 26.9 ± 4.5 | 24.3 ± 3.2 |
| | **LGRF** | | |
| | Mean Force (N/kg) | 17.3 ± 2.8 | 14.2 ± 3.1 |
| Meylan et al. (30) | Zigzag COD (s) | 10.86 ± 0.66 | 11.17 ± 0.61 |

| | | **Dominant Leg** (mean ± SD) | **Non-Dominant Leg** (mean ± SD) |
|---|---|---|---|
| Henry et al. (20) | Reactive Agility (s) | 1.48 ± 0.07 | 1.56 ± 0.12 |

| | | **Non-Studded** (mean ± SD) | **Natural Stud** (mean ± SD) | **Synthetic Stud** (mean ± SD) |
|---|---|---|---|---|
| Brock et al. (2) | **180° COD VGRF** | | | |
| | Peak Force (N/kg) | 4.8 ± 0.9 | 5.0 ± 0.7 | 5.0 ± 0.7 |
| | **180° COD LGRF** | | | |
| | Peak Force (N/kg) | 1.3 ± 0.2 | 1.3 ± 0.3 | 1.4 ± 0.3 |

**Table 2.3. Mean and standard deviation of lateral jump kinetic and performance variables**. [a]GRF data reported as pooled kinetic variables, [b]Peak force = force at push-off, [c]Minimum force = braking force, VGRF = vertical ground reaction forces, HGRF = horizontal ground reaction forces, LGRF = lateral ground reaction forces.

| | | | | |
|---|---|---|---|---|
| | | **Lateral Countermovement Jumps** | | |
| | | **Dominant Leg** (mean ± SD) | | **Non-Dominant Leg** (mean ± SD) |
| Meylan et al. (32) | Jump Distance (m) | 1.51 ± 0.12 | | 1.44 ± 0.12 |
| | **VGRF** | | | |
| | Eccentric Peak Force (N) | 1174 ± 154 | | 1165 ± 179 |
| | Concentric Peak Force (N) | 1250 ± 176 | | 1258 ± 170 |
| | Concentric Peak Power (W) | 1098 ± 279 | | 1102 ± 244 |
| | **LGRF** | | | |
| | Eccentric Peak Force (N) | 397 ± 140 | | 362 ± 128 |
| | Concentric Peak Force (N) | 643 ± 160 | | 561 ± 121 |
| | Concentric Peak Power (W) | 1356 ± 497 | | 1065 ± 337 |
| Hewit et al. (21) | Jump Distance (m) | 1.50 ± 0.11 | | 1.50 ± 0.14 |
| | **VGRF** | | | |
| | Peak Force (N) | 451 ± 73 | | 432 ± 63 |
| | Peak Power (W) | 1279 ± 427 | | 1280 ± 461 |
| | | **Male** (mean ± SD) | | **Female** (mean ± SD) |
| Lockie et al. (27) | Jump Distance (Right) (m) | 1.64 ± 0.25 | | 1.21 ± 0.21 |
| | Jump Distance (Left) (m) | 1.62 ± 0.25 | | 1.26 ± 0.22 |
| | | **Lateral Reactive Jumps** | | |
| | | **Dominant Leg** (mean ± SD) | | **Non-Dominant Leg** (mean ± SD) |
| Henry et al. (20)[a] | Jump Distance (m) | 2.08 ± 0.16 | | 2.02 ± 0.15 |
| | RSI ($m \cdot s^{-1}$) | 5.95 ± 0.96 | | 5.70 ± 0.83 |
| | **VGRF** | | | |
| | Peak Force (N/kg) | | -24.7 ± 2.4 | |
| | Mean Force (N/kg) | | -18.1 ± 1.4 | |
| | **HGRF** | | | |
| | Peak Force[b] (N/kg) | | 2.3 ± 0.4 | |
| | Minimum Force[c] N/kg) | | -3.3 ± 1.0 | |
| | Mean Force (N/kg) | | -0.1 ± 0.4 | |
| | **LGRF** | | | |
| | Peak Force (N/kg) | | 7.7 ± 1.2 | |
| | Mean Force (N/kg) | | 5.4 ± 0.7 2 | |
| | | **Non-Studded** (mean ± SD) | **Natural Stud** (mean ± SD) | **Synthetic Stud** (mean ± SD) |
| Brock et al. (2) | **VGRF** | | | |
| | Peak Force (N/kg) | 4.8 ± 0.9 | 5.0 ± 0.7 | 5.0 ± 0.7 |
| | **LGRF** | | | |
| | Peak Force (N/kg) | 1.3 ± 0.2 | 1.3 ± 0.3 | 1.4 ± 0.3 |

**Relationship Between Multi-Directional Jump and COD Performance**

Unilateral lateral jumps were used in 5 of the included studies. Only two of these research groups reported relationships between unilateral lateral jumps and COD performance. Henry et al. (20) and Lockie et al. (27) noted very weak (reactive lateral jump ($r = -0.12$)) to strong (lateral CMJ ($r = -0.67$)) associations between lateral jump distances (m) and COD completion time (s).

The same two research groups also investigated the relationship between vertical and horizontal jump and COD performance. These studies (20, 27) reported weak (reactive vertical jump ($r = -0.28$)) to moderate (vertical CMJ ($r = -0.46$)) associations between COD completion time (s) and vertical jump distances (m). The same researchers also reported very weak (reactive horizontal jump ($r = -0.15$)) to strong (horizontal CMJ ($r = -0.66$)) associations between COD completion time (s) and horizontal jump distances (m).

Henry et al. (20) was the only study in this review to quantify the relationship between jump GRF performance measures and COD performance. Henry et al. (20) reported very weak to moderate associations ($r = -0.01$ to $0.48$) between lateral, vertical and horizontal reactive jump GRFs and reactive agility time (s). The strongest associations were reported for the lateral ($r = 0.45$) and horizontal ($r = 0.48$) jump peak GRFs in the vertical plane while the weakest associations were observed for lateral ($r = -0.01$) jump peak GRFs in the horizontal plane and vertical ($r = -0.05$) jump peak GRF in the lateral plane (Table 2.4).

**The Effect of Sex and Maturation**

Six of the included studies reported the effect of sex (5, 6, 18, 23, 27, 30) and one study examined the effect of maturation (29) on jump and COD performance.

**Table 2.4. Mean and standard deviation of lateral, horizontal and vertical jump performance variables and correlations between COD performance**. [a]Peak force = push-off force, [b]Minimum force = braking force, LCMJ = lateral countermovement jump, HCMJ = horizontal countermovement jump, VCMJ = vertical countermovement jump, RLJ = reactive lateral jump, RHJ = reactive horizontal jump, RVJ = reactive vertical jump, VGRF = vertical ground reaction forces, HGRF = horizontal ground reaction forces, LGRF = lateral ground reaction forces, IAT = Illinois Agility Test, NA = not available.

| | | **Lateral Jumps** | | | | **Horizontal Jumps** | | | | **Vertical Jumps** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Performance | Correlation | | | Performance | Correlation | | | Performance | Correlation | | |
| Henry et al. (20) | | **RLJ** | **Reactive Agility** | | | **RHJ** | **Reactive Agility** | | | **RVJ** | **Reactive Agility** | | |
| | Distance (m) | 2.05 ± 0.15 | -0.12 | | | 2.25 ± 0.18 | -0.15 | | | 0.30 ± 0.04 | -0.28 | | |
| | **VGRF** | | | | | | | | | | | | |
| | Peak Force (N/kg) | -24.7 ± 2.4 | 0.45 | | | -25.0 ± 2.5 | 0.48 | | | -25.9 ± 5.1 | 0.38 | | |
| | Mean Force (N/kg) | -18.1 ± 1.4 | 0.43 | | | -17.9 ± 1.2 | 0.40 | | | -19.7 ± 3.5 | 0.40 | | |
| | **HGRF** | | | | | | | | | | | | |
| | Peak Force[a] (N/kg) | 2.3 ± 0.4 | -0.01 | | | 5.4 ± 0.8 | -0.10 | | | 0.6 ± 0.7 | -0.26 | | |
| | Minimum Force[b] (N/kg) | -3.3 ± 1.0 | 0.02 | | | -0.9 ± 0.6 | -0.06 | | | -6.1 ± 1.3 | 0.35 | | |
| | Mean Force (N/kg) | -0.1 ± 0.4 | -0.16 | | | 2.8 ± 0.6 | -0.28 | | | -4.1 ± 0.8 | 0.24 | | |
| | **LGRF** | | | | | | | | | | | | |
| | Peak Force (N/kg) | 7.7 ± 1.2 | -0.21 | | | NA | -0.23 | | | NA | -0.05 | | |
| | Mean Force (N/kg) | 5.4 ± 0.7 | -0.24 | | | -0.1 ± 0.2 | -0.04 | | | -0.2 ± -0.2 | 0.25 | | |
| Lockie et al. (27) | | **LCMJ R** | **505R** | **505L** | **IAT** | **HCMJ** | **505R** | **505L** | **IAT** | **VCMJ** | **505R** | **505L** | **IAT** |
| | Distance (m) | 1.43 ± 0.32 | -0.57 | -0.55 | -0.66 | 1.92 ± 0.41 | -0.61 | -0.60 | -0.66 | 49.53 ± 13.17 | -0.46 | -0.43 | -0.45 |
| | | **LCMJ L** | **505R** | **505L** | **IAT** | | | | | | | | |
| | Distance (m) | 1.44 ± 0.30 | -0.60 | -0.62 | -0.67 | | | | | | | | |

Six studies compared performance between male and female athletes. These studies compared vertical, horizontal and lateral jump distances, time of completion for COD tasks and GRF recorded during jumps and COD plant steps. All six studies (5, 6, 18, 23, 27, 30) found that males performed better than females in all COD performance variables including completion time (ES = -0.75 to -7.80; $p < 0.05$), GCT (ES = -4.30; $p > 0.05$), and relative force (ES = 0.15 to 0.35; $p > 0.05$).

The effect of sex on jump performance was apparent in measures of jump distance/height (ES = 6.34 to 37.2; $p < 0.05$) where males jumped further and higher than females. Most of these differences might be explained by the fact that the males used in these studies (22, 27, 30) were 4% taller on average than females. One research group (30) reported greater potential energy (PE) (ES = 0.29 to 0.33; $p < 0.05$) in their male cohort, however, this was to be expected as an important component of PE is mass, and the males were 9% heavier. One exception to the male superior performance is the research of Meylan et al. (30) where they reported females jumped further than males in vertical and horizontal jump assessments (ES = -0.75 to -2.47; $p < 0.05$).

The effect of sex on force production was difficult to disentangle as one study (22) reported males produced greater relative force than females in two vertical CMJ assessments (ES = 0.03 to 0.09; $p < 0.05$), while two other studies (5, 18) reported females produced greater relative force than males in unilateral vertical CMJ (ES = -0.12 to -0.22; $p < 0.05$) and repeated single leg hop assessments (ES = -0.41 to -0.75; $p < 0.05$).

Similarly, the effect of sex on power production during jumps was inconclusive as one study (5) found that males produced greater relative power (ES = 0.13 to 0.22; $p < 0.05$) in unilateral vertical CMJ, while another study (30) found that females produced greater relative power (ES = -0.02 to -0.06; $p < 0.05$) in vertical and horizontal CMJ assessments (Table 2.5).

**Table 2.5. Effect of sex on jump and COD performance**. D = dominant, ND = non-dominant, LL = lead leg, TL = trail leg, LCMJ = lateral countermovement jump, GCT = ground contact time, HCMJ = horizontal countermovement jump, VCMJ = vertical countermovement jump, RSLH= repeated single-leg hops, VGRF = vertical ground reaction forces, LGRF = lateral ground reaction forces, IAT = Illinois Agility Test.

| | | | | Male | Female | Effect Size |
|---|---|---|---|---|---|---|
| Ceroni et al. (5) | Unilateral VCMJ | **VGRF** | | | | |
| | | Peak Force (N/kg) | D | 9.12 ± 2.04 | 10.04 ± 2.05 | -0.219 |
| | | | ND | 9.48 ± 2.10 | 10.02 ± 2.20 | -0.117 |
| | | Peak Power (W/kg) | D | 10.44 ± 2.56 | 9.68 ± 2.32 | 0.126 |
| | | | ND | 10.96 ± 2.67 | 9.49 ± 2.54 | 0.215 |
| Condello et al. (6) | 60° COD | **VGRF** | | | | |
| | | GCT (s) | | 0.233 ± 0.03 | 0.237 ± 0.03 | -4.304 |
| | | Mean Force (N/kg) | | 26.9 ± 4.5 | 24.3 ± 3.2 | 0.153 |
| | | **LGRF** | | | | |
| | | Mean Force (N/kg) | | 17.3 ± 2.8 | 14.2 ± 3.1 | 0.345 |
| Harrison et al. (18) | RVSH | **VGRF** | | | | |
| | | Mean Force (N/Js) | D | 20 ± 4 | 31 ± 6 | -0.406 |
| | | | ND | 19 ± 4 | 31 ± 4 | -0.745 |
| | | Potential Energy (J) | D | 100 ± 15 | 50 ± 7 | 0.292 |
| | | | ND | 100 ± 14 | 50 ± 7 | 0.333 |
| Lawson et al. (23) | Step Close CMJ | **VGRF** | | | | |
| | | Peak Force (N/kg) | LL | 144 ± 13 | 130 ± 11 | 0.092 |
| | | | TL | 143 ± 19 | 123 ±16 | 0.062 |
| | | Mean Force (N/kg) | LL | 112 ± 12 | 107 ± 12 | 0.034 |
| | | | TL | 91 ± 16 | 74 ± 14 | 0.072 |
| | | Distance (m) | | 0.60 ± 0.08 | 0.42 ± 0.04 | 37.257 |
| | No Step CMJ | **VGRF** | | | | |
| | | Peak Force (N/kg) | LL | 129 ± 20 | 110 ± 15 | 0.057 |
| | | | TL | 132 ± 21 | 112 ± 18 | 0.050 |
| | | Mean Force (N/kg) | LL | 91 ± 10 | 83 ± 11 | 0.070 |
| | | | TL | 93 ± 3 | 87 ± 11 | 0.068 |
| | | Distance (m) | | 0.56 ± 0.08 | 0.40 ± 0.04 | 33.117 |
| Lockie et al. (27) | 505 R | Time (s) | | 2.54 ± 0.19 | 2.90 ± 0.25 | -6.882 |
| | 505 L | Time (s) | | 2.53 ± 0.16 | 2.94 ± 0.26 | -7.803 |
| | IAT | Time (s) | | 16.78 ± 0.99 | 19.02 ± 1.49 | -1.271 |
| | LCMJ R | Distance (m) | | 1.64 ± 0.25 | 1.21 ± 0.21 | 7.836 |
| | LCMJ L | Distance (m) | | 1.62 ± 0.25 | 1.26 ± 0.22 | 6.341 |
| | SBJ | Distance (m) | | 2.23 ± 0.25 | 1.59 ± 0.25 | 10.052 |
| | VJ | Distance (m) | | 0.59 ± 0.11 | 0.40 ± 0.07 | 20.383 |
| Meylan et al. (30) | VCMJ | **VGRF** | | | | |
| | | Power (W/kg) | | 33.8 ± 3.9 | 34.1 ± 3.9 | -0.020 |
| | | Distance (m) | | 0.239 ± 0.04 | 0.242 ± 0.03 | -2.473 |
| | HCMJ | **VGRF** | | | | |
| | | Power (W/kg) | | 13.2 ± 3.5 | 13.8 ± 2.8 | -0.056 |
| | | Distance (m) | | 1.42 ± 0.17 | 1.44 ± 0.15 | -0.748 |
| | Zig-Zag COD | Time (s) | | 10.86 ± 0.66 | 11.17 ± 0.61 | -0.748 |

## DISCUSSION

The aim of this review was firstly, to summarise the research examining the statistical relationships between lateral jumps and change of direction performance, and secondly, to review the effect of maturation and sex in jump and COD performance.

### Jump and COD Relationship

The two research groups (20, 27) that quantified the relationship between multi-directional jump distances (m) and COD completion time (s) reported weak to strong associations. The strongest associations were found by Lockie et al. (27) between standing broad jump distance (m) and COD time (s) (505L = −0.60, 505R = −0.61, IAT = −0.66) and moderate to strong associations between unilateral lateral jump distance (m) and COD time (s) (LJ right: 505L = −0.55, 505R = −0.57, IAT = −0.66; LJ left: 505L (s) = r = −0.62, 505R = −0.60, IAT = −0.67). The strength of the correlations between the horizontal jumps and the COD assessments may be attributed to the horizontal force requirements needed to accelerate after the COD step. Similarly, the moderate to strong associations between the lateral jumps and COD may be explained by the similar direction of applied force required in the 180° COD task. The same authors (27) reported only moderate associations between vertical jump distance (m) and COD time (s), which intuitively makes sense given the lack of correspondence in the direction of jump force application and the movement task.

Although the results presented by the aforementioned research groups reveal some positive relationships, measures of distances and times only gives a narrow understanding of performance indicators. Kinetic data that detail other measures, such as impulse, is needed to better understand what contributes to higher performances in jumping and COD tasks, given the impulse-momentum relationship. Only one study by Henry et al. (20) quantified the relationship between unilateral reactive jump GRFs and reactive agility completion time (s). Unilateral vertical jumps (r = -0.05 to 0.40), horizontal (r = -0.04 to 0.48) and lateral (r = -0.01 to 0.45) jumps all demonstrated very weak to moderate associations. It needs to be noted that these researchers assessed agility, which is described as a COD in response to a stimulus. Though not directly comparable to the COD studies, the Henry et al (20) research did meet the inclusion criteria of assessing lateral jumps and providing the associated kinetic data. Thus, agility performance is dependent on an athlete's ability to process given stimuli in addition to the physical and technical determinants of COD performance. Therefore, the very weak to moderate association between pre-planned reactive lateral jumps and reactive agility found in this study may be due the additional psychomotor determinants of an agility task. Additionally, the 45° COD used in the reactive agility assessment requires force application in both the lateral and horizontal direction compared to a 180° COD that predominantly only requires lateral force application. This bi-axial expression of force application could also contribute to the very weak to moderate associations reported by Henry et al. (20). These very weak to moderate correlations indicate small shared variance between variables and it appears that the leg strength variables of interest assessed by these research groups are not strong predictors of COD performance.

The reader should be cognizant that the study conducted by Henry et al. (20) grouped male and female participants, and therefore likely to possess bi-polar distributions due to male and female grouping, and may have artificially inflated correlations. Further, due to the small sample sizes and small number of studies included in his review, it is difficult to make any definitive conclusions. With these limitations in mind, there is a need for further research that investigates the relationship between lateral jump and lateral COD performance, with larger sample sizes and sexes segregated for greater insight into the influence of sex.

**Effect of Maturation**

The only research group to present comparisons of jump performance across maturation stages, Meylan et al. (29), investigated vertical and horizontal countermovement jump performance among athletes pre-, circa- and post-PHV. In their study, 42 male and female elite soccer players of different sexes and maturation stages (Table 2.1) were tested in the vertical CMJ and the HCMJ. The pre-PHV group produced the lowest jump distances in both the greatest jump distances (VCMJ = 0.219 ± 0.043 m, HCMJ = 1.24 ± 0.23 m; VCMJ = 0.264 ± 0.063 m, HCMJ = 1.49 ± 0.20 m). These researchers also provided GRF data, and observed the post-PHV group produced greater eccentric mean power, concentric mean power, concentric peak power in both VCMJ and HCMJ compared to the other maturation groups. In summary, post-PHV individuals produced the greatest peak power in both the vertical and horizontal countermovement, yet underperformed in jump distance, while circa-PHV individuals produced the greatest jump distances in both jumps yet produced smaller peak power than the post-PHV group (29). Firstly, the different power and distance results could be explained by a number of factors; 1) leg power and jump height/distance are often thought synonymous but in fact are very different measures with considerable unexplained variance between these measures (32, 38); 2) power involves mass in its calculation, whereas jump distance/height does not and as such the ratio of fat and lean muscle mass can have a large influence on results; 3) related to point 2, because the GRF variables were not expressed as a function of bodyweight it is unclear whether these differences are a function of growth rather than maturation. As individuals go through PHV, their rapid growth contributes to an increase in bodyweight. Often this recent increase in bodyweight and limb length can be a hinderance to performance as neuromuscular qualities such as force capability have not yet adapted to the additional weight and length (25). Further, post-PHV populations experience a rapid increase in body mass (termed as peak weight velocity), yet females experience a greater increase in fat mass than males (24). Therefore, a great deal of care is needed when reporting and interpreting performance measures as a mixed sex group, and as such when assessing youth populations across different maturation stages, it may be more effective to report force and power performance relative to the body mass to account for individual-specific differences (8).

**Effect of Sex**

Five research groups presented kinetic data that examined the sex-specific differences in jump and COD performance, while one study simply reported jump distances and COD times (27). Across all studies assessing COD performance variables, males performed better than females demonstrating small to moderate effect sizes in relative mean force (N/kg) (6), and large effect sizes in reduced ground contact time and completion times (6, 27, 30). This could partially be attributed to the fact that males have greater linear sprint ability and thus entry speed, which would influence COD completion times and mean force values.

A study by Meylan et al. (30) did offer insight into the effect of sex on performance. When maturity was controlled, differences in jump power and performance were unclear except for horizontal jump distances where a small effect size was observed for males to performance better than females ($p$ = 0.04). Differences in sprint acceleration were trivial to small ($p$ = 0.11) (30). Yet differences in 20 m ($p$ = 0.04) to 30 m ($p$ = 0.03) sprints between sexes were found to be moderate to large , and differences in COD tasks between sexes were found to be moderate ($p$ = 0.02) (30). The authors of this study identified that moderate to large differences between sexes in sprint and COD performance may be due body composition, specifically the differences in fat and lean body mass. The findings of this study are consistent with the aforementioned study (25) that reported as males and females reach PHV sex related differences would become more apparent due to maturational changes such as differences in lean body mass.

All five studies reported relative force (N/kg) during jump assessments which allows for more definitive conclusions to be made regarding the effect of sex. As discussed above, sex related differences in mass would undoubtably influence kinetic performance measures if measures of force or power were not normalised. Males only demonstrated greater relative force in one study (23) with small effect sizes. However, two research groups found that females produced greater relative peak force in unilateral vertical jumps (5) and greater relative mean force during repeated vertical single-leg hops (18) with small and moderate to large effect sizes, respectively.

Concerning the two studies wherein females produced greater relative forces, Ceroni et al. who assessed unilateral vertical CMJ performance (5) found that females produced 8% greater peak force (N/kg) than males (ES = 0.12 to 0.22; $p < 0.05$), while males produced 10% greater peak power than females (ES = 0.13 to 0.21; $p < 0.05$). Ceroni et al. concluded that although females demonstrated greater muscular strength than males, their deficiency in muscle power could be attributed to lesser muscular contraction velocity (5). This difference in power and muscular contractile velocity could be due to adolescent females possessing less lean muscle mass, and hence a decreased percentage and distribution of fast twitch muscle fibres (42). Also, it should be noted that if females have greater non-contractile mass compared to males, their velocities will naturally be slower given the different body composition for the same body mass.

The second of these studies by Harrison et al. (18) compared force attenuation between sexes during repeated vertical single-leg hops and found that females produced 41% larger relative mean forces (ES = 0.41 to 0.74; $p < 0.05$) and 58% greater relative force loading rates (ES = 0.15; $p < 0.05$) than males during the 15 repeated single-leg hop assessment. However, males demonstrated 50% greater PE (ES = 0.29 to 0.33; $p < 0.05$) in a repeated single leg hop assessment. This research conducted by Harrison et al. (18) expected mass and vertical jump height would be greater in males compared to females and as such, used a normalised PE that considered mass, acceleration due to gravity and vertical single-leg jump height. Even though females possessed less PE, they experienced significantly greater landing forces. The authors concluded that these findings could be indicative of inefficient attenuation of impact forces (30). This difference in jump attenuation is consistent with other studies comparing landing strategies between sexes. Sigward et al. (39) examined drop jumps and reported knee/hip energy absorption ratios between sexes and maturation stages. Females across all maturation stages produced greater knee dependant loading strategies (knee/hip ratio: males = 2.0 ± 0.1, female = 2.9 ± 0.1) (39).

Of the three studies that reported jump distances (m), males produced 28% greater jump distances (ES = 6.34 to 37.2; $p < 0.05$) in two of the studies (23, 27). The one exception to the male trend in jump performance is the research of Meylan et al. (30) where they reported females (11.3 ± 0.9 yr) jumped 1% further (ES = -0.75 to -2.47; $p < 0.05$) than males (11.0 ± 1.1 yr.). This observation may be a consequence of females typically experience their adolescent growth starting at 10 and experience PHV at age 12, while males typically begin to experience adolescent growth at 12 and PHV at 14 (24). During adolescent growth prior to PHV, accelerated improvements occur in strength, speed, explosive strength and endurance (24). This maturation advantage could largely explain the observations of Meylan et al. (30) in a group of predominantly 11-year-old male and female athletes.

Although the differences in jump and COD performances have been investigated, it is noted that only one research group (16) investigated the effect of sex on the efficacy of jump performance as a predictor of COD performance. Lockie et al. (27) used a stepwise linear regression analysis between COD speed and sex, 0–20 m sprint intervals, vertical jump, standing broad jump, lateral jump, and absolute and relative isometric midthigh pull. Lockie et al. (27) found that the 505L was best predicted by sex, 0-20m sprint, and LJ L (r = 0.85), the 505R was best predicted by sex, 0-20m sprint, and LJ L (r = 0.89) and the Illinois agility test was best predicted by sex, 0-20m sprint, LJ R, and relative IMTP (r = 0.93). No doubt these results were influenced by the bi-polar (male-female) data, with sex being the best single predictor of COD. It is not surprising that linear sprint ability and lateral jump performance added value to the COD predictor equations given the more linear nature of the tests examined.

There are very few researchers that have investigated the effect of sex and maturation on lateral jump and lateral COD performance. These researchers seem to suggest that males often produced better performance in the COD variables of interest and males also produced greater jump distances than females. From the limited number of researchers that investigated GRF variables during jump assessments, females have produced larger relative GRFs while males have produced greater relative power measures, both of which may be due to differences in lean muscle mass associated with sex and maturational anthropometric changes. A great deal more research is needed before definitive conclusions can be made concerning what stages of maturation may affect male or female lateral leg power and COD capabilities.

**PRACTICAL APPLICATIONS**

This review of the literature has demonstrated several important considerations for coaches and practitioners.

Firstly, moderate to large correlations have been observed between lateral jump distances and lateral COD performance times. Practitioners may be able to use lateral jumps as a predictive tool for the development of lateral COD performance. This could be part of a framework of multi-directional jump assessments that could provide diagnostic information on an athlete's COD ability and guide individualised training for a greater influence on performance. However, it should be noted that there was a fair degree of unexplained variance in correlations between the two tasks, suggesting coaches should refrain from determining lateral COD ability solely based on one assessment as COD ability requires a multifaceted approach.

Secondly, sex and maturation will influence jump and COD performance due to differences in muscle qualities and body composition. The investigations considering the effect of sex on jump and COD performance demonstrated that males typically outperform females. Those investigating the effects of maturation found that post-PHV athletes outperformed other maturation stages, however, in both cases many of the researchers did not consider the influence of body mass in GRF measures, which no doubt has influenced the interpretation of results. To truly understand differences between groups, GRF measures should be reported relative to body mass. Additionally, coaches should consider the ratio of fat and lean muscle mass between males and females that may be affecting muscle qualities required by lateral jump and COD performance.

Finally, more research is needed to understand relationships between lateral jump and COD performance, and the influences of sex and maturation. Research consisting of randomised control designs used to determine the effects of lateral jump training programmes and subsequent changes in COD performance would be of particular interest.  Future research regarding jumps that require applied force predominantly in the medio-lateral direction will allow practitioners to confidently use lateral jumps as an effective developmental and predictive tool.

# CHAPTER 3 – VARIABILITY OF LATERAL JUMP AND CHANGE OF DIRECTION KINEMATICS AND KINETICS IN YOUTH ATHLETES

*This chapter is currently pending review in International Journal of Sports Science and Coaching.*

Reference:

Noudehou, M., Neville, J., Bourgeois, F.A., Cahill, M.J., Deiwald, S. and Cronin, J.B. Variability of Lateral Jump and Change of Direction Kinematics and Kinetics in Youth Athletes. *International Journal of Sports Science and Coaching* (Submitted 4/16/2021).

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Noudehou M, 80%; Neville J, 5%; Bourgeois FA, 5%; Deiwald S, 5%; Cronin JB, 3%; Cahill MJ, 2%.

**PRELUDE**

The previous chapter evaluated the current research regarding the relationship between lateral jump performance measures and COD performance and demonstrated a need for more research investigating the shared characteristics between lateral jump and 180° COD performance. Additionally, this identified a need for investigations that consider for the effect of sex and maturation on lateral jump and COD performance.

Before a cross-sectional study can be conducted to determine the associations between lateral jump variables and 180° COD performance, the reliability of kinematic and kinetic variables of lateral jumps must be established.

Chapter 3 has established the variability of kinematic and kinetic performance variables associated with single-leg lateral countermovement jump, a single-leg lateral reactive jump, and 180° COD assessments. Due to a limited participant sample size resulting from the impact of COVID-19, this study was not able to investigate the reliability of these assessment across all maturation groups.

**INTRODUCTION**

Lateral change of direction (COD) ability is considered an essential factor of success in field- and court-based sports. Currently, coaches commonly use jumps (e.g. vertical or broad jump) to evaluate leg muscle qualities that contribute to COD performance. Practically, jumps should be classified in terms of the direction of force application (i.e. vertical, anterior-posterior and medio-lateral), and whether the movement involves unilateral or bilateral force production (3). Additionally, jumps can be classified by whether they assess fast stretch shortening cycle (SSC) qualities, often tested using reactive type jumps (RJ) or whether they assess slow SSC qualities, often assessed through countermovement jumps (CMJ) (16). Fast SSC involve short contraction times (<0.25 seconds) and little angular displacement in the hip knee and ankle joints, while slow SSC involves long contraction times and large angular displacement in the joints (16). Jumps performed on vertical and anterior-posterior axes may be inappropriate to assess and develop lateral COD performance as these jumps share less similar dynamic correspondence with tasks requiring predominantly medio-lateral force application. Of interest is whether using a lateral CMJ (LJ - slow SSC) or lateral reactive jump (LRJ - fast SSC) would allow for a practical and individualised assessment of lateral qualities that contribute to COD performance.

Prior to using any test, it is important to understand the variability associated with measurements of interest. Acceptable variability of vertical CMJs and horizontal CMJs kinematic and kinetic variables have been established in many investigations (29, 32). Previously, single-leg LJ have been used in several investigations, however some research groups neglected to report assessment variability (26). Single-leg LJ have been reported (31) to have acceptable variability (CV = 4.0 to 4.6%), however, these researchers chose not to establish the consistency of any kinetic variables associated with single-leg LJ and only assessed within-session variability. Meylan et al. (32) did investigate the variability of both kinematic and kinetic variables of single-leg LJ and found peak force and peak power to be reliable (CV = 3.6 to 14.1%, ICC = 0.70 to 0.96), however, this research was conducted with an adult cohort. Researchers have assessed LRJ performance, initiated from a range of approach jump distances (4, 17, 20). Yet, these research groups did not determine the variability of their unique jump assessments. Research conducted by Weltin et al. (44) has investigated the variability of LRJ using adult participants and found acceptable variability (ICC > 0.86), but only reported the within-session ICC values. Dos' Santos et al. (11) have established acceptable variability of the 505 (a 180° COD assessment) completion times and kinetic variables. Similarly, Dugdale et al. (13) observed low variability in the modified 505 (CV = 0.0 to 5.3%, ICC = 0.84 to 0.89), nonetheless this research group only investigated the variability of completion times.

Given the paucity of research and the cited limitations, the aim of this study was to quantify the variability (CVs and ICCs) of LJ, LRJ and COD kinematic and kinetic performance variables in youth populations, across multiple testing sessions (test-retest reliability). The findings will enable coaches and practitioners to understand respective variables when seeking to describe changes in lateral jump and COD performance.

## METHODS

### Experimental Approach to the Problem

A 3-week repeated measures design was used to quantify the between-session variability of the LJ and LRJ distances, COD completion times, and LJ, LRJ and COD plant-step kinetics in youth male and female soccer players. The jumps and 180° COD assessment were performed across three testing sessions, each separated by seven days. A force plate was used to record GRF of two trials performed on each leg for each of the three assessments.

### Participants

Fourteen participants, eight female and six male, (mass = 50.7 ± 14.6 kg, height = 1.59 ± 0.12 m, leg length = 0.95 ± 0.08 m, age = 12.2 ± 1.9 yr, PHV = 0.02 ± 1.60) took part in this study. The cohort comprised active youth club soccer athletes. All participants were cleared by their coaches and the research team to be physically capable of performing all assessments. In addition, all participants had at least one year of organised sports training and trained <10 hr·wk$^{-1}$. All the participants and their parents provided signed informed assent and consent forms. This research was approved by the Auckland University of Technology Ethics Committee (AUTEC 19/447).

**Testing Procedures**

Anthropometrics (body mass, seated height, standing height and right leg-length) were recorded using a calibrated scale and stadiometer (Seca 769 Value Digital Column Scale with Stadiometer, Seca, China), and a tape measure, respectively. Leg length was measured from the right anterior superior iliac crest to their lateral malleolus (33). All participants were measured by the same researcher to reduce measurement variability. Prior to each data collection, individuals were required to undertake a standardised 15-minute warm up consisting of dynamic stretching, submaximal running and jumping, which included three familiarisations of each jump and COD assessment. Participants were then asked to complete two attempts of each of the two jumps assessments: LJ and LRJ. During all jump assessments, participants were allowed the use of their arms. Finally, participants completed a 180° COD assessment, performing two attempts on each leg. Participants were allotted one minute rest between trials. Instructions and feedback were specific to each assessment and mentioned below. Participants repeated identical testing procedures twice more, each session separated by seven days.

**Assessments**

*Single-leg Lateral Countermovement Jump (LJ)*. Each participant started with the medial edge of the jump leg behind the starting line on the centre of the force plate in an upright position with their hands extended above head. Participants were instructed to quickly swing arms down, squat to a self-selected depth, jump as far as possible contralaterally, and land on two feet. Landings were deemed successful if the participants landed on two feet while maintaining balance. Single-leg LJ distance was measured from the lateral edge of the foot nearest the start line. Jump distances were recorded using a tape measure and confirmed using video analysis software (Kinovea, Version 0.8.15). Triaxial GRF data was collected using an embedded force plate (AMTI Optima 600900, Massachusetts, USA) using a sampling rate of 1000 Hz. AMTI force plate software was used to extract time-series GRF data.

*Single-leg Lateral Reactive Jump (LRJ).* Each participant assumed an identical start position to the LJ. However, jump distances were set relative to individual leg-lengths of 1.0 x leg-length (LRJ1.0) and 0.5 x leg-lengths (LRJ0.5). From an upright position with their hands extended above head participants were instructed to quickly swing arms down, squat to a self-selected depth, jump medially, landing on the opposite foot within a designated 1.0 m x 1.2 m contact zone on the force plate. Once contact was made participants were instructed to immediately perform a maximal second single-leg reactive jump while minimising ground contact time (GCT) back towards their start location, and land on two feet. Trials were deemed successful if participants landed on two feet and maintained balance. Single-leg LRJ distance (i.e. the second jump) was measured from the medial edge of the foot landing on the force plate to the lateral edge of the foot closest to the start line. Jump distance and kinetic variables were measured using the identical method of the LJ.

*180° COD.* A modified 505 assessment was used to evaluate 180° COD performance (13, 34). Participants began in a two-point staggered stance, 9.14 m away from the force plate, with their preferred foot forward. Participants were instructed to sprint forward, turn 180° on a predetermined leg within the designated contact zone on the force plate, and sprint back 4.57 m to finish. Participants were instructed to sprint as fast as possible to ensure near maximal approach speeds. Trials that were deemed submaximal were repeated. The dual-laser timing gates were set 4.57 m ahead of the start line, at hip and knee height. The time taken to complete the last half of the approach sprint (4.57 m), the change direction and exit sprint (4.57 m) were recorded using timing gates (OptoJump, Microgate, Bolanza, Italy). Kinetic measures of the plant-step during the

180° COD were collected via embedded force plates using methods identical to the LJ and LRJ assessments. Within- and between-individual plant-step variability was controlled by placing a 1.0 m x 1.2 m contact zone in the centre of the force plate. Kinovea video analysis was used to control the quality of movement to ensure participants stepped on the force plate without stumbling during the entry and exit of the 180° COD assessment.

**Data Analysis**

Force plate data was collected using AMTI software (AMTI Optima 600900, Massachusetts, USA) and exported as csv files. Using MATLAB (R2020a, Version 9.8, March 28, USA) a custom algorithm was created to import force-time data. Graphical representations of force-time data were created for each trial to enable the manual selection of force onset and force offset points, as well as removing trials that were visually identified as unsuccessful trials. Performance variables of interest included relative peak force (PF), relative total impulse (TI), and GCT, and were automatically extracted for each of the jump and COD trials using customised software.

**Statistical Analysis**

Mean and standard deviations were calculated for all variables to describe the centrality and spread of data. RStudio IDE (Version 1.4.869, 2009 – 2020 RStudio, PBS) was used to examine the variability of the metrics of interest across the three testing days. Data was collected on both left and right legs, however, given no significant interlimb differences, the best two trials of each leg were averaged and used for analysis. Normality was visually assessed using Q-Q Plots, and intra-session z-scores were then calculated. Of the 90 variables collected over the three testing sessions, 10 variables were found to be non-normally distributed ($p < 0.05$) via the Shapiro-Wilks statistics and removed from further analysis. Z-scores greater than 3 were considered outliers. Trials that produced outliers in multiple variables were cross examined using video analysis. Outliers were removed if participants demonstrated great variability in jump and COD strategies within-session.

The within-subject CV, and ICC (two-way mixed effects, single, absolute agreement) were used to analyse absolute, and relative consistency, respectively. Within-subject CV were calculated using the root mean square approach. Confidence intervals of 95% were reported. An ICC < 0.67 and CV > 15% were deemed as having large variability, moderate variability when either the ICC > 0.67 or the CV < 15%, but not both, and small variability when ICC > 0.67 and CV < 15% (36, 41).

**RESULTS**

The means, standard deviations, CVs and ICCs for all variables across testing occasions can be observed in Table 3.1. It appears there was better consistency (i.e. lower variability) associated with the day 3-2 comparisons (12 variables with low variability), as compared with day 2-1 comparisons (9 variables with low variability), therefore hereafter the results and discussion will focus on day 3-2 data.

In terms of the LJ, distance was the only variable to have acceptable variability (CVs < 4.6%, ICCs > 0.84). The kinetic variables absolute consistency (CV = ~20-44%) and relative consistency (ICC = ~0.32 – 0.66) did not meet acceptable standards of consistency.

Regarding the LRJ1.0 and LRJ0.5, all but one variable had moderate to low variability, with CVs ranging from 4.5% (distance) to 15.8% (total impulse), and ICCs from 0.14 (peak force) to 0.89 (distance and GCT). It appears that the left limb results are less variable than the right with two variables (GCT and total impulse) having low variability in addition to the jump distance for both limbs. The LRJ0.5 was slightly less consistent than the LRJ1.0, having high variability in left leg total impulse.

Concerning the 180° COD, completion time was the only variable with low variability (CVs < 3.2%, ICCs > 0.85). Peak force and total impulse variables absolute consistency (CV = ~15-19%) and relative consistency (ICC = ~0.03-0.45) did not meet acceptable standards of consistency however, GCT variables was found to have moderate variability (CV = 10.5%, ICC = 0.479).

**Table 3.1. Between session variability of LJ, LRJ and COD performance variables.** LJ = lateral jump, LRJ = reactive lateral jump, COD = 180° change of direction, GCT = ground contact time, SD = standard deviation, CV = coefficient of variation, ICC = interclass correlation coefficients, LL = lower limit, UL = upper limit, LJ = lateral jump, LRJ = reactive jump, COD = 180° COD, GCT = ground contact time. ***= Small Variability, ** = Moderate Variability; * = Large Variability

| | **Performance Variable** | ***Mean + SD*** | | | ***CV (%) [CI]*** | | ***ICC [LL, UL]*** | |
|---|---|---|---|---|---|---|---|---|
| | | **Day 1** | **Day 2** | **Day 3** | **Days 2-1** | **Days 3-2** | **Days 2-1** | **Days 3-2** |
| **$LJ_R$** | **Distance (m)*** ** | 1.43 ± 0.19 | 1.40 ± 0.17 | 1.43 ± 0.16 | 4.5 [3.1, 5.5] | 4.5 [0, 6.4] | 0.89 [0.70, 0.96] | 0.84 [0.59, 0.95] |
| **$LJ_L$** | **Distance (m)*** ** | 1.44 ± 0.18 | 1.45 ± 0.15 | 1.51 ± 0.15 | 4.5 [2.1, 6] | 3.2 [2.2, 3.9] | 0.86 [0.62, 0.95] | 0.86 [0.32, 0.96] |
| **$LJ_R$** | **Peak Force (N/kg)*** | 1.12 ± 0.32 | 1.03 ± 0.31 | 1.08 ± 0.28 | 22.6 [10.6, 30.1] | 20.7 [0, 31.2] | 0.59 [0.07, 0.85] | 0.64 [0.19, 0.87] |
| **$LJ_L$** | **Peak Force (N/kg)*** | 1.00 ± 0.23 | 1.08 ± 0.26 | 1.15 ± 0.33 | 19 [8.2, 25.6] | 23.2 [14.1, 29.7] | 0.48 [-0.02, 0.79] | 0.32 [-0.23, 0.72] |
| **$LJ_R$** | **Total Impulse (m/s)*** | 0.53 ± 0.27 | 0.47 ± 0.16 | 0.49 ± 0.22 | 33.3 [21.4, 42] | 20 [11.3, 25.9] | 0.34 [-0.25, 0.74] | 0.66 [0.22, 0.88] |
| **$LJ_L$** | **Total Impulse (m/s)*** | 0.44 ± 0.19 | 0.50 ± 0.20 | 0.53 ± 0.25 | 43.6 [21.3, 57.8] | 44 [28.3, 55.5] | -0.17 [-0.67, 0.40] | 0.12 [-0.46, 0.61] |
| **$LRJ1.0_R$** | **Distance (m)*** ** | 1.42 ± 0.22 | 1.33 ± 0.18 | 1.38 ± 0.18 | 6.3 [3.7, 8.1] | 5.5 [0, 8.2] | 0.81 [0.20, 0.95] | 0.84 [0.52, 0.95] |
| **$LRJ1.0_L$** | **Distance (m)*** ** | 1.41 ± 0.21 | 1.37 ± 0.19 | 1.41 ± 0.17 | 4.5 [0, 6.4] | 4.5 [0, 6.4] | 0.89 [0.67, 0.96] | 0.89 [0.68, 0.96] |
| **$LRJ1.0_R$** | **Peak Force (N/kg)*** | - | 1.76 ± 0.17 | 1.83 ± 0.23 | - | 9.5 [0, 13.8] | - | 0.14 [-0.41, 0.61] |
| **$LRJ1.0_L$** | **Peak Force (N/kg) *** | - | - | - | - | - | - | - |
| **$LRJ1.0_R$** | **Total Impulse (m/s)**** | 0.63 ± 0.13 | 0.58 ± 0.10 | 0.56 ± 0.14 | 14.8 [7.6, 19.6] | 15.8 [0, 24] | 0.36 [-0.13, 0.73] | 0.70 [0.28, 0.89] |
| **$LRJ1.0_L$** | **Total Impulse (m/s)*** ** | 0.64 ± 0.15 | 0.60 ± 0.14 | 0.58 ± 0.16 | 15.5 [7.9, 20.4] | 10.5 [7.2, 12.9] | 0.53 [0.03, 0.82] | 0.84 [0.57, 0.94] |
| **$LRJ1.0_R$** | **GCT (s)**** | 0.71 ± 0.12 | 0.70 ± 0.10 | 0.66 ± 0.89 | 10.5 [0, 14.8] | 8.9 [4.1, 12] | 0.44 [-0.12, 0.78] | 0.63 [0.17, 0.86] |
| **$LRJ1.0_L$** | **GCT (s)*** ** | 0.71± 0.11 | 0.70 ± 0.13 | 0.68 ± 0.15 | 11 [5.6, 14.5] | 7.1 [4.3, 9] | 0.58 [0.08, 0.84] | 0.89 [0.70, 0.96] |
| **$LRJ0.5_R$** | **Distance (m)*** ** | 1.39 ± 0.14 | 1.29 ± 0.15 | 1.35 ± 0.17 | 5.5 [2.9, 7.2] | 5.5 [0, 7.9] | 0.76 [0.03, 0.94] | 0.80 [0.49, 0.93] |
| **$LRJ0.5_L$** | **Distance (m) ***** | 1.38 ± 0.16 | 1.36 ± 0.20 | 1.38 ± 0.22 | 5.5 [3, 7.1] | 4.5 [3.1, 5.5] | 0.86 [0.61, 0.95] | 0.90 [0.71, 0.97] |
| **$LRJ0.5_R$** | **Peak Force (N/kg)*** | 1.80 ± 0.20 | 1.81 ± 0.13 | - | 9.5 [1, 13.4] | - | -0.14 [-0.68, 0.43] | - |
| **$LRJ0.5_L$** | **Peak Force (N/kg)**** | 1.68 ± 0.19 | 1.82 ± 0.19 | 1.80 ± 0.22 | 10 [2.4, 13.9] | 7.1 [2.8, 9.6] | 0.34 [-0.11, 0.71] | 0.58 [0.08, 0.84] |
| **$LRJ0.5_R$** | **Total Impulse (m/s)*** ** | 0.53 ± 0.17 | 0.52 ± 0.17 | 0.51 ± 0.15 | 19 [9.6, 25] | 13.4 [9.3, 16.6] | 0.71 [0.30, 0.90] | 0.82 [0.52, 0.94] |
| **$LRJ0.5_L$** | **Total Impulse (m/s)*** | 0.54 ± 0.15 | 0.52 ± 0.17 | 0.46 ± 0.19 | 18.4 [10.5, 23.9] | 25.1 [13.8, 32.7] | 0.64 [0.17, 0.87] | 0.57 [0.11, 0.83] |
| **$LRJ0.5_R$** | **GCT (s)*** ** | 0.65 ± 0.16 | 0.62 ± 0.14 | 0.60 ± 0.10 | 16.4 [2.8, 23.1] | 8.9 [6.2, 11] | 0.47 [-0.07, 0.80] | 0.78 [0.46, 0.92] |
| **$LRJ0.5_L$** | **GCT (s)**** | 0.65 ± 0.12 | 0.64 ± 0.13 | 0.57± 0.14 | 11 [6, 14.3] | 13.8 [9.5, 17] | 0.65 [0.20, 0.87] | 0.62 [0.16, 0.86] |
| **$COD_R$** | **Time (s) ***** | 2.66 ± 0.19 | 2.67 ± 0.19 | 2.60 ± 0.17 | 3.2 [2.2, 3.9] | 3.2 [2.2, 3.9] | 0.89 [0.69, 0.96] | 0.85 [0.32, 0.96] |
| **$COD_L$** | **Time (s) ***** | 2.65 ± 0.18 | 2.68 ± 0.21 | 2.62 ± 0.17 | 3.2 [2.2, 3.9] | 3.2 [2.2, 3.9] | 0.86 [0.63, 0.95] | 0.89 [0.48, 0.97] |
| **$COD_R$** | **Peak Force (N/kg)*** | 2.11 ± 0.41 | 1.91 ± 0.41 | 2.14 ± 0.54 | 23.9 [0, 36] | 19 [0, 28.1] | -0.24 [-0.67, 0.31] | 0.45 [-0.03, 0.77] |
| **$COD_L$** | **Peak Force (N/kg)*** | - | - | - | - | - | - | - |
| **$COD_R$** | **Total Impulse (m/s)*** | 0.57 ± 0.09 | 0.56 ± 0.08 | 0.52 ± 0.08 | 15.8 [0, 24.2] | 15.2 [4.5, 21] | -0.03 [-0.58, 0.51] | 0.24 [-0.28, 0.66] |
| **$COD_L$** | **Total Impulse (m/s)*** | 0.55 ± 0.13 | 0.54 ± 0.11 | - | 14.1 [6.1, 19] | - | 0.61 [0.13, 0.86] | - |
| **$COD_R$** | **GCT (s)**** | 0.51 ± 0.73 | 0.52 ± 0.71 | 0.48 ± 0.65 | 5.5 [3, 7.1] | 10.5 [4, 14.3] | 0.86 [0.63, 0.95] | 0.48 [-0.01, 0.79] |
| **$COD_L$** | **GCT (s)*** | 0.47 ± 0.12 | 0.46 ± 0.11 | - | 17 [10.1, 21.9] | - | 0.53 [0.00, 0.82] | - |

**DISCUSSION**

The aim of this study was to determine the performance variability associated with LJ, LRJ1.0, LRJ0.5 and 180° COD assessments in youth soccer athletes. The main findings were: 1) There was less variability associated with the later testing sessions suggesting that some learning effects may have occurred; 2) The LJ distance variability was low, while all other variables did not meet acceptable consistency. 3) All the LRJ performance variables had low to moderate variability. 4) The 180° COD completion time variability was low, yet kinetic performance variables ranged from low to high variability. In summary, jump distances and COD completions times had the lowest variability.

The purpose of performing at least three testing sessions was to determine if there are learning, order or fatigue effects between testing occasions. It would seem that there was some learning effect occurring within later testing occasions, given the lower variability associated with the 3-2 comparisons. This suggests that participants would benefit from longer or additional familiarisation sessions. Research conducted by Stålbom et al. (40) investigating single-leg horizontal drop jump reliability similarly found less between-trial variation in the last day of testing that the authors attribute participants needed additional familiarisation.

The LJ was found to be the most variable assessment, of all the variables of interest, only LJ distance variability was low. Meylan et al. (31) also reported single-leg LJ distances were acceptably consistent (CV = 4.0 to 4.6%). However, the variability of peak force and total impulse variables was high. This may be due to the design of the assessment that allowed more degrees of freedom than the LRJ. The movement sequence required by the LJ, balance-load-jump-land, is a slower series of movements than required by the LRJ. The slowed movements allowed for more variation between sequential steps of the jump and required increased coordination and balance during the take-off phase of the jump. Additionally, participants included in this study were predominantly (80%) within two years of their PHV. This could have had an influence on the variability during assessments. Athletes at this maturation stage experience rapid limb growth that affects coordination and balance (24). Using video analysis of the most variable participants, it was evident that although the assessment cues and parameters remained consistent, participants often changed their methods with the intent of finding their best performance strategies. The larger degree of freedom combined with the biological and training ages of participants could have contributed to the increased variability of the LJ assessment. Additionally, because participants were often unable to stand completely still while balancing on the force platform, accurate selection of the force onset point was difficult due to the inconsistent stationary force prior to jump initiation. This impacted metric calculations which may have influenced the variability of the kinetic variables of interest associated with the LJ assessments.

The novel LRJ assessment proved to the most reliable assessment in terms of kinetics. This may be due to the individualised approach, relative to the participants own leg length. This is consistent with the findings of Weltin et al. (44) who found a similar lateral LRJ assessment to be reliable (ICC > 0.86). The LRJ1.0 was slightly less variable than the LRJ0.5. This may be due to the submaximal nature of the LRJ0.5 assessment. The shorter approach jumps in the LRJ0.5 allowed for more variance in strategy (i.e. predominantly more vertical or horizontal approach jumps proceeding ground contact) compared with the LRJ1.0 assessment that required an increased demand that standardised an individual's approach jump strategy.

The 180° COD performance was found to be widely variable. Consistent with previous research, completion time consistency was found to be high, as expected (11, 13). However, peak force consistency was low and total impulse and GCT consistency ranged from low to high. This may be due to the fact that kinetic performance variables were only collected from the COD plant step. Using Kinovea video analysis of the COD trials, it is clear that participants employed a variety of COD techniques that involved loading the penultimate and subsequent steps with different magnitudes and for different amounts of GCT. Inclusion of the steps surrounding the COD plant step may have reduced variability of these performance measures. For example, Dos' Santos et al. (11) used two force plates in series to record kinetic performance variables of both the penultimate foot contact and final foot contact during a 180° COD assessment, and reported acceptable variability in all kinetic variables (CV = 3.6 to 7.3%, ICC = 0.72 to 0.97).

Jump distances and COD completion times were more consistent than kinetic variables across all assessments (CV < 6.3%, ICC > 0.76). This is consistent with research conducted by Stålbom et al. (40) who found that jump displacement variability was the most consistent variable of interest (CV < 1.4%), while kinetic variables such as peak force were less consistent (CV = 4.3 to 6.5%). Likewise, research by Meylan et al. (32), investigating the variability of unilateral vertical, horizontal and lateral CMJ, found that jump distances (CV < 7%, ICC > 0.87) were more reliable than kinetic variables such as peak force and peak power (CV < 17.7%, ICC > 0.61). Although the variability of kinetic variables was more variable than jump distance and COD completion time, there is still value in understanding the kinetic variables that contribute reliably to performance outcomes that would offer coaches valuable information to determine the most effective training strategies for their athletes.

**Limitations**

A considerable limitation of this study is the small number of participants. The participant sample size ($n$ = 14) was substantially lower than desired due to restrictions and uncertainty associated with COVID-19. Although this study investigated youth participants, it was only able to assess a small segment of youth athlete population. Although the effects of sex and maturation on performance is well established, this study was not able analyse the impact sex and maturation on the variability of these assessments (24). Nonetheless, the investigation of the variability of the two lateral jumps and 180° COD variables in youth soccer athletes provided preliminary data that may guide future research investigating the predictive relationship between lateral jumps and COD performance.

Although familiarization was completed within data collection sessions prior to testing, future research completing similar lateral jump assessment could benefit from independent familiarization sessions prior to data collection. These additional familiarization sessions could decrease the variability of these assessments.

One more limitation of this investigation was the possible variation in approach speed during the COD assessment. Participants were instructed to sprint maximally, however no technology was used to track velocity during the approach. Aside from using a radar gun to track sprint velocity, future researchers could compare a participant's 10m acceleration time split to their 10m approach during the COD assessment. Acceptable thresholds could be set to ensure participants were approaching the 180° COD at a desired percentage of their maximal acceleration.

**SUMMARY**

The jumps and COD movements were relatively novel motor tasks for many of the subjects. Because less variability was observed between sessions 3-2 this suggests some learning effects and therefore it is recommended that longer or additional familiarisation sessions should be implemented if the practitioner wants to use such assessments with athletes of a similar training status. All distance and time measures had the lowest variability, which is reassuring to the practitioner who has a limited budget for equipment. LJ kinetics were shown to be highly variable and whether it would benefit from better familiarisation is unknown, however, the inclusion of this movement in a testing battery needs to be considered with caution. The individualised LRJ assessment was highly consistent can confidently be used in future research to investigate kinematic and kinetic variables. Finally, the 180° COD kinetics was found to be highly variable. As such, coaches should cautiously consider the inclusion of kinetic variables in future analysis as the variation in results may exceed quantifiable improvements.

# CHAPTER 4 - THE PREDICTIVE ASSOCIATIONS BETWEEN MULTI-DIRECTIONAL JUMP VARIABLES AND CHANGE OF DIRECTION PERFORMANCE IN MALES AND FEMALES OF DIFFERENT MATURATION STAGES

*This chapter is currently pending review in Pediatric Exercise Science*

Reference:

Noudehou, M., Neville, J., Bourgeois, F.A., Cahill, M.J., Deiwald, S. and Cronin, J.B. The Predictive Associations Between Multi-Directional Jump Variables and Change of Direction Performance in Males and Females of Different Maturation Stages. *Pediatric Exercise Science* (Submitted 5/3/2021).

Author Contributions:

Noudehou M, 80%; Neville J, 5%; Bourgeois FA, 5%; Deiwald S, 5%; Cronin JB, 3%; Cahill MJ, 2%.

**PRELUDE**

In the previous chapter, the variability of the LJ, LRJ and 180° COD was assessed, concluding that primarily kinematic variables were acceptably consistent. Generally, kinetic variables were largely unreliable for LJ and COD, however the LRJ showed good measures of reliability. Therefore, this chapter focused on the kinematic variables of all assessments and kinetic variables associated with LRJ performance.

Specifically, this chapter presents a cross-sectional study to determine the association between both the LJ and RLJ and 180° COD times across participants of different maturation statuses and sex. Additionally, because the 180° COD assessment comprises linear sprinting requiring horizontal and vertical force application, this study will compare the predictive strength of these lateral jumps to commonly used linear sprint capability as well as vertical and horizontal jump performance. Further, analysis of predictive models was conducted by subgroups separated for different sexes and maturation stages.

## INTRODUCTION

Linear sprint speed and leg muscle qualities are two of the primary contributing factors in change of direction (COD) performance (3). Hence, linear sprint and jump tests, used to assess these contributing factors, are commonly used in assessment batteries to determine COD capabilities (6, 10, 46). Coaches commonly use vertical jumps (VJ) and horizontal jumps (HJ) to assess leg power which have proven to be effective predictors of COD performance (10, 15). However, lateral jumps are less commonly used to assess leg muscle qualities that may contribute to COD performance.

Research that has assessed lateral jump performance has only reported jump distances typically ignoring kinetic performance metrics (26, 28, 33). This limitation has prevented these studies from investigating the strength of associations of both kinematic and kinetic variables to COD performance. Lockie et al. (26) who analysed how single-leg jump performance influenced COD speed only used a male cohort. Research by Meylan et al. (31) who investigated the reliability and associations between single-leg vertical, horizontal, lateral jumps and COD performance sampled an adult population. There are many confounding factors associated with these populations that could influence the relationship between jump and COD performance.

The purpose of this study was to investigate the efficacy of jump kinematic and kinetic performance metrics (distance, RSI, relative peak force, relative total impulse and GCT) recorded during four multi-directional jumps as predictors of 180° COD performance. Furthermore, the impact of sex and maturation on prediction equations was assessed.

## METHODS

### Experimental Approach

A cross-sectional study was designed to measure the strength of associations between sprint performance metrics, vertical, horizontal, and lateral jump performance metrics and COD performance in youth populations of different sexes and maturation stages. Vertical countermovement jumps (VJ), horizontal countermovement jumps (HJ), single-leg lateral countermovement jumps (LJ), and single-leg lateral reactive jumps (LRJ) were used to assess leg muscle qualities in multiple planes. A 9.14-18.28m linear sprint (*Sprint10/Sprint20*) and a modified 505 (180° COD) was used to assess linear sprint ability and COD performance. Performance was defined as completion time in seconds (s). Jump kinematics and kinetics, and COD times were recorded using tape measures, force plates and timing gates. Stepwise linear regression analysis was used to determine predictive models of COD performance within each participant group.

**Participants**

Seventy-three healthy, active youth club soccer athletes, aged 10-16, were recruited for this study (Table 4.1). All participants were cleared by their coaches and the research team to be physically capable of performing all assessments. In addition, all participants had at least one year of organised sports training and trained >10 hr/wk. All the participants and their parents provided written assent and consent forms. This research was approved by the Auckland University of Technology Ethics Committee (AUTEC 19/447). Sex and maturation subgroups, were comprised of the same participants, divided differently.

**Table 4.1 Anthropometrics of Participant Subgroups.** *M = number of males, F = number of females, St. Ht. = seated height, LL = leg length, PHV = peak height velocity, BMI = body mass index.

| | **Male (n = 39)** | | | **Female (n = 34)** | | | **Pre-PHV (n = 30)** | | | **Circa-PHV (n= 23)** | | | **Post-PHV (n = 20)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | | SD | Mean | | SD | Mean | | SD | Mean | | SD | Mean | | SD |
| Sex* | | | | | | | M: 26 | | F: 4 | M: 12 | | F: 11 | M: 1 | | F: 19 |
| Age (yr) | 13.6 | ± | 1.40 | 14.1 | ± | 1.64 | 12.7 | ± | 1.10 | 14.1 | ± | 1.28 | 15.3 | ± | 0.93 |
| Mass (kg) | 46.8 | ± | 12.2 | 52.2 | ± | 12.7 | 39.9 | ± | 6.53 | 53.5 | ± | 12.9 | 58.7 | ± | 9.62 |
| Height (m) | 1.50 | ± | 0.10 | 1.59 | ± | 0.08 | 1.50 | ± | 0.06 | 1.61 | ± | 0.07 | 1.63 | ± | 0.06 |
| St. Ht. (m) | 1.25 | ± | 0.06 | 1.28 | ± | 0.04 | 1.22 | ± | 0.03 | 1.29 | ± | 0.04 | 1.31 | ± | 0.03 |
| LL (m) | 0.96 | ± | 0.07 | 0.95 | ± | 0.06 | 0.92 | ± | 0.05 | 0.97 | ± | 0.07 | 0.99 | ± | 0.05 |
| PHV | -1.34 | ± | 1.27 | 1.01 | ± | 1.22 | -2.01 | ± | 0.67 | 0.21 | ± | 0.49 | 1.87 | ± | 0.56 |
| BMI | 18.9 | ± | 3.22 | 20.6 | ± | 3.76 | 17.5 | ± | 1.75 | 20.4 | ± | 4.12 | 22.0 | ± | 3.17 |

**Testing Procedures**

Anthropometrics (body mass, seated height, standing height, and right leg-length) were recorded using a calibrated scale (Seca 769 Value Digital Column Scale with Stadiometer, Seca, China) and a tape measurer. Leg length was measured from the right iliac crest to their lateral malleolus (33). All participants were measured by the same researcher to reduce measurement variability. After anthropometric measurements, participants were randomly divided into groups. All participant groups then executed a standardised 15-minute warm up consisting of dynamic stretching, and submaximal running and jumping, which included three familiarisation attempts of each jump and COD assessment. Each group then completed assessments in different orders. Participants were asked to complete two attempts of each of the five jumps assessments: VJ, HJ, LJ, LRJ1.0 and LRJ0.5. Jump landings were deemed successful if the participants landed on two feet and were able to keep their balance. Participants were asked to complete two attempts of a 10-20YD linear sprint. Participants also completed a 180° COD test, performing two attempts on each leg. Participants received one minute of rest between trials. Instructions and feedback were specific to each assessment and mentioned below.

**Assessments**

*Single-leg Lateral Countermovement Jump (LJ)*. Each participant started with the medial edge of the jump leg behind the starting line on the centre of the force plate in an upright position with their hands extended above head. Participants were instructed to quickly swing arms down, squat to a self-selected depth, jump as far as possible contralaterally, and land on two feet. Landings were deemed successful if the participants landed on two feet while maintaining balance. Single-leg LJ distance was measured from the lateral edge of the foot nearest the start line. Jump distances were recorded using a tape measure and confirmed using video analysis software (Kinovea, Version 0.8.15). Triaxial ground reaction force (GRF) data was collected using an in-ground force plate (AMTI Optima 600900, Massachusetts, USA) using a sampling rate of 1000 Hz. AMTI force plate software was used to extract time-series GRF data.

*Single-leg Lateral Reactive Jump (LRJ).* Each participant assumed an identical start position to the LJ. However, jump distances were set relative to individual leg-lengths of 1.0 x leg-length (LRJ1.0) and 0.5 x leg-lengths (LRJ0.5). From an upright position with their hands extended above head participants were instructed to quickly swing arms down, squat to a self-selected depth, jump medially, landing on the opposite foot within a designated 1.0 m x 1.2 m contact zone on the force plate. Once contact was made participants immediately performed a maximal second single-leg reactive jump while minimising GCT back towards their start location, and land on two feet. Single-leg LRJ distance (i.e. the second jump) was measured from the medial edge of the foot landing on the force plate to the lateral edge of the foot closest to the start line. Jump distance and GRF were measured using the identical method of the LJ.

*180° COD.* A modified 505 assessment was used to evaluate 180° COD performance (13, 15). Participants began in a two-point staggered stance, 9.14 m away from the force plate, with their preferred foot forward. Participants were instructed to sprint forward, turn 180° on a predetermined leg within the designated contact zone on the force plate, and sprint back 4.57 m to finish. The dual-laser timing gates were set 4.57 m ahead of the start line, at hip and knee height. The time taken to complete the last half of the approach sprint (4.57 m), the change direction and exit sprint (4.57 m) were recorded using timing gates (OptoJump, Microgate, Bolanza, Italy). Kinetic measures of the plant-step during the 180° COD were collected via in-ground force plates using methods identical to the LJ and LRJ assessments. Within- and between-individual plant-step variability was controlled by placing a 1.0 m x 1.2 m contact zone in the centre of the force plate. Kinovea video analysis was used to assess the quality of movement during the entry and exit of the 180° COD assessment.

*Linear Sprints (Sprint10/Sprint20).* Timing gates used to measure completion times were set on the start line, at 9.14m (10 yd) and at 18.28m (20 yd) away from the start line (OptoJump, Microgate, Bolanza, Italy). Each participant began on their own volition, in a two-point stance, 0.30 m behind the start line. Participant performance in the early acceleration phase (9.14 m) and full acceleration (18.28 m) was recorded.

*Bilateral Vertical Countermovement Jump (VJ).* Vertical jump height predicted from flight time was measured using OptoJump gates and software (OptoJump, Microgate, Bolanza, Italy). Each participant started on two legs with feet between the OptoJump gates and hands above their head. The participant, following similar instructions to the lateral countermovement jump, jumped as high as possible while keep legs straight in flight and land on two feet.

*Bilateral Horizontal Countermovement Jump (HJ).* Horizontal jump distance was measured using a tape measure with results rounded to the nearest 0.5 cm. Each participant started on two legs with the toes on the edge of the starting line and hands above head. Participants, following similar instructions to the lateral countermovement jump, jumped as far forward as possible and landed on two feet. The distance covered was measured from the heel of the foot closest to the start line.

**Data Analysis**

Variables of interest collected during jump and COD tasks were calculated using MATLAB (R2020a, Version 9.8, March 28, USA). Specifically, a custom algorithm was created to import force-time data from a csv format and create graphical representations of force-time data for each trial. The primary researcher manually selected force onset and force offset times. A manual selection of force on-set and off-set was chosen due to the influence of noise before and after jump trials causing errors in several automated methods. The force onset point was determined as the first point along the x-axis to cross a 20 N threshold. The force offset point was determined as the first point to return below the threshold in the x-axis. Manual selection was completed by one researcher to maximise intra-rater reliability. In addition to jump distances and sprint times, kinetic performance metrics of interest included relative peak force (PF, maximum force reading between selected onset and offset), relative total impulse (TI, the integration of force data from onset to offset), and ground contact time (GCT, the time between onset and offset), were automatically extracted for each of the jump and COD trials using a customised software ʻ. Kinetic variables associated with the LJ and COD assessment were found to be inconsistent and as such only kinetic variables associated with LRJ assessments were investigated. Additionally, the reactive strength index (RSI) of the LRJ1.0 and LRJ0.5 was calculated by dividing jump distance by GCT (16).

**Statistical Analysis**

The best two trials of each assessment were averaged and used for further analysis. Mean and standard deviations were calculated for all variables. To determine the magnitude of the effects due to sex or maturation, a two-way ANOVA was performed using fixed factors of sex (1 = male, 2 = female) and maturation (1 = Pre-PHV, 2 = Circa-PHV, 3 = Post-PHV). The assumptions of ANOVA were checked (normality of dependant variable, homogeneity of variances). Estimated marginal means were calculated, and pairwise contrasts were performed to determine between-subject effects. Statistical significance was set at $p < 0.05$.

The relationships between the 180° COD completion times, the distances (m), and kinetic performance metrics (relative peak force, relative total impulse and GCT) of all assessments were investigated via correlation analysis. The strength of correlation was interpreted as 0–0.1 (trivial), 0.1–0.3 (small), 0.3–0.5 (moderate), 0.5–0.7 (large), or 0.7–1 (very large) (22). Correlation matrices were calculated within each subgroup to determine the strength of association between COD time and all variables.

Stepwise linear regression was conducted on the combined data and each subgroup (male, female, pre-PHV, crica-PHV, and post-PHV) to determine whether the variables of interest observed during the lateral jump assessments predicted COD performance. The assumptions of linear regression were checked, including visually inspecting the P-P plot for residual normality. The presence of collinearity was checked to make sure VIF < 4 and Tolerance > 0.25 for all variables (35). Any colinear variables were removed from the regression models to ensure redundant variables were not included, as these may cause unreasonable beta values (37).

Statistical analysis was conducted using RStudio IDE (Version 1.4.869, 2009 – 2020 RStudio, PBS) and SPSS (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp). The statistical power of each of the stepwise regression models was determined using commercially available software G*Power (G*Power, Version 3.1.9.4) *post hoc*, with input parameters of 0.05 error probability, the sample size of the corresponding subgroup, the number of predictors in the predictive model, and the effect size determined from the model's $r^2$ value.

**RESULTS**

The means and standard deviations for the jump and sprint assessments can be observed in Table 4.2. The largest difference between male and females was found in both LRJ1.0 and LRJ0.5 total impulses (17-24%), whereas the smallest was found in Sprint10, Sprint20, LJ (distance), LRJ (peak force), and COD times (1-2%). Similarly, the largest between maturation differences were observed LRJ0.5 total impulses (18-27%), whereas the smallest was found in Sprint10, Sprint20, HJ (distance), LRJ (GCT), and COD times (1-2%).

The strength of associations between the highest correlation variables of interest and COD completion times can be observed in Table 4.3. Linear regression models predicting COD performance were calculated with linear sprint speed included (Table 4.4) and excluded (Table 4.5).

**Table 4.2 Mean and Standard deviations of jump, sprint and COD performance.** Spint10 = 9.14m sprint, Sprint20 = 18.28m sprint, VJ = vertical jump, HJ = horizontal jump, LJ = lateral jump, LRJ = lateral reactive jump, COD = 180° change of direction, RSI = reactive strength index, PF = relative peak force, TI = relative total impulse, GCT = ground contact time.

| | | **Male (n = 39)** | | | **Female (n = 34)** | | | **Pre-PHV (n = 30)** | | | **Circa-PHV (n= 23)** | | | **Post-PHV (n = 20)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | | SD | Mean | | SD | Mean | | SD | Mean | | SD | Mean | | SD |
| *Sprint10* | Time (s) | 1.92 | ± | 0.12 | 1.95 | ± | 0.09 | 1.96 | ± | 0.09 | 1.90 | ± | 0.14 | 1.91 | ± | 0.09 |
| *Sprint20* | Time (s) | 3.39 | ± | 0.24 | 3.43 | ± | 0.18 | 3.49 | ± | 0.21 | 3.33 | ± | 0.24 | 3.32 | ± | 0.16 |
| *VJ* | Distance (m) | 0.30 | ± | 0.07 | 0.29 | ± | 0.03 | 0.28 | ± | 0.05 | 0.32 | ± | 0.07 | 0.30 | ± | 0.04 |
| *HJ* | Distance (m) | 1.75 | ± | 0.26 | 1.60 | ± | 0.19 | 1.64 | ± | 0.20 | 1.72 | ± | 0.32 | 1.72 | ± | 0.18 |
| $LJ_R$ | Distance (m) | 1.37 | ± | 0.19 | 1.38 | ± | 0.18 | 1.29 | ± | 0.15 | 1.37 | ± | 0.21 | 1.50 | ± | 0.13 |
| $LJ_L$ | Distance (m) | 1.37 | ± | 0.19 | 1.40 | ± | 0.17 | 1.29 | ± | 0.15 | 1.37 | ± | 0.20 | 1.51 | ± | 0.12 |
| $LRJ_R1.0$ | Distance (m) | 1.34 | ± | 0.21 | 1.30 | ± | 0.19 | 1.24 | ± | 0.17 | 1.31 | ± | 0.23 | 1.45 | ± | 0.14 |
| | RSI | 0.20 | ± | 0.03 | 0.21 | ± | 0.04 | 0.20 | ± | 0.03 | 0.21 | ± | 0.04 | 0.22 | ± | 0.03 |
| | PF (N/kg) | 2.02 | ± | 0.37 | 2.01 | ± | 0.38 | 2.03 | ± | 0.39 | 2.09 | ± | 0.35 | 1.90 | ± | 0.36 |
| | TI (m/s) | 0.69 | ± | 0.14 | 0.57 | ± | 0.11 | 0.66 | ± | 0.16 | 0.62 | ± | 0.15 | 0.60 | ± | 0.09 |
| | GCT (s) | 0.69 | ± | 0.13 | 0.64 | ± | 0.10 | 0.66 | ± | 0.11 | 0.67 | ± | 0.15 | 0.68 | ± | 0.09 |
| $LRJ_L1.0$ | Distance (m) | 1.37 | ± | 0.19 | 1.31 | ± | 0.18 | 1.28 | ± | 0.16 | 1.33 | ± | 0.21 | 1.44 | ± | 0.14 |
| | RSI | 0.21 | ± | 0.03 | 0.21 | ± | 0.04 | 0.20 | ± | 0.03 | 0.21 | ± | 0.04 | 0.22 | ± | 0.03 |
| | PF (N/kg) | 2.09 | ± | 0.36 | 2.04 | ± | 0.40 | 2.00 | ± | 0.34 | 2.29 | ± | 0.40 | 1.90 | ± | 0.27 |
| | TI (m/s) | 0.69 | ± | 0.17 | 0.56 | ± | 0.13 | 0.67 | ± | 0.19 | 0.62 | ± | 0.15 | 0.58 | ± | 0.11 |
| | GCT (s) | 0.69 | ± | 0.12 | 0.65 | ± | 0.11 | 0.66 | ± | 0.12 | 0.67 | ± | 0.13 | 0.67 | ± | 0.12 |
| $LRJ_R0.5$ | Distance (m) | 1.34 | ± | 0.16 | 1.29 | ± | 0.19 | 1.29 | ± | 0.15 | 1.26 | ± | 0.20 | 1.42 | ± | 0.14 |
| | RSI | 0.22 | ± | 0.04 | 0.24 | ± | 0.06 | 0.21 | ± | 0.04 | 0.24 | ± | 0.06 | 0.25 | ± | 0.05 |
| | PF (N/kg) | 1.86 | ± | 0.19 | 1.88 | ± | 0.28 | 1.84 | ± | 0.23 | 1.97 | ± | 0.22 | 1.82 | ± | 0.24 |
| | TI (m/s) | 0.60 | ± | 0.15 | 0.46 | ± | 0.16 | 0.63 | ± | 0.17 | 0.46 | ± | 0.16 | 0.48 | ± | 0.10 |
| | GCT (s) | 0.62 | ± | 0.10 | 0.57 | ± | 0.14 | 0.65 | ± | 0.11 | 0.55 | ± | 0.13 | 0.59 | ± | 0.10 |
| $LRJ_L0.5$ | Distance (m) | 1.35 | ± | 0.15 | 1.32 | ± | 0.17 | 1.29 | ± | 0.13 | 1.29 | ± | 0.17 | 1.44 | ± | 0.14 |
| | RSI | 0.21 | ± | 0.03 | 0.23 | ± | 0.06 | 0.21 | ± | 0.04 | 0.24 | ± | 0.05 | 0.24 | ± | 0.04 |
| | PF (N/kg) | 1.82 | ± | 0.18 | 1.86 | ± | 0.32 | 1.78 | ± | 0.17 | 1.98 | ± | 0.32 | 1.77 | ± | 0.23 |
| | TI (m/s) | 0.62 | ± | 0.14 | 0.47 | ± | 0.15 | 0.62 | ± | 0.16 | 0.49 | ± | 0.17 | 0.51 | ± | 0.11 |
| | GCT (s) | 0.65 | ± | 0.10 | 0.59 | ± | 0.14 | 0.65 | ± | 0.10 | 0.58 | ± | 0.14 | 0.63 | ± | 0.12 |
| $COD_R$ | Time (s) | 2.61 | ± | 0.15 | 2.64 | ± | 0.13 | 2.67 | ± | 0.14 | 2.58 | ± | 0.12 | 2.59 | ± | 0.13 |
| $COD_L$ | Time (s) | 2.65 | ± | 0.19 | 2.65 | ± | 0.13 | 2.71 | ± | 0.15 | 2.61 | ± | 0.19 | 2.61 | ± | 0.11 |

With regards to the combined analysis, the strongest correlates ($r > 0.71$) of COD time were linear 9.14 m (10 yd) and 18.28 m (20 yd) sprint times. HJ ($r = -0.67$) and VJ ($r = -0.70$) displacements were the best jump correlates of COD time, whereas the strength of association for all other jump variables was less than -0.54. The best predictive model of COD time involved Sprint20 time and VJ height (Adjusted $r^2 = 0.63$), yet when the influence of linear sprints was removed from linear regression analysis, the model was comprised of a vertical, horizontal, and lateral jump—VJ height, HJ distance, and $LRJ_L0.5$ RSI (Adjusted $r^2 = 0.55$).

**Table 4.3 Strongest correlations (r) to COD performance.** D = distance, T = time, RSI = reactive strength index, PF = relative peak force, TI = relative total impulse, GCT = ground contact time. *Correlation is significant at $p < 0.05$, **correlation is significant at $p < 0.01$.

| Combined | | Male | | Female | | Pre-PHV | | Circa-PHV | | Post-PHV | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **r** | **Variable** | **r** | **Variable** | **r** | **Variable** | **r** | **Variable** | **r** | **Variable** | **r** |
| T_Sprint20 | 0.78** | T_Sprint20 | 0.81** | T_Sprint20 | 0.69** | T_Sprint20 | 0.78** | D_VJ | -0.73** | T_Sprint10 | 0.81** |
| T_Sprint10 | 0.72** | D_HJ | -0.79** | D_VJ | -0.65** | T_Sprint10 | 0.71** | T_Sprint20 | 0.67** | T_Sprint20 | 0.78** |
| D_VJ | -0.70** | T_Sprint10 | 0.78** | T_Sprint10 | 0.58** | D_VJ | -0.69** | D_HJ | -0.67** | D_HJ | -0.66** |
| D_HJ | -0.67** | D_VJ | -0.73** | Age | -0.51** | D_HJ | -0.68** | T_Sprint10 | 0.64** | D_LRJ$_{R}$1.0 | -0.58** |
| D_LJ$_{R}$ | -0.53** | D_LJ$_{R}$ | -0.58** | PHV | -0.51** | RSI_LRJ$_{L}$0.5 | -0.56** | TIz_LRJ$_{L}$1.0 | -0.55** | D_VJ | -0.56** |
| D_LJ$_{L}$ | -0.49** | D_LJ$_{L}$ | -0.57** | RSI_LRJ$_{R}$1.0 | -0.48** | RSI_LRJ$_{L}$1.0 | -0.56** | D_LJ$_{R}$ | -0.49** | D_LRJ$_{R}$0.5 | -0.55** |
| RSI_LRJ$_{R}$0.5 | -0.47** | RSI_LRJ$_{R}$0.5 | -0.56** | D_LJ$_{R}$ | -0.48** | RSI_LRJ$_{R}$0.5 | -0.55** | D_LJ$_{L}$ | -0.46* | D_LJ$_{R}$ | -0.50* |
| D_LRJ$_{L}$0.5 | -0.44** | D_LRJ$_{L}$0.5 | -0.52** | RSI_LRJ$_{R}$0.5 | -0.48* | D_LJ$_{R}$ | -0.41* | D_LRJ$_{R}$1.0 | -0.45* | D_LRJ$_{L}$0.5 | -0.50* |
| D_LRJ$_{R}$1.0 | -0.44** | RSI_LRJ$_{L}$0.5 | -0.50** | D_HJ | -0.47** | PFz_LRJ$_{R}$0.5 | -0.40* | PFz_LRJ$_{L}$1.0 | 0.43* | BMI | 0.49* |
| Seated Height | -0.42** | Seated Height | -0.48** | D_LRJ$_{R}$1.0 | -0.47** | D_LRJ$_{L}$0.5 | -0.38* | PF_LRJ$_{L}$1.0 | 0.42* | Mass | 0.48* |

Overall stronger individual variable correlations with COD performance were seen with the male group. Despite this, similar predictors made the top ten across groups including, Sprint20 times, (r = 0.69 to 0.81), HJ (r = -0.47 to -0.79), VJ (r = -0.65 to -0.73), LJ (r = -0.48 to -0.58), LRJ (r = -0.47 to -0.56). Notable differences in the top ten correlations between the groups were seen with anthropometrics. The top ten associations in males included, seated height (r = -0.48), while the top association in females include age and PHV (r = -0.51). Although the best predictor model including sprint time for both male and female groups relied on Sprint20 time, each group made use of different jumps to complete the model with males using HJ distance and females using VJ distance (Adjusted $r^2$ = 0.70 and 0.56 respectively).

Table 4.4 Summary of stepwise linear regression models by subgroups (With linear sprints). D = distance, T = time, PF = peak force, TI = total impulse, RSI = reactive strength index, VJ = vertical jump, HJ = horizontal jump, LJ = lateral jump, LRJ = lateral reactive jump. *Model is significant at $p < 0.05$, **Model is significant at $p < 0.01$.

| *Group* | **Models** | ***r*** | ***r²*** | **Adjusted *r²*** |
|---|---|---|---|---|
| *Combined* | (Constant), T_Sprint20, D_VJ** | .801 | .641 | .631 |
| *Male* | (Constant), T_Sprint20, D_HJ** | .846 | .716 | .700 |
| *Female* | (Constant), T_Sprint20, D_VJ** | .768 | .589 | .563 |
| *Pre-PHV* | (Constant), T_Sprint20** | .779 | .607 | .593 |
| *Circa-PHV* | (Constant), D_VJ, PFy_LRJ$_{L}$1.0** | .809 | .655 | .620 |
| *Post-PHV* | (Constant), T_Sprint10, PFy_LRJ$_{L}$0.5, Seated Height, PFy_LRJ$_{L}$1.0** | .938 | .881 | .849 |

Analysis of the different maturation stages showed very large correlations between linear sprinting and COD times in pre-PHV and post-PHV groups (r = 0.71 to 0.81). However, linear sprinting did not demonstrate similar strengths of associations in the circa-PHV group (r = 0.64 to 0.67). Jumps represented in the top ten associations of all three maturation groups included HJ (r = -0.66 to -0.68), VJ (r = -0.56 to -0.73), LJ (r = -0.41 to -0.50), and LRJ (r = -0.38 to -0.58). Notable differences in the top ten correlations between the groups were observed. Stronger LRJ RSI associations were seen in the pre-PHV group compared to other groups. Stronger associations were seen between VJ (r = -0.73) and COD performance than linear sprinting in the circa-PHV group. Anthropometric measures of mass and BMI had moderate associations in the post-PHV group, while only demonstrating trivial associations in all other subgroups. Pre-PHV and post-PHV COD performance was predictive models both included Sprint20 time (Adjusted $r^2$ = 0.59 and 0.85, respectively). However, circa-PHV models did not include linear sprint speed, but instead were comprised of VJ (height) and $LRJ_L1.0$ (vertical peak force) (Adjusted $r^2$ = 0.62).

When linear sprint speed was removed from the stepwise linear regression, COD performance pre-PHV and circa-PHV predictive models both included VJ height and LRJ variables (Adjusted $r^2$ = 0.52 and 0.62, respectively). Post-PHV predictive models also included LRJ variables, but additionally included HJ distance and mass (Adjusted $r^2$ = 0.81).

Table 4.5. Summary of stepwise linear regression models by subgroups (without linear sprints). D = distance, T = time, PF = peak force, TI = total impulse, RSI = reactive strength index, VJ = vertical jump, HJ = horizontal jump, LJ = lateral jump, LRJ = lateral reactive jump. *Model is significant at $p < 0.05$, **Model is significant at $p < 0.01$.

| *Group* | **Models** | ***R*** | ***$R^2$*** | **Adjusted *$R^2$*** |
|---|---|---|---|---|
| *Combined* | (Constant), D_VJ, D_HJ, RSI_$LRJ_L0.5$** | .754 | .568 | .549 |
| *Male* | (Constant), D_HJ** | .786 | .618 | .607 |
| *Female* | (Constant), D_VJ, Age** | .736 | .542 | .512 |
| *Pre-PHV* | (Constant), D_VJ, RSI_$LRJ_L1.0$** | .746 | .557 | .524 |
| *Circa-PHV* | (Constant), D_VJ, PFy_$LRJ_L1.0$** | .809 | .655 | .620 |
| *Post-PHV* | (Constant), D_HJ, Mass, D_$LRJ_R0.5$, TIz_$LRJ_L1.0$, PFy_$LRJ_L0.5$** | .928 | .860 | .811 |

Using estimated marginal means, between-subject effects were determined. Significant differences in jump distance (m) were observed in all tasks when accounting for the effect of sex or the effect of maturation. When accounting for the combined effect of sex and maturation, no significant differences were observed except for the $RJ0.5_R$ task (*p* = 0.009). Differences in COD performance variables considering for sex or maturation all demonstrated significant differences in COD completion times (s). Additionally, pairwise comparisons of jump distances (m) between sexes within each maturation groups were conducted to better understand the effect of sex and maturation on performance. Although differences in jump performance (m) were observed in all maturation groups between males and female, differences between circa-PHV males and females proved to be the most significant demonstrating mean differences greater than 0.238 m (*p* = 0.00), while pre-PHV and post-PHV males and females demonstrated mean differences less than 0.109 m (*p* > 0.155) and less than 0.284 m (*p* > 0.058).

DISCUSSION

The purpose of this study was to investigate the efficacy of multi-directional jump kinematic and kinetic performance metrics as a predictor of 180° COD performance. Furthermore, the study intended to determine the contributing performance variables of COD performance within males and females, and pre-, circa- and post-PHV athletes. The main findings were: 1) Linear sprinting was the most important predictor of 180° COD performance across all subgroups; 2) HJ and VJ were the most effective jump predictors of COD performance in all groups; 3) Comparing the predictive strength of jump assessments, male COD performance was better predicted by HJ while female performances were best predicted by the VJ; 4) Maturation groups showed different associations with pre-PHV prioritising LJR RSI variables, circa-PHV being less reliant on linear sprint speed than all other groups, and post-PHV predictive variables included measures of mass, in addition to sprint speed and jump distances.

Linear sprint times were found to be the strongest predictors of 180° COD performance across all subgroups (r = 0.64 to 0.81). Although the researchers attempted to limit the influence of sprint ability by shortening the length of the assessment, the 180° still involved 13.7m of linear sprinting. The very large and large associations found between linear sprint and COD assessment is consistent with research conducted by Condello et al. (6) who observed similar associations (r = 0.55 to 0.90) when investigating relationships between a 15 m sprit and a 15 m sprint with two 60° CODs. Other studies have found similarly significant associations between linear sprinting and COD times (9, 31), and suggest that the magnitude of influence of linear sprinting may have on a COD assessment is related to the entry speed, degree of the COD and total linear sprinting distance included in the assessment (1). Of specific interest to this study was that the lateral peak forces (2.29 N/kg) recorded during the COD plant step were larger than the vertical peak forces (0.98 N/kg) indicating that lateral leg qualities should have influence on the COD plant step performance. However, if we consider that the full COD task is comprised of many linear steps (horizontal and vertical force production), any influence lateral performance may have during the plant step is minimised by the influence of vertical and horizontal performance. Lockie et al. (28) after finding no significant relationships between lateral jump distances and COD performance, similarly concluded that the longer linear sprint distances included in their COD assessments may have limited the impact of lateral power had on performance. Assessments of COD performance that similarly include linear sprinting may find it difficult to isolate the determining lateral performance variables associated with effective plant steps of a COD. As such, linear regression models were created without the influence of linear sprinting to better understand the predictive associations between jumps and COD performance.

Analysing the predictive strength of jump assessments and their associated kinematic and kinetic variables, HJ and VJ displacement was consistently found to be the strongest predictors demonstrating moderate to large associations (HJ: r = -0.47 to -0.79; VJ: r = -0.56 to -0.73). This follows previous research on the associations between VJ and HJ displacement (26, 31). Strong associations between VJ and HJ, and 180° COD times may be because the COD assessment involved a larger degree of deceleration and acceleration, actions that require predominantly vertical and horizontal force.

Comparing the strongest predictors in each sex, the most effective jump predictor of COD time differed in males and females. In males, HJ distance was closely associated to COD times, whereas in females, the strongest associations we observed between VJ height and COD time. This difference was reinforced by male linear regression models that included HJ distance while female models included VJ height. Research by Meylan et al. (31) investigating the interrelationships of vertical, horizontal and lateral unilateral jumps and their ability to predict COD performance also found that COD times were best predicted by a HJ ($r^2$ = 0.489) in males and by a VJ ($r^2$ = 0.493) in females. This may be due to different loading and propulsive strategies used by males and females. Sigward et al. (39) previously showed that females demonstrated greater knee dependent loading strategies associated with drop jumps. If females employ predominantly anterior jump and landing strategies compared to males, it follows that VJ height would be a stronger predictor of performance in females.

Concerning difference between maturation groups, pre-PHV athletes, unlike circa-and post-PHV groups, demonstrated moderate associations between LRJ RSI performance variables and COD times (r = -0.55 to -0.56). Additionally, the pre-PHV COD performance predictive model included $LRJ_L$1.0 RSI (Adjusted $r^2$ = 0.52). As athletes at this stage in maturation have not begun to gain muscle mass (24), pre-PHV performance may have greater dependence on the reactive strength rather than absolute strength. As stated previously, the predictive models of most subgroups included linear sprint times, however, the circa-PHV linear regression models did not include linear sprint variables. Yet models comprised VJ height and $LRJ_L$1.0 lateral peak force (Adjusted $r^2$ = 0.62). It is understood that athletes at this stage in maturation experience rapid limb growth that affects coordination and balance (24). Lack in coordination may have limited the influence of linear sprint speed, and placed more predictive weight on leg muscle qualities shared by the VJ and LRJ.

Further, when comparing COD completion times (s) between sexes across maturation stages you see a convergence (Mean Difference = -0.055 to -0.092 s, $p$ = 0.086 to 0.405) in the circa-PHV groups (Figure 4.1). This is contrary to all jump distances where circa-PHV males and females demonstrated significant differences (Mean Difference = -0.145 to -0.270 s, $p$ = 0.008 to 0.249). It is interesting that circa-PHV females were demonstrated improved COD sprint ability despite demonstrated similar jump capabilities to the pre-PHV females. This may be because circa-PHV participants, regardless of sex, have demonstrated a lack of coordination as they near PHV due to increased limb lengths and rapid changes in body mass (24). Although pre-PHV and post-PHV populations demonstrate significant differences between sexes in COD performance, circa-PHV populations both undergo a relearning of motor skills that may be diminishing the differences between sexes. Contrary to all other subgroups, post-PHV COD times were found to have moderate associations with body mass and BMI, while these same variables often had trivial correlations in all other groups. Leg power, a determinant of COD performance, involves mass in its calculation, whereas COD times do not and as such the ratio of fat and lean muscle mass can have a large influence on performance if large differences exist within a participant sample. As individuals go through PHV, their rapid growth contributes to an increase in bodyweight. Often this recent increase in bodyweight and limb length can be a hinderance to performance as neuromuscular qualities, such as force capability, have not yet adapted to the additional weight and length (25). Further, post-PHV populations experience a rapid increase in body mass, yet females experience a greater increase in fat mass than males (24). Coaches should take care to when assessing performance in post-PHV populations by attempting to assess performance relative to lean muscle mass.

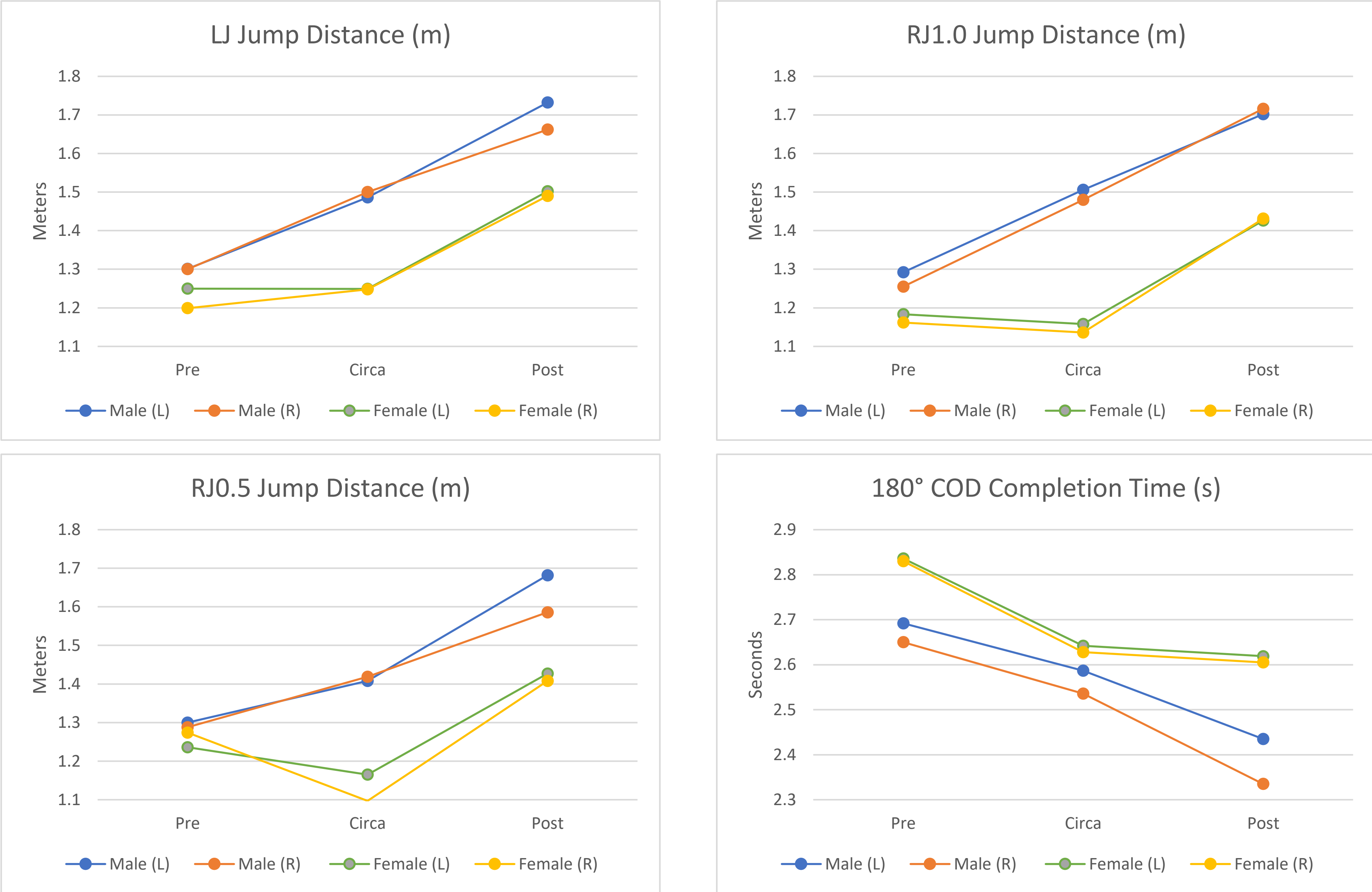


**Figure 4.1.** Estimated marginal means of males and females across PHV groups.

**CONCLUSION**

Coaches should note that linear sprint speed, and VJ and HJ distances were the most effective predictors of 180° COD performance. Of these two bilateral jumps, HJ assessments would be a more effective predictor in male populations, while VJ assessments would be a more effective predictor in females. Due to a lack of absolute leg strength qualities in pre-PHV athletes, reactive strength measures associated with reactive jumps may be more effective at predicting COD performance. In circa-PHV athlete's linear sprinting may have less deterministic value in COD performance due to rapid changes in leg muscle qualities and limb coordination. Coaches therefore should consider using assessments of leg power and coordination in circa-PHV populations. Finally, post-PHV COD performances were best predicted by linear sprinting and multi-directional jump distances. Coaches should take care to consider the effect of increased mass in post-PHV athletes and create assessments that rate COD performance relative to lean muscle mass ratios.

# CHAPTER 5 – CONCLUSION

**Summary**

The primary aim of this thesis was to identify shared performance characteristics between lateral jumps and 180° COD. The secondary objective was to investigate the effect of sex and maturation on these lateral performance characteristics. The research question of the thesis was "Can single-leg lateral jumps be used as a predictor of 180° COD performance among male and female youth athletes pre-, circa-, and post-PHV?"

The first step to answering this question was to investigate the current understanding of the relationships between lateral jump and COD ability, specifically among male and female athletes across maturation stages. A methodical literature review was conducted, and analysis of the results led to the following findings:

1) Strong to moderate correlations have been observed between lateral jump distances and lateral COD performance times ($r = -0.55$ to $-0.67$).

2) Sex and maturation will influence jump and COD performance due to differences in muscle qualities.

3) More research is needed to understand the links between lateral jump and COD performance, and thereafter the effects of sex or maturation.

The next step to answering the research question was to determine reliable assessments of lateral jump and 180° COD performance. Study 3 determined acceptable variability in kinematic performance variables of the LJ LRJ and 180° COD, and acceptable kinetic performance variables in the LRJ. The main findings of the 3-week test-retest variability analysis of youth athletes were:

1) There was less variability associated with the later testing sessions suggesting that some learning effects may still be occurring.

2) The LJ distance variability was low (CV < 4.6%, ICC > 0.84), while all kinetic variables did not meet acceptable consistency.

3) All the LRJ performance variables had low to moderate variability (CV = 4.5 to 15.8%, ICC = 0.14 to 0.89).

4) The 180° COD completion time variability was low (CV < 3.2%, ICC > 0.85), yet kinetic performance variables ranged from low to high variability.

The final step to answering the research question was to quantify the relationships between lateral jumps and COD ability across different populations. This was done by investigating strengths of correlation between the LJ and LRJ performance variables and 180° COD performance. These associations were compared to the associations between vertical and horizontal to 180° COD performance. Finally, stepwise linear regression model analysis was conducted to create predictive models of 180° COD performance for each subgroup. The main findings of Chapter 4 were:

1) Linear sprinting was the most important predictor of 180° COD performance across all subgroups (r > 0.71).

2) HJ (r = -0.67) and VJ (r = -0.70) were the most effective jump predictors of COD performance in all groups.

3) Comparing the predictive strength of jump assessments, male COD performance was better predicted by HJ while female performances were best predicted by the VJ.

4) Pre-PHV COD performance was moderately associated with LJR RSI variables.

5) Circa-PHV COD performance was less reliant on linear sprint speed than all other groups.

6) Post-PHV predictive variables included measures of mass, in addition to sprint speed and jump distances.

**Practical Applications**

The following practical applications should be considered:

- Both previous research and the current thesis have observed strong to moderate correlations between lateral jump distances and lateral COD performance times. Practitioners may be able to use lateral jumps as a predictive tool for the development of lateral COD performance. This could be part of a framework of multi-directional jump assessments that could provide diagnostic information on an athlete's COD ability and guide individualised training to better effect.
- However, it needs to be noted that there was a fair degree of unexplained variance in the correlations between the two tasks, and coaches should refrain from determining lateral COD ability solely based on one assessment as COD ability requires a multifaceted approach.
- More than one assessment may be needed to identify the specific needs of athletes. The use of both fast and slow SSC would give coaches the information to know what leg muscle qualities need improvement. This knowledge would allow coaches to create individualized programming to address specific athlete needs. Using multiple jumps in athlete assessments that could, for example, include a Squat jump (No SCC), countermovement vertical jump (Slow SSC) and a drop jump (Fast SSC) to determine an athlete's deficiencies. Then jumps can be prescribes based on a specific athlete's needs.
- Coaches should note that linear sprint speed, and VJ and HJ distances were the most effective predictors of 180° COD performance. Of these two bilateral jumps, HJ assessments would be a more effective predictor in male populations, while VJ assessments would be a more effective predictor in females.

- Due to a lack of absolute leg strength qualities in pre-PHV athletes, reactive strength measures associated with reactive jumps may be more effective at predicting COD performance. In circa-PHV athlete's linear sprinting may have less deterministic value in COD performance due to rapid changes in leg muscle qualities and limb coordination. Coaches therefore should consider using assessments of leg power and coordination in circa-PHV populations. Finally, post-PHV COD performances were best predicted by linear sprinting and multi-directional jump distances. Coaches should take care to consider the effect of increased mass in post-PHV athletes and create assessments that rate COD performance relative to lean muscle mass ratios.
- When monitoring improvements in jump performance in youth populations, only improvements of large effect sizes should be used to indicate true adaptation in response to training. Coaches can confidently assess performance improvements of large effect sizes through jump distances measures.

**Limitations**

The following limitations should be considered:

- The current research is specific to the youth population that was recruited as participants. All the findings of this research have been demonstrated within active youth athlete populations but do not necessarily apply to all populations.
- The use of the modified 505, a common COD assessment was used to limit the influence of linear sprinting (shortened approach distances) and assess 180° COD. However, this one assessment is not representative of all COD performance.
- COD performance was defined as completion times of the 180° COD assessment which involved linear sprinting. This assessment did not isolate the determining leg muscle qualities of the COD turn separate from the influence of linear sprinting.

**Future Research**

In the context of this research, future research should consider investigating the following:

- Randomised control designs should be used to determine the effects of lateral jump focussed training programs and subsequent changes in COD performance.
- Considering the effectiveness of linear sprint speed as a predictor of COD performance, correlating step frequency to COD performance would be a subsequent step in this line of research.
- This research only considered lateral jumps and thus a logical extension would be to investigate the associations between single-leg rotational jumps and 180° COD performance to mimic the horizontal and rotation nature of the turn.
- Future research concerned with COD performance should establish reliable measures of assessing the isolated COD plant step in the turn separate from the influence of linear sprinting.

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# APPENDICES

## Appendix I. – Published Abstracts

Assessing Lateral Leg Power in COD Performance Through Lateral Jumps: A Literature Review Considering the Effects of Sex and Maturation.

**Abstract**

Lateral change of direction (COD) ability is considered an essential factor of success in field and court-based sports. Currently, coaches use measures of leg power, linear sprinting, and COD tasks to evaluate COD performance. An accurate understanding of which specific leg muscle qualities contributes to lateral COD performance would therefore be valuable to practitioners. Further, a better understanding of the sex and maturation related differences in development that directly affect COD performance would be valuable to practitioners programming to improve lateral performance. The aim of this review was firstly; to summarise the current research examining the statistical relationships between lateral jump performance and lateral COD performance, and secondly, to review the effect of sex and maturation on lateral jump and COD performance. A literature review was conducted systematically to identify relevant articles. Eleven research articles were found and reviewed. Moderate to strong relationships ($r > 0.55$) were observed between lateral jump and COD assessments, suggesting both tasks share some similar neuromuscular qualities that contribute to performance. Only one study reported sex to be a strong predictor ($r < 0.64$) of COD performance. No studies investigated the strength of association between maturation and COD performance. Further studies investigating the relationship between lateral jump performance measures and COD performance and how this relationship may be affected by sex and maturation, are needed to address the gaps in the literature.

**Key Words:** Peak Height Velocity, Youth Performance, Force Plates, Kinetics.

Variability of Lateral Jump and Change of Direction Kinematics and Kinetics in Youth Athletes

**Purpose**

The primary aim of this study was to quantify performance consistency in two types of single-leg lateral jumps and a 180° COD assessment in a cohort of youth athletes.

**Method**

Fourteen subjects volunteered for a 3-week repeated measures study design that determined the between session variability of single-leg lateral countermovement jumps (LJ), single-leg lateral reactive jumps (LRJ) and 180° change of direction (COD) assessments in youth soccer players. Coefficients of variation (CV) and intraclass correlation coefficient (ICC) were used to quantify the variability over three occasions separated by seven days.

**Results**

Variability was less in later sessions. Only LJ distance was found to have acceptable variability (CV = 4.5% to 5.5%, ICC = 0.81 to 0.89). In terms of the LRJ assessment, low to moderate variability was found in all but one of the kinematic and kinetic measures (CV = 4.5% to 15.8%, ICC = 0.14 to 0.89). COD time was the only variable found to have acceptable consistency (CV = 3.2%, ICC = 0.85 to 89).

**Conclusion**

Athletes may benefit from longer or additional familiarisation sessions given the lower variability in the later sessions. All jump distances and COD times were found to have low variability, the practitioner can use these variables with confidence. Force plate measures for the LRJ can also be used with some measure of confidence.

# The Predictive Associations Between Multi-Directional Jump Variables and Change of Direction Performance in Males and Females of Different Maturation Stages


PURPOSE

This study aimed to investigate the efficacy of jump kinematic and kinetic performance variables of multi-directional jumps as predictors of change of direction performance. Furthermore, the impact of participant sex and maturation on the predictor's performance was assessed.

METHOD

This cross-sectional study measured the associations between vertical, horizontal, and lateral jump variables, with change of direction performance across youth athletes of different sexes and maturations. Stepwise linear regression was used to create predictive models of change of direction performance by subgroup.

RESULTS

Linear sprinting was the greatest predictor of change of direction performance across all subgroups. The best jump predictor of change of direction performance was the horizontal jump in males, the vertical jump in females, the vertical and lateral reactive jump in pre-PHV, the vertical and lateral reactive jump in circa-PHV and the horizontal and lateral reactive jump in post-PHV.

CONCLUSION

Linear sprint speed should be used to effectively predict change of direction performance in all youth athletes. Coaches seeking to assess contributing leg muscle qualities through jumps should use horizontal jump distance in males, and vertical jump height in females. Each maturation subgroup exhibited different predictive variables, suggesting the implementation of different strategies during change of direction.

## Appendix II. – Regression Equations

**Supplementary Table 1. Summary of stepwise linear regression models by subgroups (With linear sprints included).** M = model number, D = distance, T = time, PF = peak force, TI = total impulse, RSI = reactive strength index, VJ = vertical jump, HJ = horizontal jump, LJ = lateral jump, LRJ = lateral reactive jump.

| *Group* | M | Variables | Unstandardized Coefficients | | Std. Coef. | t | Sig. | 95.0% Confidence Interval for B | | Adj. $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | B | Std. Error | Beta | | | Lower | Upper | |
| *Combined* | 1 | (Constant) | .714 | .185 | | 3.85 | .000 | .344 | 1.084 | .598 |
| | | T_Sprint20 | .565 | .054 | .777 | 10.39 | .000 | .457 | .673 | |
| | 2 | (Constant) | 1.442 | .321 | | 4.50 | .000 | .803 | 2.082 | .631 |
| | | T_Sprint20 | .416 | .075 | .572 | 5.52 | .000 | .266 | .567 | |
| | | D_VJ | -.753 | .276 | -.283 | -2.73 | .008 | -1.303 | -.202 | |
| *Male* | 1 | (Constant) | .666 | .233 | | 2.86 | .007 | .193 | 1.138 | .649 |
| | | T_Sprint20 | .580 | .069 | .811 | 8.45 | .000 | .441 | .719 | |
| | 2 | (Constant) | 1.834 | .485 | | 3.78 | .001 | .851 | 2.816 | .700 |
| | | T_Sprint20 | .362 | .103 | .507 | 3.52 | .001 | .154 | .571 | |
| | | D_HJ | -.246 | .091 | -.387 | -2.69 | .011 | -.431 | -.061 | |
| *Female* | 1 | (Constant) | .829 | .338 | | 2.47 | .020 | .141 | 1.517 | .459 |
| | | T_Sprint20 | .530 | .098 | .690 | 5.39 | .000 | .330 | .730 | |
| | 2 | (Constant) | 1.789 | .447 | | 4.00 | .000 | .878 | 2.701 | .563 |
| | | T_Sprint20 | .373 | .103 | .486 | 3.61 | .001 | .162 | .584 | |
| | | D_VJ | -1.482 | .506 | -.394 | -2.93 | .006 | -2.515 | -.450 | |
| *Pre-PHV* | 1 | (Constant) | .689 | .305 | | 2.26 | .032 | .064 | 1.314 | .593 |
| | | T_Sprint20 | .574 | .087 | .779 | 6.57 | .000 | .395 | .752 | |
| *Circa-PHV* | 1 | (Constant) | 3.107 | .106 | | 29.29 | .000 | 2.886 | 3.328 | .513 |
| | | D_VJ | -1.583 | .322 | -.732 | -4.92 | .000 | -2.252 | -.914 | |
| | 2 | (Constant) | 2.807 | .148 | | 19.02 | .000 | 2.499 | 3.115 | .620 |
| | | D_VJ | -1.521 | .285 | -.703 | -5.33 | .000 | -2.115 | -.926 | |
| | | PFy_LRJ$_L$1.0 | .118 | .045 | .347 | 2.63 | .016 | .024 | .212 | |
| *Post-PHV* | 1 | (Constant) | -.036 | .444 | | -.080 | .937 | -.969 | .898 | .643 |
| | | T_Sprint10 | 1.380 | .233 | .813 | 5.93 | .000 | .892 | 1.869 | |
| | 2 | (Constant) | -.542 | .412 | | -1.32 | .206 | -1.410 | .327 | .748 |
| | | T_Sprint10 | 1.498 | .200 | .883 | 7.51 | .000 | 1.077 | 1.919 | |
| | | PFy_LRJ$_L$0.5 | .153 | .053 | .343 | 2.92 | .010 | .042 | .264 | |
| | 3 | (Constant) | -2.119 | .706 | | -3.00 | .008 | -3.616 | -.622 | .811 |
| | | T_Sprint10 | 1.615 | .178 | .952 | 9.05 | .000 | 1.236 | 1.993 | |
| | | PFy_LRJ$_L$0.5 | .169 | .046 | .378 | 3.68 | .002 | .071 | .266 | |
| | | Seated Height | .010 | .004 | .267 | 2.59 | .020 | .002 | .018 | |
| | 4 | (Constant) | -2.010 | .634 | | -3.17 | .006 | -3.361 | -.658 | .849 |
| | | T_Sprint10 | 1.554 | .162 | .916 | 9.59 | .000 | 1.208 | 1.899 | |
| | | PFy_LRJ$_L$0.5 | .151 | .042 | .338 | 3.61 | .003 | .062 | .240 | |
| | | Seated Height | .009 | .004 | .242 | 2.60 | .020 | .002 | .017 | |
| | | PFy_LRJ$_L$1.0 | .083 | .037 | .205 | 2.23 | .042 | .004 | .162 | |

## Appendix III. – Ethics Approval for Chapters 3 & 4

17 December 2019

Jonathon Neville
Faculty of Health and Environmental Sciences

Dear Jonathon

Re Ethics Application: **19/444 The relationship between single left lateral jump ability and performance in single leg lateral change of direction tasks in youth athletes**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 17 December 2022.

**Non-Standard Conditions of Approval**

1. Removal of the reference to 'son' on the email invitation.
2. Removal of the reference to interviews on the assent form.
3. The committee is of the view that children under the age of 12 would have difficulty understanding some of the content in the Information Sheet. Please tailor an information Sheet suitable for ages approx. 8 to 12 years old.

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

**Standard Conditions of Approval**

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted. When the research is undertaken outside New Zealand, you need to meet all ethical, legal, and locality obligations or requirements for those jurisdictions.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

Yours sincerely,

Kate O'Connor
Executive Manager
**Auckland University of Technology Ethics Committee**

**Appendix IV. – Participants Consent Forms**

Parent/Guardian Consent Form

Project title: The Relationship Between Single-Leg Lateral Jump Ability and Performance in Single-Leg Lateral Change of Direction Tasks in Youth Athletes.

Project Supervisor: Jonathon Neville Researcher: Matoko Noudehou

○ I have read and understood the information provided about this research project in the Information Sheet dated 17 November 2019.

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

○ I understand that I will be filmed for analysis purposes during testing.

○ I understand that my deidentified results along with the results of all other participants will be shared with coaches as group results.

○ I understand that my data and results will be deidentified and stored for six years before being destroyed.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw my child/children and/or myself from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw my child/children and/or myself from the study then I will be offered the choice between having any data that is identifiable as belonging to my child/children and/or myself removed or allowing it to continue to be used. However, once the findings have been produced, removal of our data may not be possible.

○ I agree to my child/children taking part in this research.

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

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

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

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

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

……………………………………………………………………………………..

……………………………………………………………………………………..

Date:

**Approved by the Auckland University of Technology Ethics Committee on November 17 2019, AUTEC Reference number 19065370.**

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

**Appendix V. – Participant Assent Forms**

Assent Form

Project title: The Relationship Between Single-Leg Lateral Jump Ability and Performance in Single-Leg Lateral Change of Direction Tasks in Youth Athletes.

Project Supervisor: Jonathon Neville

Researcher: Matoko Noudehou

○ I have read and understood the sheet telling me what will happen in this study and why it is important.

○ I have been able to ask questions and to have them answered.

○ I understand that I will be filmed for analysis purposes during testing.

○ I understand that my deidentified results along with the results of all other participants will be shared with coaches as group results.

○ I understand that my data and results will be deidentified and stored for six years before being destroyed.

○ I understand that I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○ If I stop being part of the study, I understand that then I will be offered the choice between having any information that that other people can know is about me removed or letting the researcher keep using it. I also understand that sometimes, if the results of the research have been written, some information about me may not be able to be removed.

○ I agree to take part in this research.

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

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

Participant Contact Details (if appropriate):

………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

**Approved by the Auckland University of Technology Ethics Committee on November 17 2019, AUTEC Reference number 19065370.**

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

**Appendix VI. – Participant Information Sheets**

Participant Information Sheet

Date Information Sheet Produced:

17 November 2019

Project Title

The Relationship Between Single-Leg Lateral Jump Ability and Performance in Single-Leg Lateral Change of Direction Tasks in Youth Athletes.

**An Invitation**

You are invited to take part in the above mentioned research project. Your participation in this research is voluntary. You are free to withdraw consent and discontinue participation from the study at any time without influencing any present and/or future involvement with the Auckland University of Technology.

Your consent to participate in this research will be indicated by your signing and dating the consent form. Signing the consent form indicates that you have freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT.

What is the purpose of this research?

While there has been substantial research examining the relationship between the leg muscle qualities shared by plyometric and COD tasks, there is a lack of experimental research exploring the relationship between unilateral jumping and COD, specifically among youth athletes. Further research is needed to understand how sex, chronological age, and biological age influence the leg muscle qualities required to perform both unilateral jumping and COD tasks in the lateral direction. COD assessments are often used by practitioners for recruiting and selection purposes. The findings of the proposed research will improve how coaches assess COD ability. Further, the research will offer strength and conditioning coaches improved methods of monitoring COD performance in youth athletes.

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

You were identified to participate in this study as you are a youth athletes between the ages of 8 and 18. All participants must be cleared by the sports medicine staff and physically capable of performing all assessments. In addition, all participants must have at least one year of organised sports training. Participants that meet inclusion criteria will be selected on a “first come first served” basis.

How do I agree to participate in this research?

Your participation in this research is voluntary (i.e. it is your choice) and whether or not you choose to participate will neither advantage or disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible. Be aware that the youth participant is able to decline assent, even if the parent or legal guardian has consented.

What will happen in this research?

You will be asked to participate in three one-hour testing session.

First, your body mass, standing height, seated height and leg length will be measured.

Next, you will perform a 15-minute dynamic warm up.

Next, you will perform 4 types of jumps from your right and left leg.

Next, you will perform a 20 YD Sprint

Finally, you will perform a 5.0.5 YD change of direction sprint.

What are the discomforts and risks?

Participants 8-18 years old will not be asked to do anything outside of what they are accustomed to in their normal training. Therefore, no vulnerability or risks are foreseen.

What are the benefits?

The outcomes of this research are designed to benefit both participants, their social group, and researchers. This research has the potential to establish a practical and easily repeatable method of predicting lateral COD performance would be valuable to coaches and sport scientists alike.

How will my privacy be protected?

The data from the project will be coded and held anonymously in secure storage under the responsibility of the principal investigator of the study in accordance with the requirements of the New Zealand Privacy Act (1993).

All reference to participants will be by code number only in terms of the research project and publications. Identification information will be stored on a separate file and computer from that containing the actual data. Only the investigators will have access to computerised data obtained from the participants. All data will be kept for six years in the secured SPRINZ database before being destroyed.

In the case of you recording a potential medical issue it will be discussed with the appropriate person or guardian.

What are the costs of participating in this research?

Participants will commit three hours of their time to data collection sessions. There are no additional costs involved with this research, all equipment is supplied.

What opportunity do I have to consider this invitation?

Potential participants will have two weeks to consider the invitation.

Will I receive feedback on the results of this research?

A summary of the team results will be made available to the team coach and manager if the participant gives consent to do so. All individual data will be deidentified. Copies of the team results will be printed and given to both the athletes and their coaches. When the study is published, the coaches and athletes will be sent copies.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Jonathon Neville, jono.neville@aut.ac.nz, +61433718997

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext. 6038.

Whom do I contact for further information about this research?

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

***Researcher Contact Details:***

Matoko Noudehou (Performance Coach), Athlete Training and Health, mnoudehou@athleteth.com, +16085143727

***Project Supervisor Contact Details:***

Dr Jonathon Neville - SPRINZ, AUT Millennium, jono.neville@aut.ac.nz, +61433718997

**Approved by the Auckland University of Technology Ethics Committee on November 17 2019, AUTEC Reference number 19065370.**