

Spring 2021

## Relationship of General Athletic Performance Markers to Intra-Team Ranking Of Sport Performance

Steven Keith Scruggs II

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RELATIONSHIP OF GENERAL ATHLETIC PERFORMANCE MARKERS TO INTRA-TEAM RANKING  
OF SPORT PERFORMANCE

by

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Submitted in Partial Fulfillment of the Requirements

For the Degree of Doctor of Philosophy in

Physical Education

College of Education

University of South Carolina

2021

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## DEDICATION

To Emily

Your patience was immeasurable.

Your support was unfathomable.

I cannot begin to imagine how you did it, but I will be forever grateful.

I LOVE YOU

## ACKNOWLEDGEMENTS

**Dr. Stodden:** I will probably never understand why you chose to take a chance on me, but I am thankful you did. You somehow found a way to help me lasso my loose cattle of applied concepts and put them into words. Through your mentorship I ventured down many rabbit holes and I always came out the other side a better person, practitioner, and real-world “researcher”. Thank you for everything thus far and thank you in advance for continued mentorship for years to come.

**Billy Anderson:** Without you providing me with an opportunity none of this would have ever been possible. You probably thought this would never come to fruition, and that would make two of us. I will be forever grateful the right set of circumstances occurred and your help getting me to where I am going – wherever that may be.

**Moritz and RJ:** Somehow I convinced you to trust me to view things through a different lens, and you provided me with a unique perspective from your world. Through our relationship I discovered myself far beyond the beach, the science, and the coaching side of life. Now give me 3 claps and a Ric Flair!

**My Parents (Keith and Kelly Scruggs):** Thank you for supporting me and allowing me to explore life. No matter where I am or where I end up I always know where “home” is. I love you!

## ABSTRACT

A foundational principle in sport science involves applying an evidence-based approach to training and development of athletes. The primary objective is to provide an effective training program, while monitoring general athletic performance (GAP) development (i.e., athlete-monitoring), ensuring intended adaptations are occurring. Much of the literature has focused on GAP markers (e.g., physical qualities related to strength, speed, power, agility, and endurance) which are only suggested to influence competitive sport performance (SP) outcomes (e.g., yards per carry, batting average, hitting percentage, rank or placement, etc.; B. Alejo, personal communication, July 13, 2019). This gap in the literature should be filled via examination of motor control principles and theories (i.e., impulse-variability theory) as it relates to GAP and SP. The work presented herein focuses on investigating the relationship of non-traditional GAP markers (e.g., squat jump peak velocity and impulse-momentum) and tenants of the impulse-variability theory to SP outcomes (e.g., intra-team rank of SP and starter vs non-starter group membership) in an elite (e.g., top 8 nationally ranked) NCAA DI beach volleyball team ( $n = 20$ ; age =  $19.75 \pm 1.52$ ; height =  $173.32 \pm 6.49$  cm). The first study examined associations between traditional and non-traditional maximal output GAP markers to each other, as well as associations and contribution of GAP markers to SP outcomes (e.g., intra-team rank of SP and group membership). Results demonstrate

strong associations between traditional and non-traditional GAP markers, while non-traditional demonstrated strong association and independent contribution to SP outcomes. Intra-set jump-based GAP variability (i.e., variable error) was examined in study two where only squat jump peak velocity variability demonstrated strong association and contribution to SP group membership. Study three examined predictive utility of the combined effects of maximal output GAP markers and jump-based GAP variability to SP group membership. Results demonstrated squat jump peak velocity maximum and variability correctly classified SP group membership at a 100% success rate. Overall, these data suggest non-traditional GAP maximal output and variability provide strong predictive utility to SP group membership. Future research should examine the generalizable utility of impulse-variability theory as it relates to GAP development (e.g., physical education to elite athletes) and SP outcomes.

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## LIST OF SYMBOLS

%	Percent / Percentage
±	Plus or Minus
Δ	Delta / Change in Quantity
™	Trademark
<i>r</i>	Coefficient of Correlation
<i>p</i>	p-value / Calculated Probability
≤	Less Than or Equal To
≥	Greater Than or Equal To
$R^2$	Coefficient of Determination
β	Beta
$\chi^2$	Chi-Square
$Exp(B)$	Odds Ratio
95% <i>CI</i>	95% Confidence Interval
1-β	Observed Power
~	Approximately
$\sqrt{\sum(x_i - M)^2}$	Variable Error Equation

## LIST OF ABBREVIATIONS

1RM.....	One Repetition Maximum
cm.....	Centimeters
GAP.....	General Athletic Performance
IVT .....	Impulse-Variability Theory
kg.....	Kilograms
m .....	Meters
NCAA DI.....	National Collegiate Athletic Association Division One
NSCA.....	National Strength and Conditioning Association
SJ .....	Squat Jump(s)
SP.....	Sport Performance
VJ.....	Vertical Jump(s)

## CHAPTER 1

### INTRODUCTION

The concept of identifying, measuring, and improving factors related to “sport performance” is the underlying foundation of human sport science research. Despite the fact that a large body of literature that has adopted “sport performance” terminology, the majority of the literature does not have direct association to competitive sport performance outcomes (Baker et al., 1994; Barnes et al., 2007; Conlon et al., 2013; Gonzales-Badillo et al., 2017; Israetel, 2013; Kavanaugh, 2014; Lara et al., 2005; Luebbers & Fry, 2015; Marques et al., 2011; McBride et al., 2009; Nimphius et al., 2010; Sheppard et al., 2008; Sole, 2015; Thomas, Comfort, et al., 2015; Thomas, Jones, et al., 2015; Wisloff et al., 2004). Instead, outcomes examined in the literature are mainly linked to general athletic performance markers that are suggested to influence sport performance outcomes (e.g., physiological, neuromuscular and psychological factors). Thus, the term sport performance has not been clearly defined nor delineated from human performance research (McGuigan et al., 2012). Clearly delineating sport performance outcomes, as opposed to general athletic performance factors that influence sport performance outcomes, is important to move the field forward.

Strength and conditioning professionals and sport scientist employ many types of training modalities and monitoring strategies to track general athletic performance markers across time (DeWeese et al., 2013). This principle is termed “periodization”

and constructs include: planned variation, planned rest, cyclic and periodic with stages, general to specific, prevention of overtraining and injury, extensive to intensive workloads, performance optimization, and individual response and development. Several sport scientist have called for research involving periodization principles to be updated, given advanced knowledge and technology in regards to physiological responses to training (Bompa, 1999; Bompa & Haff, 2009; Fleck, 1999; Haff G. & Haff E., 2012; Kraemer & Fleck, 2007; Kraemer & Hakkinen, 2002; Plisk & Stone, 2003; Schiötz et al., 2002; Stone et al., 1981; Stone et al., 1999a; Stone et al., 1999b; Stone M.H. & Stone M.E., 2008; Wathen et al., 2000; Zatsiorsky & Kraemer, 2006; DeWeese et al., 2013). In 2013, DeWeese and colleagues (2013, p. 14) proposed an updated definition of periodization to include this call for action:

*“...the process of balancing stress stimuli and recovery periods should be based on advanced knowledge regarding physiological, biochemical, and psychological principles related to human performance. Thus, an individual’s response to training can more effectively be measured and be made apparent through the execution of a comprehensive athlete-monitoring program and ongoing scientific study.”*

Delineating the potential impact of traditional general athletic performance markers and other novel factors, based on motor control theory (i.e., impulse-variability theory and speed-accuracy trade-off theory), on sport performance rank and outcomes will advance the field to allow practitioners (i.e., coaches, strength and conditioning professionals, and sport scientist) to become more aware of how individual athletes



respond to a given training stimulus. Advancing the field of human performance monitoring requires the merging of historical periodization principles and motor control theory, as it relates to sport performance rank and outcomes.

## CHAPTER 2

### LITERATURE REVIEW

#### **2.1. Sport Performance vs General Athletic Performance**

Sport Performance (SP) outcomes are specific to measurable competition related performance metrics (e.g., yards per carry, batting average, hitting percentage, points per game, race time, rank or placement, etc.). Conversely, General Athletic Performance (GAP) markers measure physical qualities related to strength, speed, power, agility, and endurance (B. Alejo, personal communication, July 13, 2019).

Specific sport skills (e.g., sport specific applications of kicking, throwing, striking, running and jumping) directly influence SP outcomes and one's competitive rank within a team or league (B. Alejo, personal communication, July 13, 2019). GAP markers can be developed and objectively identified concurrently with specific sport skills (e.g., batted ball velocity, throwing velocity, throwing accuracy, etc.); however, improvements in GAP markers and sport skills do not always guarantee significant positive changes in SP rank or outcomes (B. Alejo, personal communication, July 13, 2019; McGuigan et al., 2012; Stone et al., 2002; Stone et al., 2003; Suchomel et al., 2016). GAP may assist specific SP rank and outcomes in many scenarios, such as having the speed and agility to outmaneuver defenders to catch or strike a moving implement to score a goal / touchdown (e.g., football receiver, soccer midfielder / striker), or jumping high enough to hit over defenders to win the rally (e.g., volleyball outside hitter). It is apparent that

improvements in GAP markers may bolster SP rank and outcomes, but the specific contribution factors have not been examined in the literature. In addition, while improvements in GAP markers do not guarantee assurance for enhanced SP rank and outcomes (Stone et al., 2002; Suchomel et al., 2016) the absence of a robust GAP foundation can hinder or limit SP potential, and increase risk of injury if sporting demands cannot be tolerated (Haun, 2015; Sams, 2014).

## **2.2. GAP Assessments**

It is not uncommon to find athletes who have limited playing time within a team or league to rank in the top 25% of traditional GAP markers related to strength, power, agility and speed (e.g. squats, deadlifts, cleans, bench press, jump height, jump distance, sprint speed, agility , etc.). Also, performance in current GAP assessments generally demonstrate strong association to other GAP markers in athletic populations. Maximum broad jump distance has strong association to one repetition maximum (1RM) squats ( $r = .77, p \leq .05$ ; Peterson et al., 2006), while vertical jump peak power output demonstrates strong association to maximum vertical jump height ( $r = .87, p \leq .05$ ; Peterson et al., 2006). Additionally, faster (i.e., lower) times observed from the coned t-test of agility is inversely related to maximum vertical jump height ( $r = -.86, p \leq .05$ ; Peterson et al., 2006) and higher vertical jump peak velocity is inversely related to faster 10-meter sprint time ( $r = -.85, p \leq .001$ ; Conlon et al., 2013). Jimenez-Reyes and colleagues (2016) provide further support by finding that peak power output of squat jumps with additional load of 17 kilograms (kg) up to 97kg demonstrated strong association to jump height and 1RM back squat among national and international level

track and field athletes (Jimenez-Reyes et al., 2016). Others have observed similar results among athletic populations (Stone et al., 2003; Carlock et al., 2004; Kraska et al., 2009; Haun, 2015; Thomas, Comfort, et al., 2015; Thomas, Jones, et al., 2015; Barnes et al., 2007). Overall, the impact of assessing the expression of ballistic strength (e.g., peak velocity, power output, rate of force development, impulse, etc.) may provide utility towards predicted SP rank or outcomes, and afford further development of innovative GAP assessments.

### **2.3. Measurement of Ballistic GAP and Sport Skill Performance**

Ballistic multi-joint assessments that measure the impulse of neuromuscular output may demonstrate better predictive utility for SP outcomes compared to traditional assessments (Haun, 2015; Thomas, Jones, et al., 2015; Sherwood & Schmidt, 1980; Urbin et al., 2011; Urbin et al., 2012; Chappell et al., 2016; Baker & Newton, 2008; Gabbett et al., 2009; Garcia-Ramos et al., 2016; Magrini et al., 2017). In fact, recently non-traditional GAP markers (i.e., peak velocity and impulse) observed via sprints and jumps have demonstrated better predictive validity to SP rank and outcomes than traditional GAP jump and sprint markers (e.g., jump height and sprint time). Baker and Newton (2008) demonstrated the product of 10 meter (m) sprint impulse-momentum (*peak velocity at 10m x body mass*) was a better discriminator (7% difference,  $p \leq .05$ ) of competitive division within the Professional Rugby League (e.g., first division vs second division within the same club) compared to traditional speed and agility markers (e.g., 10m sprint time, 40m sprint time, and 40m agility time; .6%, .4%, and -.6% difference, respectively). Additionally, Garcia-Ramos and colleagues (2016) observed peak bar

velocity achieved during squat jumps (SJ), relative to body mass (i.e. impulse-momentum), was a better indicator of 5m, 10m, and 15m start performances in international level competitive swimming compared to peak force and peak power output relative to body mass. Specifically, SJ peak velocity with additional load of 50% of body mass demonstrated the strongest association to 5m start times ( $r = -.72$ ;  $p \leq .01$ ). Most recently, Magrini and colleagues (2017) identified SJ peak velocity, without additional load, as an important discriminating marker of minutes played during a competitive season in National Collegiate Athletic Association Division I (NCAA DI) women's soccer (2.36 vs 2.11 m/s;  $p \leq .01$ ; Cohen's  $d = 1.36$ ).

More specifically, SJ with an additional 20kg load exhibited the highest impulse ( $F\Delta t$ ) compared to eight different load conditions and impulse had direct implication to tasks such as initial the acceleration phase in sprinting, throwing, kicking, or striking an object (Jidovtseff et al., 2014). Furthermore, Mizuguchi and colleagues (2015) state that when using impulse as a preparedness marker (i.e., central nervous system readiness assessment) in athletes, SJ performed at body mass up to 11kg loads do not delineate resultant preparedness or fatigue compared to 20kg load conditions. Thus, 20kg SJ may provide greater sensitivity to detect changes in performance due to alterations in central nervous system preparedness (e.g., change in rate of force production per unit mass).

#### **2.4. Impulse-Momentum Theorem**

Assessment of impulse-momentum produced by ballistic, multi-joint movements (e.g., squat jumps) identifies velocity at departure (e.g., upon toe-off during a jump), as

determined by the preceding impulse generated by the athlete (Ruddock & Winter, 2015). Impulse, in the traditional sense, is the area calculated within the force-time curve ( $Impulse = Force \Delta time$ ). The area calculated underneath the curve is the combination of accelerative forces acting in a desired direction of movement, given that force is generally noted as a vector quantity (Schmidt et al., 1979). The duration of impulse is determined from initiation of force for a given movement lasting until force is no longer being applied, such as immediately upon toe-off in a jumping action when the body becomes a projectile object. Using Newton's second law ( $Force = mass \times acceleration = \frac{mass \Delta velocity}{\Delta time}$ ), the velocity of the body at the end of acceleration (e.g., immediately upon toe-off during a squat jump) measures the impulse when mass is constant (i.e., *Impulse – Momentum Theorem = mass  $\Delta$ velocity*). Simply stated, any variables that influence the magnitude of force, or the duration of the action, influences the resultant velocity of the movement (e.g., SJ peak velocity) and the measured impulse, relative to system mass (e.g., body mass plus any additional load).

### **2.5. Impulse-Variability Theory**

Impulse has an intimate relationship with GAP markers, such as jump height (Winter, 2005; Mizuguchi et al., 2015), provides predictive utility to competitive division in the National Rugby League (Baker & Newton, 2008), and a postdictor (Sands & McNeil, 2000) of minutes played in NCAA DI women's soccer (Magrini et al., 2017). Furthermore, recent investigations of multijoint ballistic motor skills (i.e., kicking and throwing) suggest a potential relationship of the variability in neuromuscular impulse

and execution of specific sport skills, with potential implications on SP rank and outcomes (Urbin, et al., 2011; Chappell et al., 2016; Molina, 2015; Molina et al., 2019). According to the Impulse-Variability Theory (IVT; Schmidt et al., 1979), force generated during the accelerative phase of a ballistic action contributes to the resultant speed of the movement, whereas variability in the movement outcome is mainly a function of the initial force generated by the neuromuscular system (Carlton & Newell, 1993; Schmidt et al., 1979).

Original tenants of this theory suggested a direct linear relationship between the initial force produced and its variability (Schmidt et al., 1979). Research surrounding IVT continued expanding to include examination of force capabilities at various levels of force output (Schmidt & Sherwood, 1982; Sherwood & Schmidt, 1980), temporal constraints related to force production (Newell et al., 1979; Newell et al., 1980), timing accuracy as it related to forces produced (Newell et al., 1984), and combinations of these assumptions (Sherwood et al., 1988). Notably, an inverted-U phenomenon between force and the variability in force produced was observed in some studies demonstrating that force production was most variable at approximately 60-70% of maximal output (Sherwood & Schmidt, 1980; Schmidt & Sherwood, 1982). As initial force output approached near maximal to maximal effort, force output variability decreased. Newell and colleagues (1984) demonstrated that when time to peak force was held constant, the inverted-U no longer was present.

While the initial research on IVT led to a better understanding of how the human system produces and regulates force output under tightly controlled settings, the

practical applications of this line of research were limited for two reasons. First, these findings were produced in controlled lab experiments and are not necessarily applicable to performance in real-world situations (i.e., SP outcomes). Highly controlled lab-based isometric assessments, although important to initially test IVT, do not necessarily demonstrate applicability to more complex tasks (e.g., multijoint sport skills). Second, IVT (Schmidt et al., 1979; Sherwood & Schmidt, 1980) was derived using single-joint laboratory tasks, which also limits the generalizability to more complex skilled behaviors, such as multijoint ballistic skills (e.g., jumping, throwing, striking, kicking). Wulf and Shea (2002) called for more complex skills to be examined in order to gain further insight on these principles for the purpose of generalization to real-world (i.e., SP) outcomes. Recently, several researchers have moved beyond lab-based isometric assessments in order to further investigate the relationship between IVT and multi-joint ballistic skill performance (i.e., speed, accuracy, and variability), such as throwing and kicking (Urbin et al., 2011; Urbin et al., 2012; Chappell et al., 2016; Molina, 2015; Molina et al., 2019).

Findings from overarm throwing in young adults, ages 18-25, supported the notion of the inverted-U phenomenon when examining throwing speed (e.g., a proxy for systemic force output) across a range of individual throwing speed percentages, where the highest variability was witnessed at roughly 60% of maximum throwing speed and high-skill performers exhibited less variability at maximal effort compared to the low-skill group (Urbin et al., 2012). There also was no difference in variability trends across individuals' throwing speed skill levels. In addition, the accuracy of throws at a target



was not different across the force continuum (i.e., percentages of maximum throwing speed), which has further implications for SP outcomes.

## **2.6. Speed-Accuracy Trade-Off**

A speed-accuracy trade-off, which is a robust application of Fitts' Law (1954), indicates that when speed of a movement increases, the accuracy of a movement should decrease. In essence, this decreased outcome accuracy may be a function of the increased variability produced by the initial force impulse that influences variability in force. However, the findings from Urbin and colleagues (2012) did not support this contention as there was no change in throwing accuracy across throwing speed conditions. In addition, Molina and colleagues (2019), in a review of the applications of Impulse-Variability Theory provide additional evidence that the speed-accuracy trade-off may not generally apply in multijoint ballistic skill performance.

Recently, a few researchers demonstrated specific evidence that failed to support speed-accuracy trade-off in throwing and kicking performance ; however, they also failed to support the inverted-U phenomenon, demonstrated by Urbin and colleagues (2012), with kicking performance in adults and throwing performance in children (Chappell et al., 2016; Molina & Stodden, 2017). To note, kicking requires a double accuracy task constraint (i.e., accuracy in contacting the ball as well as the accuracy of the kick), creating an additional limitation of that study for directly assessing force output accuracy and variability of the overall system. In addition, the overall variability in children's performance, based on growth and maturation development influences on neuromuscular performance, is a potential issue when assessing the

generalizability of the inverted-U phenomenon (Molina, 2015). Overall, as throwing, kicking and striking accuracy are critically important to SP rank and outcomes in many sports, it is important to understand the relationship between impulse-momentum, impulse-variability and accuracy performance in these types of specific sport skills, as well as GAP markers.

### ***2.7. Measuring Impulse-Variability via Jumps***

It is important to note that competency in jumping, as well as specific sport skills important to SP (e.g., kicking, throwing and striking), does not occur naturally as it must be taught and refined over time in order to consistently improve and carryover to SP rank and outcomes (Logan et al., 2012). Thus, high-level athletes may be the most advantageous sample to examine whether impulse, velocity, accuracy, and the variability in multijoint GAP markers are predictive of SP rank and outcomes. Using the Goldilocks' Principle (Kidd et al., 2012) it is theorized that combined effects of maximal output multijoint ballistic GAP markers (e.g., impulse, peak velocity of jumping) and their variability (i.e., consistency) exhibited during multiple trials have direct implications on SP rank and outcomes. More research is warranted in this field to investigate potential association between motor control theory, GAP, and SP rank or outcomes. Specifically, a bolstered understanding of the dynamics of intra- and intermuscular force production and its variability to their resultant expression in GAP and SP outcomes will significantly influence current sport science literature in this area.

## **2.8. Statement of Purpose**

Athlete monitoring has been a foundational aspect of periodized training programs for over a century and has become a critical component in the high-to-elite level competitive sport environments (DeWeese et al., 2013). For many years, 1RM assessments have been widely considered to be the “gold standard” for monitoring strength adaptations; however, GAP and SP rely on more than maximal strength for optimal GAP and SP outcomes (Stone et al., 2002; Bazzyler, 2013). Additionally, 1RM assessment protocols have a high metabolic cost and have considerably higher inherent risk of injury compared to alternative monitoring strategies (i.e., jump-based GAP assessments; Bazzyler, 2013; Haun, 2015). Furthermore, collinearity of 1RM strength and other GAP markers have been identified numerous times in the literature illustrating potential use of alternative assessments that may be employed for athlete monitoring (Stone et al., 2003; Carlock et al., 2004; Peterson et al., 2006; Kraska et al., 2009; Haun, 2015; Thomas, Comfort, et al., 2015; Thomas, Jones, et al., 2015; Barnes et al., 2007). In recent years, more emphasis has been placed on identifying “best practices” (e.g., evidence-based) in regard to monitoring strategies of GAP and their potential impact on fatigue, preparedness, and SP outcomes (DeWeese et al., 2013; Sams 2014; Haun, 2015; Gabbett et al., 2017; Sato & Driggers, 2019).

Jump-based assessments have been adopted by a number of coaches, practitioners, and researchers due to their efficacious and universal nature (e.g., can be used across a broad population spectrum). Additionally, several variables can be derived from jump-based assessments, such as: touch height, jump height (i.e., jump

displacement), eccentric : concentric rate of force development, peak velocity and impulse. While a number of researchers have examined impulse, either derived from force plate ( $Force\Delta time$ ) or jump velocity markers ( $mass\Delta velocity$ ), as a potential important candidate for monitoring GAP (Hunter et al., 2005; Kirby et al., 2011; Conlon et al., 2013; Marques & Izquierdo, 2014; Jimenez-Reyes et al., 2016; Perez-Castilla et al., 2019), limited research has examined jump velocity as a discriminator of SP rank or outcomes (Garcia-Ramos et al., 2016; Magrini et al., 2017).

No research to date has examined peak velocity or impulse-momentum variability, exhibited during jump-based GAP assessments, and the potential impact on SP rank and outcomes. Additionally, no research has examined how SP is impacted due to the combined effects of maximal output and variability observed via jump-based GAP assessments. Thus, there is a need to investigate GAP markers with a different lens (i.e., by incorporating tenets of impulse-variability theory) using non-traditional assessments and markers (e.g., 20kg SJ maximal output and variability), to identify potential influence on SP rank and outcomes.

## **2.9. Introduction of Aims**

**1.A.** Examine and compare associations among GAP markers from seven traditional assessments and two non-traditional assessments in NCAA Division I beach volleyball athletes.

### **a. Traditional – Ballistic:**

- i. Vertical Jump Displacement (maximum)
- ii. Approach Vertical Jump Height (maximum)
- iii. Medicine Ball Toss (maximum)
- iv. Power Clean (maximum)

v. Modified Cone T-test of Agility (best time)

**b. Traditional – Maximal Strength:**

- i. Hex Bar Deadlift (maximum)
- ii. Front Squat (maximum)

**c. Non-Traditional – Ballistic:**

- i. 20kg Squat Jump Peak Velocity (maximum)
- ii. 20kg Squat Jump Impulse-Momentum (maximum)

**Hypotheses 1.A.** GAP markers from all assessments will have moderate-to-strong associations to each other.

**1.B<sub>1</sub>.** Examine associations of GAP, anthropometric, and demographic markers to intra-team rank of SP (via expert raters) in an NCAA DI beach volleyball team.

**a. Traditional – Ballistic:**

- i. Vertical Jump Height (maximum)
- ii. Approach Vertical Jump Height (maximum)
- iii. Medicine Ball Toss (maximum)
- iv. Power Clean (maximum)
- v. Modified Cone T-test of Agility (best time)

**b. Traditional – Maximal Strength:**

- i. Hex Bar Deadlift (maximum)
- ii. Front Squat (maximum)

**c. Non-Traditional – Ballistic:**

- i. 20kg Squat Jump Peak Velocity (maximum)
- ii. 20kg Squat Jump Impulse-Momentum (maximum)

**a. Anthropometric and Demographic:**

- i. Age (years)
- ii. Height (cm)
- iii. Reach (cm)
- iv. Fat Mass (%)

**Hypotheses 1.B<sub>1</sub>.** GAP markers will demonstrate statistically significant associations to intra-team rank of SP in an NCAA DI beach volleyball team.

**1.B<sub>2</sub>.** Examine the contribution of GAP markers, from traditional and non-traditional assessments, to intra-team rank of SP (via expert raters) in an NCAA DI beach volleyball team.

- a. **Traditional – Ballistic:**
  - i. Significant associations from 1.B<sub>1</sub>.
- b. **Traditional – Maximal Strength:**
  - i. Significant associations from 1.B<sub>1</sub>.
- c. **Non-Traditional – Ballistic:**
  - i. Significant associations from 1.B<sub>1</sub>.

**Hypothesis 1.B<sub>2</sub>.** GAP markers will demonstrate a statistically significant contribution to intra-team rank of SP in an NCAA D1 beach volleyball team.

**1.C<sub>1</sub>.** Examine associations of GAP, anthropometric, and demographic markers when comparing starters and non-starters in an NCAA DI beach volleyball team.

- a. **Traditional – Ballistic:**
  - i. Significant associations from 1.A. and 1.B<sub>1</sub>.
- b. **Traditional – Maximal Strength:**
  - i. Significant associations from 1.A. and 1.B<sub>1</sub>.
- c. **Non-Traditional – Ballistic:**
  - i. Significant associations from 1.A. and 1.B<sub>1</sub>.
- d. **Anthropometric and Demographic:**
  - i. Age (years)
  - ii. Height (cm)
  - iii. Reach (cm)
  - iv. Fat Mass (%)

**Hypotheses 1.C<sub>1</sub>.** GAP markers will demonstrate statistically significant associations to starters and non-starters in an NCAA DI beach volleyball team.

**1.C<sub>2</sub>.** Examine the contribution of GAP markers, from traditional and non-traditional assessments, to starters and non-starters in an NCAA DI beach volleyball team.

**a. Traditional – Ballistic:**

i. Significant associations, without collinearity, from 1.C<sub>1</sub>.

**b. Traditional – Maximal Strength:**

i. Significant associations, without collinearity, from 1.C<sub>1</sub>.

**c. Non-Traditional – Ballistic:**

i. Significant associations, without collinearity, from 1.C<sub>1</sub>.

**Hypotheses 1.C<sub>2</sub>.** GAP markers will demonstrate significant predictive utility to group membership in an NCAA DI beach volleyball team.

**2.A.** Determine intra-set variability from two traditional and two non-traditional jump-based GAP assessments.

**a. Traditional – Ballistic:**

i. Vertical Jump Height Variability (3 trials)

ii. Approach Vertical Jump Height Variability (3 trials)

**b. Non-Traditional – Ballistic:**

i. 20kg Squat Jump Peak Velocity Variability (5 trials)

ii. 20kg Squat Jump Impulse-Momentum Variability (5 trials)

**2.B<sub>1</sub>.** Examine associations of intra-set variability from two traditional and two non-traditional jump-based GAP assessments to intra-team rank of SP in an NCAA DI beach volleyball team.

**a. Traditional – Ballistic:**

i. Vertical Jump Height (3 trials)

ii. Approach Vertical Jump Height (3 trials)

**b. Non-Traditional – Ballistic:**

i. 20kg Squat Jump Peak Velocity (5 trials)

ii. 20kg Squat Jump Impulse-Momentum (5 trials)

- Hypotheses 2.B<sub>1</sub>.** Intra-set variability will demonstrate statistically significant associations to intra-team rank of SP in an NCAA DI beach volleyball team.
- 2.B<sub>2</sub>.** Examine the contribution of intra-set variability, from jump-based GAP assessments, to intra-team rank of SP in an NCAA DI beach volleyball team.
- a. **Traditional – Ballistic:**
    - i. Significant associations 2.B<sub>1</sub>.
  - b. **Non-Traditional – Ballistic:**
    - i. Significant associations 2.B<sub>1</sub>.

- Hypotheses 2.B<sub>2</sub>.** Intra-set variability from jump-based GAP assessments will demonstrate significant predictive utility to intra-team rank of SP in an NCAA D1 beach volleyball team.
- 2.C<sub>1</sub>.** Examine associations of intra-set variability from two traditional and two non-traditional jump-based GAP assessments when comparing starters and non-starters in an NCAA DI beach volleyball team.

- a. **Starters and Non-Starters:**
  - i. Top 10 vs Bottom 10 Rank of SP
- b. **Traditional – Ballistic:**
  - i. Vertical Jump Height (3 trials)
  - ii. Approach Vertical Jump Height (3 trials)
- c. **Non-Traditional – Ballistic:**
  - i. 20kg Squat Jump Peak Velocity (5 trials)
  - ii. 20kg Squat Jump Impulse-Momentum (5 trials)

**Hypotheses 2.C<sub>1</sub>.** Intra-set variability from jump-based GAP assessments will demonstrate statistically significant association to group membership in a NCAA DI beach volleyball team.



**2.C<sub>2</sub>.** Examine the contribution of intra-set variability, from jump-based GAP assessments, to starters and non-starters in an NCAA DI beach volleyball team.

**a. Traditional – Ballistic:**

i. Significant associations, without collinearity, from 2.C<sub>1</sub>.

**b. Non-Traditional – Ballistic:**

i. Significant associations, without collinearity, from 2.C<sub>1</sub>.

**Hypotheses 2.C<sub>2</sub>.** Variability from jump-based GAP assessments will demonstrate significant predictive utility to group membership in an NCAA DI beach volleyball team.

**3.A.** Examine the predictive utility of GAP maximum, in conjunction with intra-set variability, to intra-team rank of SP in an NCAA DI beach volleyball team.

**a. Traditional – Ballistic:**

i. Significant associations, without collinearity, from 1.B<sub>1</sub>. and 2.B<sub>1</sub>.

**b. Traditional – Maximal Strength:**

i. Significant associations, without collinearity, from 1.B<sub>1</sub>. and 2.B<sub>1</sub>.

**c. Non-Traditional – Ballistic:**

i. Significant associations, without collinearity, from 1.B<sub>1</sub>. and 2.B<sub>1</sub>.

**Hypotheses 3.A.** The combination of GAP maximum and intra-set variability will demonstrate predictive utility to intra-team rank of SP in an NCAA DI beach volleyball team.

**3.B.** Examine the predictive utility of GAP maximum, in conjunction with intra-set variability, for distinguishing starters and non-starters in an NCAA DI beach volleyball team.

**a. Traditional – Ballistic:**

i. Significant associations, without collinearity, from 1.C<sub>1</sub>. and 2.C<sub>1</sub>.

**b. Traditional – Maximal Strength:**

i. Significant associations, without collinearity, from 1.C<sub>1</sub>.

c. **Non-Traditional – Ballistic:**

- i. Significant associations, without collinearity, from 1.C<sub>1</sub>. and 2.C<sub>1</sub>.

**Hypotheses 3.B.** The combination of GAP maximum and intra-set variability will demonstrate predictive utility to group membership in an NCAA DI beach volleyball team.

## CHAPTER 3

### METHODS

These studies used historically collected data from an established database maintained by the Sports Science Committee at the university (see Appendix A). The following methods were established and implemented by members of the Sports Performance department, at the time of collection. Additionally, the assessments are routinely conducted as part of the strength and conditioning training and athlete monitoring program for the beach volleyball team at the university.

#### ***Participants and Setting***

A convenience sample of twenty ( $n = 20$ ) female beach volleyball athletes on a nationally ranked NCAA team participated in this study. Their ages ranged from 18 to 22 ( $m = 19.75 \pm 1.52$ ) with a mean height of  $173.32 \pm 6.49$  cm (see Table 3.1.). Each participant signed informed consent documents, per Sports Science Committee protocol, that allows for on-going athlete-monitoring, medical assessments were performed by medical professionals, and the University Institutional Review Board granted exempt approval of historically collected data for research purposes.

Participants who were under the care of a physician that excluded them from physical activity (e.g., heart condition, chest pain, injury, pregnancy, chronic illness) were not allowed to participate. Inclusion criteria included those with: (a) no pending medical

examinations and (b) no ankle, knee, or back pathology within the preceding fall semester of regular sport training and conditioning. All testing occurred at university owned and operated facilities.

### ***Procedures***

The GAP assessments were conducted during “Week 0” of the 2017 pre-season (i.e., the week prior to the initiation of organized practice and start of the spring semester). On Monday of Week 0, athletes performed jump-based assessments in the order of vertical jump, approach vertical jump, and squat jump. On Wednesday, the athletes performed the medicine ball toss and agility assessments, respectively. No organized practice or conditioning sessions were performed between assessment dates. Additionally, the traditional maximal strength assessments were routinely assessed during pre-season (i.e., four weeks prior to the start of competition) and the best maximal effort attempts were documented for analysis. The athletes were familiar with each of the assessments as they are part of their on-going athlete-monitoring program (e.g., off-season, pre-season, in-season, and post-season assessments) and had regularly performed these throughout the preceding fall semester.

### ***Warm-Up Protocols***

On day one, body mass was measured on an electronic scale (DRS Electronic Scale by AmCell) in kilograms. Thereafter, athletes were allotted 15 minutes of self-selected activation activities (e.g., foam rolling, bike, mobility exercises, etc.) prior to initiating the standardized warm-up protocol. The warm-up protocol consisted of two

sets of the following: 50 jump ropes, 5 kettlebell swings (15kg), 5 step-downs each leg (12-inch box), 3 box jumps and depth lands each (24-inch box).

Wednesday consisted of 15 minutes allotted towards self-selected activation activities followed by a standardized dynamic warm-up performed on the sand volleyball courts. The warm-up consisted of one set of each of the following on one half of the court (e.g., 8m): jog, high knees, butt-kicks, windmills, carioca, alternating knee tucks (walking), alternating quad pulls (walking), alternating leg cradles (walking), alternating hamstring kicks (walking), alternating forward lunges, alternating lateral lunges, side shuffles, and sprint-to-deceleration. Athletes were familiar with all warm-up exercises as they are used throughout their strength training program. Upon completion of the designated warm-up protocol, athletes were given approximately 3 minutes of rest prior to testing the GAP assessments to control for fatigue and to receive instruction (Haff & Triplett, 2016).

## **ASSESSMENTS**

### *Vertical Jump*

The vertical jump (i.e., countermovement vertical jump) and approach vertical jump assessments (i.e., self-selected approach countermovement vertical jump) were administered following the National Strength and Conditioning Association (NSCA) guidelines of assessment (Haff & Triplett, 2016). Each athlete had their standing reach recorded by standing flat-footed underneath the Vertec™ (Jump USA; Sunnyvale, CA; adjustable stack of moveable color-coded horizontal plastic vanes, organized in half-inch increments), and reaching up with their dominant hand to move the highest attainable

plastic vane without going to toes nor dropping the opposite shoulder. The vane stack was then raised within a range where the athlete could not jump higher or lower than the allotted stack 2 foot of horizontal vanes. Standing reach was used to determine jump height for both block and approach vertical jumps. Jump height was recorded as an athletes' jump touch minus their standing reach, as measured by the Vertec™ vertical jump assessment tool.

For the vertical jump, athletes were instructed to stand with both arms up in a flat-footed position beneath and slightly behind the horizontal vanes, allowing for vertical clearance, with their dominant arm proximal to the Vertec™. Without a preparatory step (e.g., drop step, depth land, etc.) the athletes performed a set of three countermovement jumps reaching upward with the dominant hand to move the highest attainable horizontal vane. Approximately 30 seconds of rest was taken between each of the three trials and approximately 1.5 minutes of rest prior to proceeding to the approach vertical jump assessment to control for fatigue (Oliveira et al., 2018). All trials were recorded. Maximal jump height and intra-set variability (i.e., variable error) were used for data analysis.

#### *Approach Vertical Jump*

Athletes could self-select their distance of approach for the approach vertical jump assessment, which typically consisted of two to three steps prior to their penultimate step and vertical jump. As with the vertical jump, athletes made their approach with their dominant arm proximal to the Vertec™ then proceeded to jump and touch the highest attainable horizontal vane. Athletes were given three attempts with

approximately 30 seconds of rest between trials and approximately 1.5 minutes of rest prior to proceeding to the squat jump assessment to control for fatigue (Oliveira et al., 2019). All trials were recorded. Maximal jump height and intra-set variability (i.e., variable error) were used for data analysis.

### *Weighted Squat Jumps*

All weighted (20kg) SJs were completed within a squat rack containing safety bars and followed similar protocols from previous studies (Kraska et al., 2009; Kavanaugh, 2014; Haun, 2015; Haun et al., 2017). Additionally, athletes were familiar with the SJ assessment. They had undergone prior assessments during the fall semester, and it is also used as an exercise within their annual strength training regimen.

Athletes were instructed to step within the squat rack where a 20kg barbell (Eleiko Olympic Weightlifting Bar) sat approximately chest-height on hook attachments on the squat rack. First, appropriate hand placement was found, approximately 6-8 inches outside of shoulder width, and athletes were instructed to step under the barbell placing it centered across the neck just below the C7 vertebrae, commonly referred to as the “high-bar” position (Kraska et al., 2009). Upon finding appropriate barbell and hand placement athletes were instructed to stand up and take one step back with feet placed in a “jump stance”, within the parameters of hip-to-shoulder width. Lastly, instructions were made to make a “W” with their arms while firmly pulling the barbell down into the shoulders to prevent bar-to-body jump height throughout the assessment. Furthermore, a linear position transducer (TENDO™ Weightlifting Analyzer

System; Trencin, Slovak Republic) was placed approximately 12-15 inches parallel to the right foot while the tethered end was strapped firmly around the barbell, approximately 4-6 inches laterally from the outside of the right hand. The linear position transducer was used to capture peak velocity of the weighted squat jump (i.e., peak barbell velocity instantaneous with toe-off) and to calculate impulse (i.e., impulse-momentum). Peak bar velocity, via weighted squat jumps, was chosen as it has been found to have high test-retest reliability (ICC = .93,  $p \leq .05$ , Alemany et al., 2005; CV = 2.27%, Perez-Castilla et al., 2019) and the TENDO™ Weightlifting Analyzer System has high reliability and validity when assessing peak bar velocity (Garnacho-Castano et al., 2015).

Once athletes were in setup in the ready position, they were granted two warm-up jumps at 60 and 80% maximal effort approximately 30 seconds apart, using the same instructions for the maximal effort trials. Prior to each of the maximal effort trials athletes were reminded to “jump as high and as fast as possible”. Afterwards, they instructed to “squat down” to approximately 90 degrees of knee flexion. Athletes have been found to make near optimal adjustments to control initial body configuration in vertical jumps, from a static position (i.e., squat jumps), in order to achieve optimal results in the task (Bobbert et al., 2014; Petronijevic et al., 2018). Thereafter, a “3-2-1-JUMP!” command was prompted, and peak barbell velocity was recorded for the five maximal effort trials. Approximately 30 seconds of rest was allotted between trials to control for fatigue (Oliveira et al., 2019). All trials were recorded. Maximal peak velocity, maximal calculated impulse-momentum, and intra-set variability (i.e., variable error) were used for data analysis.



### *Medicine Ball Toss*

The between legs forward medicine ball toss (e.g., scoop toss) was performed using a 3.629kg (8 pounds) medicine ball (Dynamax™; Austin, TX). This assessment was chosen due to the complexity of the movement (e.g., coordination of trunk and limbs to produce force in both the horizontal and vertical planes). Additionally, it is commonly used by practitioners, but data on this assessment is not reported as frequently as other GAP assessments in peer-reviewed literature (Vallance, 2017). Athletes performed the assessment barefoot on the edge of turfed surface that was level with the sand court. Measurements were taken from the take-off mark (e.g., edge of turfed surface) to the center of initial impact mark made by the medicine ball in the sand. Distance was measured to the nearest centimeter. Athletes utilized a countermovement hip hinge allowing the ball to travel between and back through their legs while slightly bending at the knees. Athletes were allotted approximately 30 seconds of rest between trials. Distances were recorded for each of the three trials. Maximal distance tossed was used for data analysis.

### *Agility*

The cone T-test of agility has been identified as a practical evaluation of an athlete's ability to accelerate, decelerate, and change direction (Haff & Triplett, 2016). Traditionally, this assessment is administered on a firm surface (i.e., basketball court, grass, or turf) per NSCA guidelines; however, for the purpose of this study it was modified to match the sport demands, playing surface, and court dimension. Given the nature of collegiate beach volleyball, the assessment was performed on groomed sand

that meets the USA Volleyball Beach Domestic Competition Regulations (USA Volleyball, 2017). Athletes began the cone T-test in a bilateral “athletic” stance at cone A before initiating a 4-meter acceleration towards cone B. The top of cone B was touched with either hand then, turning to face either of the adjacent cones, the athletes sprinted left or right 4-meters to the adjacent cone (e.g., cone C for trials starting left and cone D for trials starting right). Athletes touched the top of the adjacent cone with the outside hand then, changed direction to sprint 8-meters in the opposite direction to the other adjacent cone. After touching the top of the cone with the outside hand the athletes then sprinted back 4-meters to cone B, touched the top of the cone, then proceeded to sprint backward past cone A, at which time the clock is stopped (see Figure 3.1.). The times of three trials left and three trials right were recorded to the nearest .10 seconds. Times were recorded using the average time of three independently recorded hand times via stopwatch to control for potential user error. Athletes had approximately three minutes of rest between trials to allow full recovery (Haff & Triplett, 2016). Additionally, the sand was groomed prior to each trial returning to a level and uniform state. All trials were recorded, and the best time was used for data analysis.

### *Traditional Strength Assessments*

Traditional strength metrics (e.g., estimated 1RM for front squats (kg), hexbar deadlift (kg), and hang power clean (kg) were calculated and documented based on best attempts performed in training during the pre-season period. To reduce risk of injury, and to optimize time devoted towards in-season training, true 1RM assessments were not performed for front squats and hexbar deadlifts. Rather, best attempts for those

movements with two to three successful repetitions were converted to estimated 1RM (e.g., 2RM x 1.07 and 3RM x 1.12, respectively) following guidelines proposed by the NSCA (Haff & Triplett, 2016). Conversely, successful 1RM hang power clean attempts during training were documented and used for estimates of appropriate training loads throughout the remainder of the season. This approach towards determining traditional strength metrics was taken for several reasons. First, although 1RM assessments are widely considered to be the “gold standard” there does not appear to be a clear consensus on protocol (Bazyler, 2013). Secondly, due to NCAA compliance restrictions, on time allotted towards training during the in-season period, efficiency and efficacy of 1RM assessments are not deemed feasible by the strength and conditioning staff. Lastly, 1RM assessments have a high metabolic cost and have considerably higher inherent risk of injury compared to calculating estimated 1RMs via training loads for a given exercises (Bazyler, 2013; Haun, 2015).

#### *Expert Rater Ranking of Sport Performance*

Sport Performance was evaluated by five expert raters consisting of three internal coaches, one external coach, and one sports information director, at the conclusion of the pre-season period. The sports information director was a former volleyball player and is responsible for collecting and disseminating in-game statistics of the athletes. To control for potential bias the athlete’s names were randomized (Microsoft Excel, func=rand) and sent separately to the expert raters in a numerical value survey format (i.e., Survey Monkey™) to minimize bias in rating. Expert raters were instructed to complete the survey, independently, using the criteria of ranking the

team members from 1-20 based on “their perception of beach volleyball specific skill and in-game ability”. Median rank for each athlete was used to appropriately assign order of intra-team rank of SP for further analysis. Use of median for ordinal (e.g., rank order) assignment reduces influence of potential outliers and controls for potential expert rater bias (Williams & Wragg, 2004; McCluskey & Lalkhen, 2007). In the sport of collegiate beach volleyball there are five pairs that represent the “starters” (n = 10), where the 1’s pair is deemed the highest-ranking pair and so forth. The athletes were further categorized into Starter vs Non-Starter group memberships (n = 10 for each group) for analysis.

### **3.1. Methods for Aim 1.A.**

*“Examine associations among GAP markers, from seven traditional assessments and two non-traditional assessments, in NCAA Division I beach volleyball athletes.”*

#### **Statistical Analysis**

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). Descriptive statistics for the GAP, demographic, and anthropometric markers are presented as mean  $\pm$  standard deviations (see Table 3.2.). Pearson’s bivariate correlation ( $r$ ) was used to examine associations among all GAP markers. A post hoc Bonferroni analysis was conducted to account for any increase in type-1 error associated with multiple comparisons (Armstrong, 2014). Thus, an alpha level of  $p \leq .006$  (i.e.,  $.05 / 9$ ) was set for qualitative interpretations of the  $r$  coefficients given the Bonferroni adjustment. Furthermore, a post hoc power analysis was

conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Table 3.3. for results of the statistical analysis.

### *Traditional GAP Markers*

The 1RM Front Squat demonstrated significant associations and sufficient observed power to 1RM HexBar Deadlift ( $r = .95, p \leq .001, 1-\beta = .99$ ), SJ Impulse-Momentum ( $r = .89, p \leq .001, 1-\beta = .99$ ), and 1RM Power Clean ( $r = .88, p \leq .001, 1-\beta = .99$ ). Additionally, strong associations were demonstrated to Approach Vertical Jump Height ( $r = .60, p \leq .006, 1-\beta = .56$ ) and SJ Peak Velocity ( $r = .60, p \leq .006, 1-\beta = .556$ ; Yuan & Maxwell, 2005).

The 1RM HexBar Deadlift demonstrated significant association with sufficient observed power to 1RM Front Squat ( $r = .95, p \leq .001, 1-\beta = .99$ ), SJ Impulse-Momentum ( $r = .88, p \leq .001, 1-\beta = .99$ ), and 1RM Power Clean ( $r = .79, p \leq .001, 1-\beta = .96$ ). Additionally, strong association was demonstrated to SJ Velo ( $r = .61, p \leq .006, 1-\beta = .58$ ).

The 1RM Power Clean demonstrated significant association with sufficient observed power to 1RM Front Squat ( $r = .88, p \leq .001, 1-\beta = .99$ ), 1RM HexBar Deadlift ( $r = .79, p \leq .001, 1-\beta = .96$ ), and SJ Impulse-Momentum ( $r = .74, p \leq .001, 1-\beta = .89$ ).

Approach Vertical Jump Height demonstrated significant association with sufficient observed power to Vertical Jump Height ( $r = .88, p \leq .001, 1-\beta = .99$ ) and SJ

Peak Velocity ( $r = .78, p \leq .001, 1-\beta = .94$ ). Additionally, strong association was demonstrated to 1RM Front Squats ( $r = .60, p \leq .006, 1-\beta = .56$ ).

Vertical Jump Height demonstrated significant association with sufficient observed power to Approach Vertical Jump Height ( $r = .88, p \leq .001, 1-\beta = .99$ ) and SJ Peak Velocity ( $r = .81, p \leq .001, 1-\beta = .97$ ). Medicine Ball Toss and the Agility T-Test failed to demonstrate significant association to any other GAP markers.

#### *Non-Traditional GAP Markers*

SJ Peak Velocity demonstrated significant association with sufficient observed power to Vertical Jump Height ( $r = .81, p \leq .001, 1-\beta = .97$ ), Approach Vertical Jump Height ( $r = .78, p \leq .001, 1-\beta = .94$ ), and SJ Impulse-Momentum ( $r = .72, p \leq .001, 1-\beta = .84$ ). Additionally, strong associations were demonstrated to 1RM HexBar Deadlift ( $r = .61, p \leq .006, 1-\beta = .58$ ) and 1RM Front Squat ( $r = .60, p \leq .006, 1-\beta = .56$ ).

SJ Impulse-Momentum demonstrated significant association with sufficient observed power to 1RM Front Squat ( $r = .89, p \leq .001, 1-\beta = .99$ ), 1RM HexBar Deadlift ( $r = .88, p \leq .001, 1-\beta = .99$ ), 1RM Power Clean ( $r = .74, p \leq .001, 1-\beta = .89$ ), and SJ Peak Velocity ( $r = .72, p \leq .001, 1-\beta = .84$ ).

#### **Discussion**

The purpose of Aim 1.A. was to examine the associations among traditional and non-traditional GAP markers. Results demonstrate agreement with several previous findings related to GAP associations. It has been well documented that power output (e.g., force per unit time) demonstrates association to jump performance and maximal strength (Stone et al., 2003; Peterson et al., 2006; Barnes et al., 2006; Jimenez-Reyes;

Kraska et al., 2009; Nimphius et al., 2010). Additionally, it has been documented that vertical jump height is a by-product of ground reaction force, vertical impulse, and resultant instantaneous peak velocity at toe-off (Reiser et al., 2006; Moir, 2008; Gonzales-Badillo et al., 2017). Lastly, 1RM markers (i.e., squat and deadlift) were strongly associated to each other, as well as Olympic weightlifting movements (e.g., cleans; Chernyak, 1976; Lucero et al., 2019).

Contrary to previous findings, these results failed to demonstrate strong associations between 1RM markers and the Agility T-Test among a similar sample of NCAA DI athletes (Peterson et al., 2006). This may be due to the assessment being performed on sand in this study, rather than a firm surface. No study to date has examined associations for agility tasks in sand to other GAP markers; however, it is known that running in sand requires ~1.60 times more energy expenditure, compared to a firm surface, and may have affected the results from this study (Lejeune et al., 1998). Additionally, the medicine ball toss failed to demonstrate strong associations to other GAP markers, as previously stated by Vallance (2017); however, the previous study used untrained individuals as subjects. Associations found between maximum dynamic output assessments (e.g., medicine ball toss, jump ability, maximum strength) among untrained subjects may lead to methodological flaws and misrepresentations of data in sport science research with respect to GAP among athletes (Nuzzo et al., 2010).

Impulse-momentum and peak velocity have been noted previously in the literature as being underlying factors related to GAP outcomes (e.g., maximal strength, jump ability, and sprinting; Linthorne, 2001; Reiser et al., 2006; Moir et al., 2008; Kirby

et al., 2011; Urbin et al., 2011; Koziris, 2012; Pupo, Detanico, & dos Santos, 2012; Jidovtseff et al., 2014; Mizuguchi et al., 2015; Ruddock & Winter, 2015; Thomas, Comfort, et al., 2015; Thomas, Jones, et al., 2015; Jimenez-Reyes et al., 2016; Gonzales-Badillo et al., 2017). These data support previous research as it indicates that impulse-momentum and peak velocity, from a 20kg SJ assessment, demonstrate strong associations to many other GAP markers (i.e., 1RM Front Squat, 1RM HexBar Deadlift, 1RM Power Clean, Vertical Jump Height, and Approach Vertical Jump Height).

Assessments performed in high performance sport settings (i.e., NCAA DI) should be concerned with safety (e.g., risk of injury) and efficacy (e.g., usable data that accurately monitors adaptations and performance). Thomas and colleagues (2015, 2015) recently suggested that dynamic assessments (i.e., 20kg SJ) should be considered over isometric tasks for athlete monitoring as they provide better indication of how an athlete produces, stabilizes, and absorbs relative forces (e.g., impulse, rate of force development, and eccentric: concentric force ratios, etc.). Additionally, Haun (2015) argues that traditional 1RM assessments induce relatively high amounts of fatigue, assume a greater risk of injury, and requires an extensive devotion of time at the expense of training other facets of athletic development and recovery. Furthermore, 20kg SJ is suggested to be a safe assessment that provides accurate and reliable data for analyzing changes in strength and jump performance (Stone et al., 2003; Kraska et al., 2009; Sams, 2014; Huan, 2015; Jimenez-Reyes et al., 2016).

Many non-traditional GAP markers have been found to have limitations when attempting to extrapolate the data for broader use. Peak force is significantly



associated with maximal strength, but it is not a reliable predictor of jump height (Kirby et al., 2011). Likewise, flight time is a valid predictor of jump height, but altered landing mechanics can cloud its validity and fails to demonstrate significant association to maximal strength (Sams, 2014). Non-traditional GAP markers observed via squat jumps, such as rate of force development, impulse, impulse-momentum, and peak velocity, have been suggested to provide valid and reliable data with utility towards assessing lower extremity maximal strength, ballistic expression of strength (e.g., power), and fatigue monitoring (Stone et al., 2003; Kraska et al., 2009; Kirby et al., 2011; Sams, 2014; Huan, 2015; Ruddock, & Winter, 2015; Jimenez-Reyes et al., 2016). Furthermore, several sport science researchers have called for more widespread examination of impulse, impulse-momentum and peak velocity due to their association to strength, power, jump ability, and sprint speed (Kirby et al., 2011; Mizuguchi et al., 2015; Ruddock & Winter, 2015; Jimenez-Reyes et al., 2016). The versatility and utility of SJ Impulse-Momentum and SJ Peak Velocity observed from this study bolsters their call for more widespread adoption among strength and conditioning professionals.

### **Limitations**

Lack of diversity (e.g., collegiate beach volleyball only) makes it difficult to assume these findings are generalizable to all athletes or teams in the collegiate athletic setting. Although there was a lack of diversity, this sample of elite athletes (e.g., ranked in the top eight in their domain; Kearney, 1999; Sands et al., 2019) provides greater depth and breadth of GAP associations to the sport science literature as access and approval for research with elite populations are difficult to attain.

Using hand times for the Agility T-test is not the most appropriate means to measure time as user error is possible. Lasered timing gates would provide more accurate and objective data. However, efforts were made to decrease risk of user error by averaging recorded hand times for each trial from three independent recorders. Additionally, performing the assessment on sand inherently requires more energy expenditure creating the possibility of invalid times. No study to date has examined associations for agility tasks in sand to other GAP markers; however, it is known that running in sand requires ~1.60 times more energy expenditure, compared to a firm surface, and may have affected the results from this study (Lejeune et al., 1998). Given that beach volleyball athletes were used for this study it was deemed appropriate and efficacious for this study; however, performing this assessment on a hard surface (i.e., grass or indoor court surface) would provide more generalizable data for the vast majority of sports.

Measurements of non-traditional GAP markers, like peak velocity and impulse-momentum, require the use of technology. Most sport science technology on the market that are valid and reliable come at high price and often cost \$1000 or more per unit. This may explain why only a few researchers have specifically discussed the association of impulse-momentum and peak velocity, derived from a squat jump assessment, to SP rank and outcomes (e.g., swim starts and minutes play in NCAA DI soccer; Garcia-Ramos et al., 2016; Magrini et al., 2017). Practitioners working within the high-performance sport setting, and with elite athletes, should consider purchasing sport performance technology for monitoring purposes as it may yield a high return on

investment in regard to information gained. Future research should emphasize the use of valid and reliable sport technology and utilize non-traditional assessments to aid in identifying novel ways to monitor GAP and SP development.

### **3.2. Methods for Aim 1.B<sub>1</sub>.**

*“Examine associations of GAP, anthropometric and demographic markers to intra-team rank of SP (via expert raters) in an NCAA DI beach volleyball team.”*

#### **Statistical Analysis**

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). A high degree of concordance among the five expert raters was found by using Kendall’s tau-b and Spearman’s rho correlation coefficients (see Table 3.4.). Median rank among the five expert raters were used for ordinal determination of intra-team rank of SP (e.g., 1-20; Williams & Wragg, 2004; McCluskey & Lalkhen, 2007). Shapiro-Wilk indicates the data normally distributed ( $W(20) = .96, p = .45$ ). Test of normality for intra-team rank of SP can be found in Figure 3.2.

Spearman’s Rho correlations were conducted to examine associations of GAP markers to intra-team rank of SP (see Table 3.5.). A post hoc Bonferroni analysis was conducted to account for any increase in type-1 error associated with multiple comparisons (Armstrong, 2014). Thus, an alpha level of  $p \leq .003$  (i.e.,  $.05 / 15$ ) was set for qualitative interpretations of the  $r$  coefficients, given the Bonferroni adjustment. Furthermore, a post hoc power analysis was conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Table 3.5. for results of the statistical analysis.

### *Anthropometric and Demographic Markers*

No anthropometric or demographic marker demonstrated significant associations to intra-team rank of SP; age ( $r = .16, p = .503$ ), height ( $r = .04, p = .863$ ), standing reach ( $r = -.08, p = .734$ ), and fat mass percentage ( $r = -.31, p = .188$ ).

### *Traditional GAP Markers*

Both traditional maximal strength GAP markers, 1RM Front Squat and 1RM HexBar Deadlift, demonstrated significant inverse associations to intra-team rank of SP ( $r = -.66, p \leq .001, 1-\beta = .62$  and  $r = -.63, p \leq .003, 1-\beta = .53$ , respectively); however, observed power was insufficient (e.g.,  $1-\beta < .75$ ; Yuan & Maxwell, 2005). Additionally, both traditional jump-based assessments, Approach Vertical Jump Height and Vertical Jump Height, demonstrated significant inverse associations to intra-team rank of SP ( $r = -.64, p \leq .003, 1-\beta = .55$  and  $r = -.63, p \leq .003, 1-\beta = .555$ , respectively); however, observed power was insufficient.

Medicine Ball Toss ( $r = -.60, p = .005, 1-\beta = .52$ ), 1RM Power Clean ( $r = -.49, p = .027, 1-\beta = .52$ ), and Agility T-Test ( $r = .44, p = .054, 1-\beta = .52$ ) failed to demonstrate significant association to intra-team rank of SP. The qualitative interpretation of the  $r$  coefficients agree with the post hoc Bonferroni analysis accounting for any increase in type-1 error associated with multiple comparisons (Armstrong, 2014).

### *Non-Traditional GAP Markers*

SJ Peak Velocity and SJ Impulse-Momentum demonstrated significant inverse associations to intra-team rank of SP with sufficient observed power ( $r = -.71, p \leq .001, 1-\beta = .76$  and  $r = -.71, p \leq .001, 1-\beta = .75$ , respectfully; Yuan & Maxwell, 2005).

### **Discussion**

The purpose of Aim 1.B<sub>1</sub>. was to examine the associations of traditional GAP markers, non-traditional GAP markers, anthropometric and demographic markers to intra-team rank of SP in an NCAA D1 beach volleyball team.

### *Anthropometric and Demographic Markers*

There are domain specific criteria (i.e., sport specific criteria) that inherently exclude some individuals from recruitment for participation at a given level of competition, even with years of deliberate practice (Ericsson et al., 1993). Aim 1.B<sub>1</sub>. demonstrated anthropometric and demographic markers were not strong predictors of intra-team rank of SP among a homogenous NCAA DI beach volleyball team. Similarly, Detterman (2014) identified a near-zero correlation between height and points scored throughout the 2013 NBA season. Mean height in the NBA was 200.70 centimeters and 173.30 centimeters for this sample of beach volleyball players, whereas mean height for adult males and females (i.e., general population) has been identified as 177.80 and 161.80 centimeters, respectfully (Fryar et al., 2018). Recruitment for high level sport participation (e.g., NCAA, Olympic, or professional league) is often a tiered system beginning around adolescence, and becomes progressively more rigorous regarding anthropometric, demographic, and GAP demands throughout each tier (e.g., junior high

school, high school, collegiate, and beyond; Detterman, 2014). Anthropometric and demographic markers are undoubtedly important for inclusion or recruitment in certain sports, such as basketball and beach volleyball, but represent domain specific criteria rather than an indicator of sport performance.

### *GAP Markers*

Of the GAP markers that demonstrated strong association to intra-team rank of SP, four are jump-based (e.g., ballistic) and two are related to maximal strength. All six markers (SJ Impulse-Momentum, SJ Peak Velocity, 1RM Front Squat, 1RM HexBar Deadlift, Approach Vertical Jump Height, and Vertical Jump height) demonstrated collinearity to one or more additional GAP marker (See Aim 1.A. and Table 3.3.), which is in concordance with a prior research indicating muscular strength has strong association to other GAP activities (e.g., sprinting and jumping; Carlock et al., 2004; Peterson et al., 2006; Barnes et al., 2007; Israetel, 2013; Suchomel et al., 2016). Additionally, the expression of maximal strength is responsible for accelerating an athlete's body for GAP activities (i.e., impulse and impulse-momentum) and has been suggested to play an important role in performing multijoint ballistic SP related skills (i.e., kicking, throwing, and striking an implement; Urbin et al., 2011; Urbin et al., 2012; Molina, 2015; Chappell et al., 2016; Molina et al., 2019). As SJ Impulse-Momentum and SJ Peak Velocity demonstrate strong associations to intra-team rank of SP it suggests ballistic expression of maximal strength appears to be important as it pertains to SP rank and outcomes.

Several sport science researchers have called for more widespread examination of impulse, impulse-momentum and peak velocity due to their association to strength,

power, jump ability, and sprint speed (Kirby et al., 2011; Mizuguchi et al., 2015; Ruddock & Winter, 2015; Jimenez-Reyes et al., 2016). Limited research examining these non-traditional GAP markers via novel assessments have identified strong association to SP rank and outcomes (Baker & Newton, 2008; Garcia-Ramos et al., 2016; Magrini et al., 2017). Furthermore, impulse and peak velocity have known associations to multijoint ballistic skills related to SP (e.g., kicking, throwing, and striking implements; Urbin et al., 2011; Urbin et al., 2012; Molina, 2015; Chappell et al., 2016; Molina et al., 2019). Provided SJ Impulse-Momentum and SJ Peak Velocity demonstrated strong associations to intra-team rank of SP in NCAA DI beach volleyball it warrants further investigation to identify their contribution and predictive utility to SP rank and outcomes.

### **Limitations**

See Aim 1.A. for general limitations that are also applicable to Aim 1.B<sub>1</sub>.

### **3.3. Methods for Aim 1.B<sub>2</sub>.**

*“Examine the contribution of GAP markers, from traditional and non-traditional assessments, to intra-team rank of SP (via expert raters) in an NCAA DI beach volleyball team.”*

### **Statistical Analysis**

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). Refer to Aim 1.B<sub>1</sub>. and Table 3.2. for information and descriptive statistics regarding intra-team rank of SP. Ordinal Logistic Regression was used to identify which GAP markers demonstrate significant contribution to intra-team rank of SP. Normative data for NCAA DI beach volleyball is unknown; therefore, GAP marker

data was normalized to t-scores for consistent interpretation of relative performance among the sample (Bernards et al., 2017). Descriptive statistics can be found in Table 3.6.

Based on results of Aim 1.A. and Aim 1.B<sub>1</sub>, a linear relationship between GAP markers and intra-team rank of SP exist, multivariate normality is present, and homoscedasticity exist; however, collinearity was identified among several GAP markers, thus violating the multicollinearity assumption (e.g.,  $r \geq .70$ ) when examined together (Draper & Smith, 1998). To address the collinearity issues, three pairings of GAP markers were identified based on associations to intra-team rank of SP (see Aim 1.B<sub>1</sub> and Table 3.5.), while complying with assumptions, and analyzed independently. Pairings were assigned as a maximal strength GAP marker paired with a jump-based GAP marker and/or traditional GAP marker paired with a non-traditional GAP marker. An alpha level of  $p \leq .05$  was set for qualitative interpretations of contribution significance. Furthermore, a post hoc power analysis was conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Table 3.7. for results of the statistical analysis.

### *SJ Impulse-Momentum and Vertical Jump Height*

SJ Impulse-Momentum and Vertical Jump Height ( $r = .53, p = .008$ ) were paired in an Ordinal Logistic Regression. No assumptions were violated relating to ordinal logistic regression. The Logit Modeling Fitting Information ( $\chi^2 = 13.10, p \leq .001$ ) and Pearson Goodness-of-Fit Test ( $\chi^2 = 197.86, p = .988$ ) determined the model was a good fit while



sufficient power was observed ( $1-\beta = .98$ ; Yuan & Maxwell, 2005). Interpretation of the Nagelkerke  $R^2$  demonstrates a large effect size and the model explained 48% of the variance for intra-team rank of SP ( $R^2 = .48$ ; small =  $R^2 \geq .02$ , medium =  $R^2 \geq .13$ , and large =  $R^2 \geq .26$ ; Hopkins et al., 2009). SJ Impulse-Momentum demonstrated the strongest independent contribution to intra-team rank of SP ( $Exp(B) = -.89$ ,  $p = .027$ , 95% CI =  $-.80$  to  $-.99$ ) while Vertical Jump Height failed to demonstrate a strong contribution to the model ( $Exp(B) = -.92$ ,  $p = .108$ ). Overall, one standard deviation improvement SJ Impulse-Momentum ( $\sim 27.21$  kg-m/s) should result in a positive (i.e., inverse) improvement to intra-team rank of SP by  $-.89$  placements. An improvement of  $\sim 30.20$  kg-m/s (e.g., 1.11 standard deviations) should result in one full placement improvement of intra-team rank of SP.

#### *SJ Peak Velocity and 1RM HexBar Deadlift*

SJ Peak Velocity and 1RM HexBar Deadlift ( $r = .61$ ,  $p = .002$ ) were paired in an Ordinal Logistic Regression. No assumptions were violated relating to ordinal logistic regression. The Logit Modeling Fitting Information ( $\chi^2 = 10.41$ ,  $p \leq .005$ ) and Pearson Goodness-of-Fit Test ( $\chi^2 = 209.35$ ,  $p = .855$ ) determined the model was a good fit while sufficient power was observed ( $1-\beta = .93$ ; Yuan & Maxwell, 2005). Interpretation of the Nagelkerke  $R^2$  demonstrates a large effect size and the model explained 41% of the variance for intra-team rank of SP ( $R^2 = .41$ ; Hopkins et al., 2009). SJ Peak Velocity demonstrated the strongest independent contribution to intra-team rank of SP ( $Exp(B) = -.90$ ,  $p = .050$ , 95% CI =  $-.81$  to  $-1.01$ ) while 1RM HexBar Deadlift failed to demonstrate a strong contribution to the model ( $Exp(B) = -.95$ ,  $p = .284$ ). Overall, one standard

deviation improvement SJ Peak Velocity ( $\sim .18$  m/s) should result in a positive (i.e., inverse) improvement to intra-team rank of SP by  $-.90$  placements. An improvement of  $\sim .20$  m/s (e.g., 1.10 standard deviations) should result in one full placement improvement of intra-team rank of SP.

#### *Approach Vertical Jump Height and 1RM Front Squat*

Approach Vertical Jump Height and 1RM Front Squat ( $r = .60, p = .002$ ) were paired in an Ordinal Logistic Regression. No assumptions were violated relating to ordinal logistic regression. The Logit Modeling Fitting Information ( $\chi^2 = 11.06, p \leq .004$ ) and Pearson Goodness-of-Fit Test ( $\chi^2 = 208.86, p = .955$ ) determined the model was a good fit while sufficient power was observed ( $1-\beta = .94$ ; Yuan & Maxwell, 2005).

Interpretation of the Nagelkerke  $R^2$  demonstrates a large effect size and the model explained 43% of the variance for intra-team rank of SP ( $R^2 = .43$ ; Hopkins et al., 2009); however, neither Approach Vertical Jump Height ( $Exp(B) = -.92, p = .130$ ) or 1RM Front Squat ( $Exp(B) = -.91, p = .080$ ) provided strong independent contribution to the model.

#### **Discussion**

The purpose of Aim 1.B<sub>2</sub> was to examine the contribution of GAP markers, from traditional and non-traditional assessments, to intra-team rank of SP in an NCAA DI beach volleyball team. Explained variance observed in Aim 1.B<sub>2</sub> suggest that non-traditional jump-based ballistic GAP markers (i.e., impulse-momentum and peak velocity) are stronger predictors of intra-team rank of SP compared to traditional GAP markers (i.e., maximal strength and vertical jump height).

As previewed in Aim 1.B<sub>1</sub>, traditional GAP markers (e.g., 1RM Front Squat, 1RM HexBar Deadlift, Approach Vertical Jump Height, and Vertical Jump Height) demonstrated strong inverse associations to intra-team rank of SP (i.e.,  $r \geq -.63$ ,  $p \leq .003$ ), but failed to demonstrate sufficient power (i.e.,  $1-\beta \leq .75$ ). Conversely, the non-traditional GAP markers (e.g., SJ Peak Velocity and SJ Impulse-Momentum) also demonstrated strong inverse associations to intra-team rank of SP in Aim 1.B<sub>1</sub>, while demonstrating sufficient observed power (i.e.,  $r \geq -.71$ ,  $p \leq .001$ ,  $1-\beta \geq .75$ ). These data may explain why the non-traditional GAP markers were the only independent variables to demonstrate strong independent contributions to intra-team rank of SP.

Prior research has documented the strong associations among traditional and non-traditional GAP markers (see Aim 1.A.; Carlock et al., 2004; Peterson et al., 2006; Barnes et al., 2007; Kirby et al., 2011; Israetel, 2013; Mizuguchi et al., 2015; Ruddock & Winter, 2015; Jimenez-Reyes et al., 2016; Suchomel et al., 2016); however, ballistic expression of these GAP properties (i.e., peak velocity, impulse, and impulse-momentum) have been identified to have relative importance for multijoint ballistic SP related skill outcomes (i.e., kicking, throwing, and striking an implement; Urbin et al., 2011; Urbin et al., 2012; Molina, 2015; Chappell et al., 2016; Molina et al., 2019). These data suggest that a robust GAP foundation may be necessary for inclusion of participation at a given level of sport (i.e., domain specific criteria; Ericsson et al., 1993), but how they are expressed during multijoint ballistic actions (i.e., squat jumps and sprinting) provide better discriminatory utility to SP rank and outcomes (Baker & Newton, 2008; Garcia-Ramos et al., 2016; Magrini et al., 2017).

Aim 1.B<sub>2</sub>. attempts to answer the call for more widespread examination of impulse-momentum and peak velocity, given their association to GAP and SP related skills, to examine their predictive utility of SP rank. These data suggest SJ Impulse-Momentum and SJ Peak Velocity are useful SP markers in NCAA DI beach volleyball; however, future research should examine these non-traditional GAP markers in other power-based sports (e.g., baseball, indoor volleyball, golf, basketball, tennis, football, etc.) to determine if generalizable utility exist. Additionally, future research should examine the association and predictive utility of these non-traditional GAP markers when comparing intra-team groups (i.e., starter vs non-starter group membership) to identify if differences are present among a homogenous cohort of athletes participating at the same level of competition. Also, these data may provide utility for recruiters and coaches when determining scholarship or draft round allocation based on the current rosters standard of excellence (i.e., talent identification system).

### **Limitations**

See Aim 1.A. for general limitations that are also applicable to Aim 1.B<sub>2</sub>.

### **3.4. Methods for Aim 1.C<sub>1</sub>.**

*“Examine associations of GAP, anthropometric, and demographic markers when comparing starters and non-starters in an NCAA DI beach volleyball team.”*

### **Statistical Analysis**

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). Descriptive statistics for Starter vs Non-Starter group membership are presented as mean ± standard deviations in Table 3.2. A Point-biserial Correlation

Coefficient (*rpb*) was used to examine associations among GAP markers and the dichotomous variable of Starter vs Non-Starter group membership (see Table 3.8.). The dichotomous variable of Starter is represented by 1 while the dichotomous variable of Non-Starter is represented by . A post hoc Bonferroni analysis was conducted to account for any increase in type-1 error associated with multiple comparisons (Armstrong, 2014). Thus, an alpha level of  $p \leq .003$  (i.e.,  $.05 / 15$ ) was set for qualitative interpretations of the *r* coefficients, given the Bonferroni adjustment. Furthermore, a post hoc power analysis was conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Table 3.8. for results of the statistical analysis.

### *Anthropometric and Demographic Markers*

No anthropometric or demographic markers demonstrated significant associations to Starter vs Non-Starter group membership; age ( $r = -.03$ ;  $p = .887$ ), height ( $r = -.14$ ,  $p = .572$ ), standing reach ( $r = .03$ ,  $p = .915$ ), and fat mass percentage ( $r = .08$ ,  $p = .727$ ).

### *Traditional GAP Markers*

Given the Bonferroni adjustment of the alpha level (i.e.,  $p \leq .003$ ) the traditional jump-based GAP markers failed to demonstrate significant association to Starter vs Non-Starter group membership; Vertical Jump Height ( $r = .58$ ,  $p = .007$ ,  $1-\beta = .54$ ) and Approach Vertical Jump Height ( $r = .55$ ,  $p = .011$ ,  $1-\beta = .47$ ).

The traditional maximal strength GAP markers also failed to demonstrate significant association to Starter vs Non-Starter group membership; 1RM Front Squat ( $r = .56, p = .011, 1-\beta = .48$ ) and 1RM HexBar Deadlift ( $r = .52, p = .019, 1-\beta = .38$ ). Furthermore, the remaining traditional GAP markers (e.g., 1RM Power Clean, Medicine Ball Toss, and T-Test Agility) also failed to demonstrate significant association to Starter vs Non-Starter group membership.

#### *Non-Traditional GAP Markers*

Both non-traditional jump-based GAP markers demonstrated significant association to Starter vs Non-Starter group membership with sufficient observed power ( $1-\beta$ ); SJ Peak Velocity ( $r = .74, p \leq .001, 1-\beta = .95$ ) and SJ Impulse-Momentum ( $r = .66, p \leq .001, 1-\beta = .79$ ; Yuan & Maxwell, 2005).

#### **Discussion**

The purpose of Aim 1.C<sub>1</sub> was to examine associations of GAP, anthropometric, and demographic markers when comparing starters and non-starters in an NCAA DI beach volleyball team.

#### *Anthropometric and Demographic Markers*

Aim 1.C<sub>1</sub> demonstrated similar results as Aim 1.B<sub>1</sub> as it was identified that anthropometric and demographic markers failed to differentiate between Starter vs Non-Starter group membership in an NCAA DI beach volleyball team. Anthropometric and demographic markers may be domain specific criteria rather than unique athletic or sport performance markers among a homogenous cohort (Ericcson et al., 1993; Baker & Newton, 2008; Melvin et al., 2014; Magrini et al., 2017). Recruitment for elite sport

participation (e.g., NCAA, Olympic, or professional league) is often a tiered system beginning around adolescence and progressively more rigorous in anthropometric, demographic, and GAP demands throughout each tier (e.g., junior high school, high school, collegiate, and beyond; Detterman, 2014). Future sport science research involving GAP and SP should focus on identifying factors aside from general anthropometric and traditional GAP markers that differentiate expert sport performers from their domain specific counterparts (i.e., starters vs non-starters on the same team, professional vs developmental athletes of the same sport, etc.).

#### *GAP Markers*

Results of Aim 1.C<sub>1</sub> indicate traditional GAP markers (e.g., maximal strength and jump height) align as domain specific criteria for participation in, or recruitment for, NCAA D1 beach volleyball, rather than demonstrating strong association to Starter vs Non-Starter group membership (Ericsson et al., 1993). These data coincide with previous research demonstrating differences in maximal strength and vertical jump height among domain specific cohorts in professional rugby and junior Olympic level swimmers were null (Baker & Newton, 2008; Garcia-Ramos et al., 2016).

The non-traditional GAP markers (e.g., impulse-momentum and peak velocity) examined in Aim 1.C<sub>1</sub> demonstrated strong association and sufficient power to intra-team Starter vs Non-Starter group membership (see Table 3.8., Figure 3.3. and Figure 3.4.). These data share commonality with previous research that identified impulse-momentum and peak velocity provide utility towards differentiating SP rank (e.g., professional vs developmental, starter vs non-starter) or outcomes (e.g., start time

performance) among homogenous cohorts in professional rugby, junior Olympic level swimming, and NCAA DI women's soccer (Baker & Newton, 2008; Garcia-Ramos et al., 2016; Magrini et al., 2017).

Published research examining these non-traditional GAP markers in the SP setting is limited, but interest in these GAP markers as potential athlete monitoring tools has continued to grow among practitioners, coaches and sport scientists in recent years. In spite of limited supportive research these data indicate there may be merit to their assumptions provided their association to, and differentiators of, intra-team Starter vs Non-Starter group membership in NCAA DI beach volleyball. Future research should explore the potential utility of these non-traditional GAP markers to SP rank and outcomes across a wide spectrum of competitive sports and divisions (e.g., youth sports, high school, NCAA, Olympic, and professional leagues). Additionally, further examination of these non-traditional GAP markers may provide the framework for exploration of motor control theories (i.e., impulse-variability theory, inverted-U phenomenon, and speed-accuracy trade-off theory) and their applicability to SP rank and outcomes from youth level to Olympic and professional sports.

### **Limitations**

See Aim 1.A. for general limitations that are also applicable to Aim 1.C<sub>1</sub>.

### **3.5. Methods for Aim 1.C<sub>2</sub>.**

*“Examine the contribution of GAP markers, from traditional and non-traditional assessments, to starters and non-starters in an NCAA DI beach volleyball team.”*



## Statistical Analysis

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). A Binary Logistic Regression was used to identify which GAP markers demonstrate significant contribution to Starter vs Non-Starter group membership. The dichotomous variable of Starter is represented by 1 while the dichotomous variable of Non-Starter is represented by 0. Normative data for NCAA Division I beach volleyball is unknown; therefore, GAP marker data was normalized to t-scores for consistent interpretation of relative performance among the sample (Bernards et al., 2017). Descriptive statistics can be found in Tables 3.2. and 3.9.

Based on results of Aim 1.A. and Aim 1.C<sub>1</sub>. (see Tables 3.3. and 3.8.), a linear relationship between GAP markers and Starter vs Non-Starter group membership exist, multivariate normality is present, and homoscedasticity exist; however, collinearity was identified among several GAP markers, thus violating the multicollinearity assumption (e.g.,  $r \geq .70$ ) when examined together (Draper & Smith, 1998). To address the collinearity issues, three GAP markers were identified based on associations to Starter vs Non-Starter group membership (see Aim 1.C<sub>1</sub>. and Table 3.8.), while complying with assumptions, and analyzed independently. An alpha level of  $p \leq .05$  was set for qualitative interpretations of contribution significance. Furthermore, a post hoc power analysis was conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Table 3.10., Figures 3.5., 3.6., and 3.7. for results and comparison of the three binary logistic regressions.

### *SJ Peak Velocity*

The Omnibus Tests of Model Coefficients ( $\chi^2 = 17.53, p \leq .001$ ) and Hosmer and Lemeshow Test ( $\chi^2 = 4.90, p = .672$ ) determined the model was a good fit. No assumptions related to binary logistic regression were violated. The jump-based non-traditional GAP marker SJ Peak Velocity demonstrated strong independent contribution to Starter vs Non-Starter group membership ( $B = .63, p = .035, Exp(B) = 1.87$ ).

Interpretation of the Nagelkerke  $R^2$  demonstrates a large effect size ( $R^2 = .78$ ; small =  $R^2 \geq .02$ , medium =  $R^2 \geq .13$ , and large =  $R^2 \geq .26$ ; Hopkins et al., 2009) and observed sufficient power ( $1-\beta = .99$ ; Yuan & Maxwell, 2005). The odds ratio of Starter group membership increased by 1.87 per every standard deviation improvement (e.g.,  $\sim .18$  m/s) of SJ Peak Velocity (95% CI = .95 to 3.66). In total the model observed 19 correct classifications and 1 misclassification in the Starter group for a 95% accuracy rate in predicted group memberships (see Figure 3.5).

### *SJ Impulse-Momentum*

The Omnibus Tests of Model Coefficients ( $\chi^2 = 11.55, p \leq .001$ ) and Hosmer and Lemeshow Test ( $\chi^2 = 10.34, p = .242$ ) determined the model was a good fit. No assumptions related to binary logistic regression were violated. The jump-based non-traditional GAP marker SJ Impulse-Momentum demonstrated strong independent contribution to Starter vs Non-Starter group membership ( $B = .25, p = .010, Exp(B) =$

1.28). Interpretation of the Nagelkerke  $R^2$  demonstrates a large effect size ( $R^2 = .59$ ; Hopkins et al., 2009) and observed sufficient power ( $1-\beta = .98$ ; Yuan & Maxwell, 2005). The odds ratio of Starter group membership increased by 1.28 per every standard deviation improvement (e.g.,  $\sim 27.21$  kg-m/s) of SJ Impulse Momentum (95% CI = 1.04 to 1.58). In total the model observed 16 correct classifications and 4 misclassifications, 2 per group, for an 80% accuracy rate of prediction of Starter vs Non-Starter group membership (see Figure 3.6).

### *Vertical Jump Height*

The Omnibus Tests of Model Coefficients ( $\chi^2 = 7.76, p \leq .005$ ) and Hosmer and Lemeshow Test ( $\chi^2 = 12.60, p = .127$ ) determined the model a good fit. No assumptions related to binary logistic regression were violated. The jump-based traditional GAP marker Vertical Jump Height demonstrated strong independent contribution towards Starter vs Non-Starter group membership ( $B = .16, p = .014, Exp(B) = 1.18$ ).

Interpretation of the Nagelkerke  $R^2$  demonstrates a large effect size ( $R^2 = .43$ ; Hopkins et al., 2009) and observed sufficient power ( $1-\beta = .90$ ; Yuan & Maxwell, 2005). The odds ratio of Starter group membership increased by 1.18 per every standard deviation improvement (e.g.,  $\sim 5.62$  inches) of Vertical Jump Height (95% CI = 1.02 to 1.36). In total the model observed 15 correct classifications and 5 misclassifications, 2 Starter and 3 Non-Starter, for a 75% accuracy rate in predicted group membership (see Figure 3.7).

### **Discussion**

The purpose of Aim 1.C<sub>2</sub> was to examine the contribution of GAP markers, from traditional and non-traditional assessments, to starters and non-starters on an NCAA DI

beach volleyball team. SJ Peak Velocity and SJ Impulse-Momentum were examined as they demonstrated significant association to Starter vs Non-Starter group membership in Aim 1.C<sub>1</sub>. ( $r = .74$ ,  $p \leq .001$ ,  $1-\beta = .95$  and  $r = .66$ ,  $p \leq .001$ ,  $1-\beta = .79$ , respectfully). Although Vertical Jump Height failed to demonstrate significance after Bonferroni adjustment (see Aim 1.C<sub>1</sub>;  $r = .58$ ,  $p \geq .003$ ,  $1-\beta = .54$ ) it was further examined due to common use as a GAP assessment, and demonstrated the next strongest association group membership (see Figures 3.5., 3.6., and 3.7.).

This is the first known examination of GAP markers and their predictive utility to Starter vs Non-Starter group membership on an NCAA DI beach volleyball team. These data demonstrated that SJ Peak Velocity provided the strongest predictive utility towards differentiating Starter vs Non-Starter group memberships with a 95% accuracy rate. These data (Starters vs Non-Starters:  $2.57 \pm .15$  vs  $2.31 \pm .10$  m/s) agree with previous research that identified SJ Peak Velocity was a strong postdictor (Sands & McNeil, 2000) of minutes played among a homogenous domain specific cohort in NCAA DI women's soccer (Starters vs Non-Starters:  $2.36 \pm .34$  vs  $2.11 \pm .14$  m/s; Magrini, et al., 2017). More research examining SJ Peak Velocity is warranted; however, these results indicate the non-traditional GAP marker provides a potentially stronger generalizability to predict SP rank and outcomes across a multitude of sports and populations.

SJ Impulse-Momentum and Vertical Jump Height also demonstrated predictive utility, but not as strong as SJ Peak Velocity, with 80% and 75% accuracy rate, respectively. Additionally, an increase of ~5.62 inches of Vertical Jump Height only improves odds of Starter group membership by 1.28. That degree of improvement,

even with a routinely supervised resistance training program, is unlikely to be observed across the span of a collegiate career (e.g., ~4.60 inches on average for NCAA DI volleyball; Kavanaugh, 2014). These data suggest that many traditional GAP markers (e.g., Vertical Jump Height) may be domain specific criteria for participation in, or recruitment for, NCAA DI beach volleyball rather than a strong contributor to Starter vs Non-Starter group membership (Ericsson et al., 1993).

Conversely, allometrically scaled peak force ( $N \cdot kg^{-0.67}$ ) has been shown to improve up to 41.2% across a collegiate volleyball career (Kavanaugh, 2014), which has direct implications on impulse-momentum and peak velocity observed via jump-based GAP assessments (Winter, 2005; Bobbert et al., 2008; Cormie et al., 2011). In this sample of NCAA DI beach volleyball athletes, the percent difference between minimum-to-mean SJ Peak Velocity and SJ Impulse Momentum was 11% and 20%, respectively; and, the percent difference between minimum-to-maximum SJ Peak Velocity and SJ Impulse-Momentum was 29% and 57%, respectively. Improvements in SJ Peak Velocity of 11-29% may be more attainable across a collegiate career compared to increasing Vertical Jump Height by ~5.62 inches, and these data suggest it would provide strong contribution towards the odds of Starter group membership. Furthermore, this information may be useful for strength and conditioning professionals when evaluating the efficacy of longitudinal training outcomes, as well as assist with recruitment strategies (e.g., talent identification) for sport coaches, provided similar results have been observed across several NCAA DI sports (e.g., beach volleyball, indoor volleyball, and soccer; Kavanaugh, 2014; Magrini et al., 2017)

The squat jump GAP assessment is performed with maximal intent, full recovery between trials, and several trials are conducted per assessment; thus, this assessment affords future researchers ability to explore potential implications of motor control theories (i.e., impulse-variability theory, inverted-U phenomenon, and speed-accuracy trade-off theory) and their association to SP rank and outcomes. Previous researchers have examined implications of motor control theories related to ballistic multi-joint SP related tasks (i.e., throwing and kicking; Urbin et al., 2011; Molina, 2015; Chappell et al., 2016; Molina & Stodden, 2017) suggesting applicability in the high-performance sport setting and sport science research. Specifically, Urbin et al. (2012) demonstrated that skilled performers in overhead throwing exhibited less variability of throwing speed at maximal effort compared to nonskilled performers. Thus, future research also should examine variability of SJ Peak Velocity and SJ Impulse-Momentum to determine if association and contribution to SP rank and outcomes may be identified via non-traditional GAP markers.

### **Limitations**

See Aim 1.A. for general limitations that are also applicable to Aim 1.C<sub>2</sub>.

### **3.6. Methods for Aim 2.A.**

*“Determine intra-set variability from two traditional and two non-traditional jump-based GAP assessments.”*

### **Statistical Analysis**

Variability was calculated, via the variable error formula ( $\sqrt{\sum(x_i - M)^2}$ ), using Microsoft Excel® (Microsoft Corporation, Redmond, Washington) for each of the two

traditional and two non-traditional jump-based GAP assessments (Urbin et al., 2012; Chappell et al., 2016). Normative data for variability observed via jump-based GAP markers is unknown; therefore, data were normalized to t-scores for consistent interpretation of relative performance among the sample (Bernards et al., 2017).

## Results

Data were selected for analysis due to commonality (e.g., all being jump-based GAP markers), maximal effort exhibited by participants, and multiple trials performed for each assessment. Multiple trials affords assessment of within-subject intra-set variability, thus why traditional maximal strength GAP markers (e.g., 1RM Front Squat and 1RM HexBar Deadlift) were excluded. Associations of maximal output from these GAP markers to intra-team rank of SP and Starter vs Non-Starter group membership were examined in Aims 1.B<sub>1</sub> and 1.C<sub>1</sub>, respectfully. To recall, associations to intra-team rank of SP and Starter vs Non-Starter group membership were: SJ Peak Velocity ( $r = -.71$ ,  $p \leq .001$ ,  $1-\beta = .76$  and  $r = .74$ ,  $p \leq .001$ ,  $1-\beta = .95$ ), SJ Impulse-Momentum ( $r = -.71$ ,  $p \leq .001$ ,  $1-\beta = .75$  and  $r = .66$ ,  $p \leq .001$ ,  $1-\beta = .79$ ), Vertical Jump Height ( $r = -.64$ ;  $p \leq .003$ ,  $1-\beta = .55$  and  $r = .58$ ,  $p = .007$ ,  $1-\beta = .54$ ), and Approach Vertical Jump Height ( $r = -.63$ ,  $p \leq .003$ ,  $1-\beta = .55$  and  $r = .55$ ,  $p \leq .011$ ,  $1-\beta = .47$ ). Descriptive statistics for jump-based GAP variability can be found in Table 3.11., reported as raw scores and t-scores, and presented as mean  $\pm$  standard deviations.

## Discussion

The purpose of Aim 2.A. was to determine intra-set variability from two traditional and two non-traditional jump-based GAP assessments for further

examination in Aims 2.B<sub>1</sub>, 2.B<sub>2</sub>, 2.C<sub>1</sub>, 2.C<sub>2</sub>, 3.A. and 3.B.. To date, there are no known studies in the sport science literature that have examined variability of traditional and non-traditional jump-based (e.g., ballistic) GAP markers in an athletic population to understand their potential association to SP rank or outcomes. Variability of force modulation and human movement are rooted in motor control research (Newell et al., 1979; Sherwood & Schmidt, 1980; Newell et al., 1980; Schmidt and Sherwood, 1982; Newell et al., 1984) with limited research applying variability in sport performance type skill assessments (Urbin et al., 2012; Molina, 2015; Molina & Stodden, 2017; Molina et al., 2019); however, variability has yet to be directly examined in association to GAP and SP.

Variability of performance in ballistic movements (e.g., jump-based GAP) is the result of proximal-to-distal sequencing (i.e., distal modulation theory; Bobbert et al., 2008). This implies a proximo-distal reaction from muscle-to-muscle and joint-to-joint via perturbation that stems from an established cerebral motor function that progressively fades throughout the duration of the movement (i.e., neural feedback loops; Bobbert et al., 2008; Maffiuletti et al., 2016). In addition, it has been proposed that neural factors at the onset and early phase of ballistic tasks (e.g., within the first 50ms) are responsible for inter-individual variability of measurable outcome variables (i.e., peak force, rate of force production, impulse, and peak velocity; Maffiuletti et al., 2016). Errors (e.g., variability) observed in these outcome variables are products of disturbances in neuromuscular efficacy and may have direct implications on SP rank and outcomes (e.g., starter vs non-starter group membership, throwing accuracy, hitting



percentage, etc.). Although this theory has yet to be examined among an athletic population it provides credence to the hypothesis that athletes demonstrating less variability during GAP tasks (e.g., jump-based assessments) are more likely to execute SP related skills with greater proficiency (e.g., consistency and accuracy in SP related skill execution).

Using squat jumps, and examining non-traditional GAP markers (e.g., peak velocity and impulse-momentum), may provide clarity to the hypothesis of less variability observed in GAP assessments are associated to better SP rank and outcomes. To support this idea and method of examination, research has demonstrated that athletes make adjustments to control initial body configuration in squat jumps in order to achieve optimal, valid, and reliable outcome variables (Bobbert et al., 2008; Mitchell et al., 2014; Petronijevic et al., 2018). Mitchell et al. (2014) found only trivial differences in SJ performance (e.g., relative net impulse, flight time, peak velocity, peak force, and peak power) when knee angles were constrained to 90 and 100 degrees of flexion at the knee. In addition, Petronijevic et al. (2018) suggest an athlete-preferred range between 90 and 100 degrees of knee flexion provides ecological validity, grants flexibility with different anthropometric qualities among athletes, and provides greater reliability of observed GAP markers compared to fixed (e.g., standardized) starting positions. Furthermore, it has been documented that squat jumps performed with additional load (i.e., up to 60% of 1RM back squat) do not affect the sequence or coordination of muscle activation; thus, illustrating a 20kg SJ assessment affords valid and reliable

examination of variability provided appropriate technology to collect the data (Giroux et al., 2015).

### **Limitations**

In addition to the aforementioned limitations (see Aim 1.A.) there are specific limitations for Aim 2.A. related to measurement of variability.

Vertical jump assessments performed via Vertec™ may not yield sensitive enough data, compared to non-traditional GAP markers (e.g., peak velocity and impulse-momentum), to examine minute differences (e.g., variability) in GAP performance. The Vertec™ is only accurate to the half inch, and that is assuming that the athlete touches the protruding peg at the pinnacle of their vertical jump (e.g., as opposed to the “upswing” or “downswing”). A lasered device (e.g., Brower Vertical Jump System; Brower Timing Systems, Draper, Utah) may provide more insightful data if this study were replicated.

Traditionally, a minimum of five trials of a given assessment is used to calculate intra-set variability (Maffiuletti et al., 2016); however, performing five trials for the tasks noted in the methods may demonstrate fatigue and compromise the assessment of variability in multijoint maximum effort tasks. In addition, measuring multiple assessment outcomes with five trials in a collegiate strength and conditioning environment is not always feasible due to time and personnel constraints. Although five trials were administered for the non-traditional jump-based assessment, only three trials were administered for each of the traditional jump-based assessments. Maffiuletti and colleagues (2016) further noted that, while more work is required in this emerging

area of study, examining variability via three trials is acceptable when formulating or bolstering a novel theory where testing constraints are present.

Practitioners working in high performance sport and elite athletes should consider purchasing sport technology for monitoring purposes as it may yield a high return on investment. This is especially important when considering only one to three percent differences of SP outcomes are often witnessed at the elite level of sport (i.e., Olympic Games; Mujika & Padilla, 2003). Additionally, DeWeese et al. (2013) make a call for sport scientists to update and enhance athlete monitoring procedures to match the demands of high-performance sport in the 21<sup>st</sup> century, and beyond. Future research should emphasize the use of sport technology and non-traditional assessments to aid in identifying novel ways to monitor GAP development and SP outcomes.

### **3.7. Methods for Aim 2.B<sub>1</sub>.**

*“Examine associations of intra-set variability, from two traditional and two non-traditional jump-based GAP assessments, to intra-team rank of SP in an NCAA DI beach volleyball team.”*

### **Statistical Analysis**

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). Spearman’s Rho correlations were conducted to examine associations of intra-set variability, from four jump-based GAP assessments, to intra-team rank of SP (see Aim 2.A. and Table 3.12.). A post hoc Bonferroni analysis was conducted to account for any increase in type-1 error associated with multiple comparisons (Armstrong, 2014). Thus, an alpha level of  $p \leq .01$  (i.e.,  $.05 / 5$ ) was set for

qualitative interpretations of the  $r$  coefficients given the Bonferroni adjustment.

Furthermore, a post hoc power analysis was conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Table 3.12. for results of the statistical analysis.

### *Intra-Team Rank of SP*

See Aim 1.B<sub>1</sub>., Table 3.5., and Figure 3.2. for analysis.

### *Intra-Set Variability*

Provided the Bonferroni adjustment ( $p \leq .01$ ) intra-set variability from SJ Peak Velocity ( $r = .43, p = .057, 1-\beta = .25$ ) failed to demonstrate significant association and observed insufficient power (Yuan & Maxwell, 2005). Additionally, intra-set variability from the remaining jump-based GAP markers (SJ Impulse-Momentum, Vertical Jump Height, and Approach Vertical Jump Height) failed to demonstrate significant association to intra-team rank of SP.

## Discussion

The purpose of Aim 2.B<sub>1</sub>. was to examine associations of intra-set variability, from two traditional and two non-traditional jump-based GAP assessments, to intra-team rank of SP in an NCAA DI beach volleyball team. To date, this is the first known study to examine the association between GAP variability and SP rank. Although the results for SJ Peak Velocity ( $r = .43, p = .057, 1-\beta = .25$ ) failed to demonstrate significant association or sufficient observed power, these data provide direction for future questions and research related to implications of motor control (i.e., impulse-variability

theory, inverted-U phenomenon, and speed-accuracy trade-off theory) in the high performance sport setting.

Intra-set variability of jump-based GAP markers provide information regarding consistency of output regardless of domain specific criteria or GAP demands necessary for inclusion at a given level of competition (e.g., anthropometric, demographic, specific sport skills, and maximal GAP output). Results from SJ Peak Velocity variability ( $r = .43$ ,  $p = .057$ ,  $1-\beta = .25$ ) failed to demonstrate strong association or sufficient power to SP rank; however, the data allude to potential association and utility of differentiating groups of skilled sport performers among homogenous cohorts (e.g., starters vs non-starters on the same team, professional vs developmental athletes of the same sport, etc.). Future research should increase the sample size and examine implications for GAP variability in differentiating groups of skilled sport performers.

### **Limitations**

See Aim 1.A. for general limitations and Aim 2.A. for limitations specific to Aim 2.B<sub>1</sub>. Additionally, the relatively small sample size may have contributed to the low observed power. Another contributing factor that may have influenced power was the minute differences in observed intra-set variability of the jump-based GAP markers; however, given the sample was a homogenous cohort of NCAA DI beach volleyball players the prerequisite sport specific skills are established and only minute differences in SP differentiate rank and Starter vs Non-Starter group membership. Further examination of IVT in association to GAP and SP is warranted in the high performance sport setting.

### 3.8. Methods for Aim 2.B<sub>2</sub>.

*“Examine contribution of intra-set variability, from jump-based GAP assessments, to intra-team rank of SP in an NCAA DI beach volleyball team.”*

#### **Discussion**

The purpose of Aim 2.B<sub>2</sub> would have been to examine contribution of intra-set variability, from jump-based GAP assessments, to intra-team rank of SP in an NCAA DI beach volleyball team; however, due to insignificant results in Aim 2.B<sub>1</sub> (i.e., jump-based GAP variability failed to demonstrate significant association to SP rank) further analysis via regression was not warranted. Although the results for SJ Peak Velocity ( $r = .43$ ,  $p = .057$ ,  $1-\beta = .25$ ) failed to demonstrate significant contribution or sufficient observed power, these data provide direction for future questions and research related to implications of motor control (i.e., impulse-variability theory, inverted-U phenomenon, and speed-accuracy trade-off theory) in the high performance sport setting.

As discussed in Aim 2.B<sub>1</sub>, jump-based GAP variability markers only account for intra-set consistency of output (i.e., jump height, peak velocity, and impulse-momentum) witnessed for the assessment, regardless of domain specific criteria and GAP maximal outputs. These data (e.g., Aim 2.B<sub>1</sub>) indicate independent examination of jump-based variability, in absence of domain specific criteria, fail to demonstrate strong association or contribution to intra-team rank of SP. However, GAP variability may provide utility towards differentiating homogenous groups of skilled sport performers (e.g., starters vs non-starters on the same team, professional vs developmental athletes in the same sport, etc.) and it has yet to be examined in the literature.

Implications of motor control (e.g., impulse-variability theory, inverted-U phenomenon, and speed-accuracy trade-off), with respect to sport performance, is an area of research that merits further consideration provided results from recent studies (Urbin et al., 2011; Molina, 2015; Chappell et al., 2016; Molina & Stodden, 2017). Most notably, when examining low vs high-skill overarm throwing performances Urbin et al. (2012) observed both groups exhibited less variability as they approached near peak throwing velocities; thus, violating tenets of speed-accuracy trade-off (Fitts, 1954) while simultaneously supporting the inverted-U phenomenon (Schmidt et al., 1979; Sherwood & Schmidt, 1980; Schmidt & Sherwood, 1982). Furthermore, the high-skill group exhibited less variability in throwing speed during maximal effort attempts compared to the low-skill group. Although subjects were separated into low vs high-skill overarm throwing groups none of the participants were athletes competing in high performance sport compared to this sample of elite athletes (e.g., ranked in the top eight in their domain; Kearney, 1999; Sands et al., 2019); however, access to and approval for research with elite athletic populations are difficult to attain.

More data is needed to bolster the hypothesis that GAP variability may provide utility in differentiating high and low-skill sport performers among a homogenous cohort (e.g., Starter vs Non-Starter group membership). It has been suggested that high-skill sport performers (e.g., starters) may utilize neural feedback loops more effectively (Maffioletti et al., 2016) and demonstrate superior ballistic motor skills (i.e., detect and correct errors throughout proximo-distal sequencing of movement; Bobbert et al., 2008) regardless of differences in maximal output (e.g., SJ Peak Velocity). Future research

should examine the independent association and contribution of variability of jump-based GAP markers to intra-team status (e.g., Starter vs Non-Starter group membership) for evidence of generalizable implications of motor control in the high performance sport setting.

### **Limitations**

See Aim 1.A. for general limitations and Aim 2.A. for limitations specific to Aim 1.B<sub>2</sub>. Additionally, see 1.B<sub>2</sub>. discussion for statistical limitations preventing further analysis of intra-set variability to intra-team rank of SP.

### **3.9. Methods for Aim 2.C<sub>1</sub>.**

*“Examine associations of intra-set variability, from two traditional and two non-traditional jump-based GAP assessments, when comparing starters and non-starters in an NCAA DI beach volleyball team.”*

### **Statistical Analysis**

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). A Point-biserial Correlation Coefficient (*r<sub>pb</sub>*) was used to examine associations of intra-set variability among jump-based GAP markers and the dichotomous variable of Starter vs Non-Starter group membership (See Aim 2.A., Table 3.13., and Table 3.14.). The dichotomous variable of Starter is represented by 1 while the dichotomous variable of Non-Starter is represented by . A post hoc Bonferroni analysis was conducted to account for any increase in type-1 error associated with multiple comparisons (Armstrong, 2014). Thus, an alpha level of  $p \leq .01$  (i.e.,  $.05 / 5$ ) was set for qualitative interpretations of the *r* coefficients, given the Bonferroni adjustment.



Furthermore, a post hoc power analysis was conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Table 3.14. for results of the statistical analysis.

### *Non-Traditional GAP Markers*

Intra-set variability of SJ Peak Velocity ( $r = -.62, p \leq .01$ ) was the only variable that demonstrated a significant and inverse association to Starter vs Non-Starter group membership (e.g., less intra-set variability is associated to Starters group membership; see Figure 3.8.), and observed sufficient power ( $1-\beta = .83$ ; Yuan & Maxwell, 2005).

Intra-set variability of SJ Impulse-Momentum also demonstrated an inverse association to Starter vs Non-Starter group membership (see Figure 3.9.); however, failed to demonstrate significance ( $r = -.54, p = .014$ ), provided the Bonferroni adjustment, and observed power was insufficient ( $1-\beta = .68$ ).

### *Traditional GAP Markers*

Intra-set variability from the traditional jump-based GAP markers, Vertical Jump Height and Approach Vertical Jump Height, failed to demonstrate a significant association to Starter vs Non-Starter group membership and observed power was insufficient ( $r = .09, p = .701, 1-\beta = .83$  and  $r = -.42, p = .064, 1-\beta = .69$ , respectfully).

## Discussion

The purpose of Aim 2.C<sub>1</sub> was to examine associations of intra-set variability, from two traditional and two non-traditional jump-based GAP assessments, when comparing starters and non-starters in an NCAA DI beach volleyball team. To date, this

is the first known study to examine the association of jump-based GAP variability and Starter vs Non-Starter group membership among a homogenous group of athletes in the high performance sport (e.g., collegiate athletics) setting.

The strong association demonstrated between intra-set variability in SJ Peak Velocity and Starter vs Non-Starter group membership ( $r = -.62, p \leq .01, 1-\beta = .83$ ) provides partial support for the inverted-U phenomenon (e.g., the Starter group generally exhibited less variability observed via SJ Peak Velocity compared to the Non-Starter group; Sherwood & Schmidt, 1980; Schmidt & Sherwood, 1982). The phrase “consistency is key” is often echoed in the realm of sports; however, aside from in-game statistics (e.g., sport performance) the sport science literature has failed to examine “consistency” in regard to GAP with association and contribution to SP rank or outcomes.

Impulse-variability theory (IVT), and eventually the inverted-U phenomenon, were originally observed via lab-based single joint isometric tasks which limited the generalizability to more complex skilled behavior, such as multijoint ballistic skills (e.g., throwing, and kicking; Schmidt et al., 1979; Sherwood & Schmidt, 1980; Schmidt & Sherwood, 1982). These data suggest further insight on these principles are needed for the purpose of generalization to SP outcomes (e.g., athletes that exhibit less GAP variability have greater potential to execute SP related skills with greater proficiency). Future research should examine the association of intra-set variability of SJ Peak Velocity in other power-based sport (i.e., indoor volleyball, baseball, golf, tennis, basketball, etc.) and predictive utility to skilled group membership (i.e., starters vs non-

starters on the same team, professional vs developmental athletes in the same sport, etc.).

### **Limitations**

See Aim 1.A. for general limitations and Aim 2.A. for limitations that are specific to Aim 2.C<sub>1</sub>.

### **3.10. Methods for Aim 2.C<sub>2</sub>.**

*“Examine the contribution of intra-set variability, from jump-based GAP assessments, to starters and non-starters in an NCAA DI beach volleyball team.”*

### **Statistical Analysis**

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). A Binary Logistic Regression was used to identify significant contributions, from intra-set variability via jump-based GAP assessments, to Starter vs Non-Starter group membership (See Aim 2.A., Table 3.13., and Table 3.15.). The dichotomous variable of Starter is represented by 1 while the dichotomous variable of Non-Starter is represented by .

Based on results from Aim 2.B<sub>1</sub>., a linear relationship between non-traditional GAP variability markers and Starter vs Non-Starter group membership exist, multivariate normality is present, and homoscedasticity exist; however, collinearity was identified between SJ Peak Velocity and SJ Impulse-Momentum, thus violating the multicollinearity assumption (e.g.,  $r \geq .70$ ) when examined together (Draper & Smith, 1998). To address the collinearity issues, the GAP variability markers were analyzed independently. An alpha level of  $p \leq .05$  was set for qualitative interpretations of

contribution significance. Furthermore, a post hoc power analysis was conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Table 3.15. for results of the statistical analysis.

### *Intra-Set Variability of SJ Peak Velocity*

The Omnibus Tests of Model Coefficients ( $\chi^2 = 10.10, p \leq .001$ ) and Hosmer and Lemeshow Test ( $\chi^2 = 6.63, p = .58$ ) determined the model was a good fit. No assumptions related to binary logistic regression were violated. Intra-set variability from SJ Peak Velocity demonstrated significant contribution to Starter vs Non-Starter group membership ( $B = -.23, p = .017, Exp(B) = .79$ ). Interpretation of the Nagelkerke  $R^2$  demonstrates a large effect size ( $R^2 = .53$ ; small =  $R^2 \geq .02$ , medium =  $R^2 \geq .13$ , and large =  $R^2 \geq .26$ ; Hopkins et al., 2009) and observed sufficient power ( $1-\beta = .95$ ; Yuan & Maxwell, 2005). The odds ratio of Starter group membership increased by .79 per every standard deviation improvement (e.g., decrease in observed variable error by  $\sim .02$  m/s) of intra-set variability of SJ Peak Velocity (95% CI = .64 to .98). In total the model observed 15 correct classifications and 5 misclassifications, 2 in the Starter and 3 in the Non-Starter group, for a 75% accuracy rate in predicted group memberships.

### *Intra-Set Variability of SJ Impulse-Momentum*

The Omnibus Tests of Model Coefficients ( $\chi^2 = 6.96, p \leq .008$ ) and Hosmer and Lemeshow Test ( $\chi^2 = 12.26, p = .140$ ) determined the model was a good fit. Intra-set variability from SJ Impulse-Momentum demonstrated significant contribution to Starter

vs Non-Starter group membership ( $B = -.16$ ,  $p = .020$ ,  $Exp(B) = .85$ ). Interpretation of the Nagelkerke  $R^2$  demonstrates a large effect size ( $R^2 = .39$ ; Hopkins et al., 2009) and observed sufficient power ( $1-\beta = .84$ ; Yuan & Maxwell, 2005). The odds ratio of Starter group membership increased by .85 per every standard deviation improvement (e.g., decrease in observed variable error by  $\sim 1.36$  kg-m/s) of intra-set variability in SJ Impulse-Momentum (95% CI = .73 to .99). In total the model observed 13 correct classifications and 7 misclassifications, 4 in the Starter and 3 in the Non-Starter group, for a 65% accuracy rate in predicted group membership.

## Discussion

The purpose of Aim 2.C<sub>2</sub>. was to examine the contribution of intra-set variability, from jump-based GAP assessments, to starters and non-starters in an NCAA DI beach volleyball team. To date this is the first known study to examine the contribution of jump-based GAP variability to Starter vs Non-Starter group membership among a homogenous group of athletes on a NCAA DI team. The strong contributions demonstrated by intra-set variability, in SJ Peak Velocity and SJ Impulse-Momentum, to Starter vs Non-Starter group membership alludes to generalizable application of impulse-variability theory (IVT) and violations of Fitts' Law (e.g., speed-accuracy trade-off; Fitts, 1954) in the high performance sport setting.

Aims 2.C<sub>1</sub>. and 2.C<sub>2</sub>. provide support that IVT may serve a purpose for practitioners by demonstrating strong association and predictive utility of intra-set variability of SJ Peak Velocity to Starter vs Non-Starter group membership. Although intra-set variability of SJ Impulse-Momentum failed to demonstrate strong association

to group membership (see Aim 2.C<sub>1</sub>;  $r = -.54$ ,  $p = .014$ ,  $1-\beta = .68$ ) it was further examined, via binary logistic regression, due to the intimate relationship with (i.e., *Impulse – Momentum = system mass  $\Delta$ velocity*; Ruddock & Winter, 2015) and collinearity to SJ Peak Velocity ( $r = .97$ ,  $p \leq .001$ ;  $1-\beta = .99$ ; see Chapter 2.4 for Impulse-Momentum Theorem).

Results for SJ Impulse-Momentum demonstrate predictive utility ( $B = -.16$ ,  $p = .020$ ,  $Exp(B) = .85$ , Nagelkerke  $R^2 = .39$ ,  $1-\beta = .84$ ) to Starter vs Non-Starter group memberships, but not as strong as SJ Peak Velocity ( $B = -.23$ ,  $p = .017$ ,  $Exp(B) = .79$ , Nagelkerke  $R^2 = .53$ ,  $1-\beta = .95$ ). These data suggest that an improvement of observed intra-set variability of SJ Peak Velocity, regardless of improvements to maximal output, affords greater odds of Starter group membership ( $Exp(B) = .79$ ) and the potential to execute SP related skills with greater proficiency (e.g., less error in output). If coaches, practitioners, and researchers agree that “consistency is key” in regard to SP it is time for implications of IVT to be examined while conducting jump-based GAP assessments.

Variability of performance in ballistic movements (e.g., jump-based GAP assessments) is the result of failure to detect and correct errors via neural feedback loops (Bobbert et al., 2008; Maffiuletti et al., 2016). Additionally, it has been proposed that inter-individual variability of measurable outcome variables (i.e., peak force, rate of force production, impulse, and peak velocity) are largely the result of neuromuscular disturbances witnessed within the first 50ms of initiating a ballistic action (Maffiuletti et al., 2016). Given the association and contribution of SJ Peak Velocity variability to Starter vs Non-Starter group membership future research should consider inspecting

impulse variability (e.g.,  $Impulse = Force \Delta time$ ) via force plate technology at a more precise time point (i.e.,  $\leq 50ms$ ) to improve efficacy of examining IVT via jump-based assessments in the high performance sport setting. Furthermore, future research should examine the combination of GAP maximum (e.g., SJ Peak Velocity, SJ Impulse-Momentum) and GAP variability (e.g., intra-set variability of exhibited GAP maximum) as it may provide better predictive utility of SP outcomes, rank, or group membership (e.g., starters vs non-starters) than independent evaluations of GAP maximum and GAP variability.

### **Limitations**

See Aim 1.A. for general limitations and Aim 2.A. for limitations specific to Aim 2.C<sub>2</sub>.

### **3.11. Methods for Aim 3.A.**

*“Examine the predictive utility of GAP maximum, in conjunction with intra-set variability, to intra-team rank of SP in an NCAA DI beach volleyball team.”*

### **Discussion**

The purpose of Aim 3.A. would have been to examine the predictive utility of GAP maximum, in conjunction with intra-set variability, to intra-team rank of SP in an NCAA DI beach volleyball team; however, due to insignificant results in Aim 2.B<sub>2</sub> (e.g., no significant correlations identified between jump-based GAP variability and SP rank) further analysis via regression was not warranted. SJ Peak Velocity variability ( $r = .43$ ,  $p = .057$ ,  $1-\beta = .25$ ) failed to demonstrate significant association to SP rank; therefore, a regression analysis would have only confirmed results from Aim 1.B<sub>2</sub> (e.g., SJ Impulse-

Momentum maximum and SJ Peak Velocity maximum demonstrate strong independent contribution to intra-team rank of SP in NCAA DI beach volleyball).

In spite of SJ Peak Velocity variability failing to demonstrate significant association to SP rank it was further examined to Starter vs Non-Starter group membership in Aims 2.C<sub>1</sub>. and 2.C<sub>2</sub>. These data (SJ Peak Velocity variability;  $r = -.62$ ,  $p \leq .01$ ,  $1-\beta = .83$  and  $B = -.23$ ,  $p = .017$ ,  $Exp(B) = .79$ ,  $1-\beta = .95$ , respectfully) indicate potential utility of differentiating groups of skilled sport performers among homogenous cohorts (e.g., starters vs non-starters on the same team, professional vs developmental athletes of the same sport, etc.). Future research should examine the combined effects of intra-set variability and maximal output, observed via SJ Peak Velocity, and their predictive utility when comparing intra-team groups (i.e., Starter vs Non-Starter group membership). Visual representation of the combined effects of SJ Peak Velocity maximum and SJ Peak Velocity variability by SP rank (see Figure 3.10), in conjunction with results from Aims 1.C<sub>1</sub>, 1.C<sub>2</sub>, 2.C<sub>1</sub>. and 2.C<sub>2</sub>, provide evidence that predictive utility may be demonstrated when examined to Starter vs Non-Starter group memberships. More data is necessary to identify if tenants of impulse-variability theory are present among a homogenous cohort of athletes participating at the same level of competition.

Additionally, future research should longitudinally examine changes in SJ Peak Velocity and SJ Impulse-Momentum, maximum and variability, across a collegiate athletic career. Collectively, the data from these Aims suggest SJ Impulse-Momentum maximum, SJ Peak Velocity maximum, and SJ Peak Velocity variability are useful SP markers in NCAA DI beach volleyball; however, future research should examine these



non-traditional GAP markers in other power-based sports (e.g., baseball, indoor volleyball, golf, basketball, tennis, football, etc.) to determine if generalizable utility exist. These considerations may be useful for strength and conditioning professionals when evaluating the efficacy of longitudinal training outcomes, as well as assist with recruitment strategies for sport coaches.

### **Limitations**

See Aim 1.A. for general limitations and Aim 2.A. for limitations specific to Aim 3.A. Additionally, see 3.A. discussion for statistical limitations preventing further analysis.

#### **3.12. Methods for Aim 3.B.**

*“Examine the predictive utility of GAP maximum, in conjunction with intra-set variability, for distinguishing starters and non-starters in an NCAA DI beach volleyball team.”*

### **Statistical Analysis**

All statistical analyses were performed using IBM SPSS® version 26.0 (IBM, Armonk, New York). A forward stepwise (Wald) Binary Logistic Regression was used to determine if any combination of maximum and intra-set variability from GAP markers demonstrate predictive utility towards differentiating Starter vs Non-Starter group membership in a NCAA DI beach volleyball team. Predictor variables were evaluated individually to examine differences, changes and contribution in model fit. This continued until all remaining variables were significant and/or the removal of an additional variable significantly reduced model fit (Stodden et al., 2005).

The dichotomous variable of Starter is represented by 1 while the dichotomous variable of Non-Starter is represented by 0. Normative data for NCAA DI beach volleyball is unknown; therefore, GAP marker data was normalized to t-scores for consistent interpretation of relative performance among the sample (Bernards et al., 2017). Descriptive statistics can be found in Table 3.16. Results of Aims 1.A., 1.C<sub>2</sub>, 2.C<sub>1</sub>, and 2.C<sub>2</sub> demonstrate a linear relationship exist between GAP markers and Starter vs Non-Starter group membership, multivariate normality is present, and homoscedasticity exist; however, collinearity was identified among several GAP markers, thus violating the multicollinearity assumption (e.g.,  $r \geq .70$ ) when examined together. To address the collinearity issues, two separate mixed models of GAP maximum and GAP variability markers were identified based on associations to Starter vs Non-Starter group membership (see Aims 1.C<sub>1</sub> and 2.C<sub>1</sub>), while complying with assumptions, and analyzed independently. An alpha level of  $p \leq .05$  was set for qualitative interpretations of contribution significance. Furthermore, a post hoc power analysis was conducted to account for any increase in type-2 error and significance was set at  $1-\beta \geq .75$  (Yuan & Maxwell, 2005).

## Results

See Tables 3.17. and 3.18. for results of the statistical analysis.

### *SJ Peak Velocity Maximum and SJ Peak Velocity Intra-Set Variability*

The Omnibus Tests of Model Coefficients (SJ Peak Velocity maximum –  $\chi^2 = 17.53, p \leq .001$  and SJ Peak Velocity variability –  $\chi^2 = 10.10, p \leq .001$ ) and Hosmer and Lemeshow Test (SJ Peak Velocity maximum –  $\chi^2 = 4.90, p = .67$  and SJ Peak Velocity

variability –  $\chi^2 = 6.63, p = .58$ ) determined the independent models were a good fit. No assumptions related to binary logistic regression were violated. SJ Peak Velocity maximum and SJ Peak Velocity variability demonstrate strong independent contribution to Starter vs Non-Starter group membership ( $B = .63, p = .035, Exp(B) = 1.87$  and  $B = -.23, p = .017, Exp(B) = .79$ , respectfully). Additionally, the interpretation of the Nagelkerke  $R^2$  demonstrates large effect sizes for both ( $R^2 = .78$  and  $.53$ , respectively; small =  $R^2 \geq .02$ , medium =  $R^2 \geq .13$ , and large =  $R^2 \geq .26$ ; Hopkins et al., 2009) and observed power was  $1-\beta = .99$  and  $.95$ , respectively (Yuan & Maxwell, 2005). The independent model for SJ Peak Velocity maximum demonstrated 95% accuracy in predicted group membership with one member of the Starter group misclassified as a Non-Starter. Conversely, SJ Peak Velocity variability demonstrated 75% accuracy with five members misclassified, three from the Non-Starter and two from the Starter groups.

When SJ Peak Velocity maximum and SJ Peak Velocity variability were included together model strength for the Omnibus Tests of Model Coefficients ( $\chi^2 = 27.73, p \leq .001$ ) and Hosmer and Lemeshow Test ( $\chi^2 = .00, p = 1.000$ ) increased, and determined the model was a good fit. Additionally, Nagelkerke  $R^2$  witnessed an increase in explained variance with a large effect size demonstrated ( $R^2 = 1.00$ ; Hopkins et al., 2009) and observed power was  $1-\beta = .99$  (Yuan & Maxwell, 2005). The combination of SJ Peak Velocity maximum and SJ Peak Velocity variability demonstrated 100% accuracy in predicted Starter vs Non-Starter group membership; thus, improving predictive utility of the independent models by 5% and 25%, respectfully.

*SJ Impulse-Momentum Maximum, Vertical Jump Height Maximum, and SJ Peak Velocity Intra-Set Variability*

The Omnibus Tests of Model Coefficients (SJ Impulse-Momentum maximum –  $\chi^2 = 11.55, p \leq .001$ , VJ Height maximum –  $\chi^2 = 7.78, p \leq .005$ , and SJ Peak Velocity variability –  $\chi^2 = 10.10, p \leq .001$ ) and Hosmer and Lemeshow Test (SJ Impulse-Momentum maximum –  $\chi^2 = 10.34, p = .242$ , VJ Height maximum –  $\chi^2 = 12.60, p = .127$ , and SJ Peak Velocity variability –  $\chi^2 = 6.63, p = .578$ ) determined the independent models were a good fit. No assumptions related to binary logistic regression were violated. SJ Impulse-Momentum maximum, VJ Height maximum, and SJ Peak Velocity variability demonstrate strong independent contribution to Starter vs Non-Starter group membership ( $B = .25, p = .010, Exp(B) = 1.28$ ,  $B = .16, p = .014, Exp(B) = 1.18$ , and  $B = -.23, p = .017, Exp(B) = .79$ , respectfully). Additionally, the interpretation of the Nagelkerke  $R^2$  demonstrates large effect sizes for all ( $R^2 = .59, .43$ , and  $.53$ , respectively; Hopkins et al., 2009) and observed power was  $1-\beta = .98, .90$ , and  $.95$ , respectively (Yuan & Maxwell, 2005). The independent model for SJ Impulse-Momentum maximum demonstrated 80% accuracy in predicted group membership with two members each in Starter and Non-Starter groups misclassified. VJ Height maximum demonstrated 75% accuracy in predicted group membership with three Starter and two Non-Starter group members misclassified. Conversely, SJ Peak Velocity variability demonstrated 75% accuracy with five members misclassified, three from the Non-Starter and two from the Starter groups.

When all three GAP markers were examined together VJ Height maximum was eliminated via stepwise procedure as it did not improve model fit or predictive utility. However, SJ Impulse-Momentum maximum and SJ Peak Velocity variability increased model strength for the Omnibus Tests of Model Coefficients ( $\chi^2 = 19.71, p \leq .001$ ) and Hosmer and Lemeshow Test ( $\chi^2 = 1.16, p = .997$ ), and determined the model was a good fit. Additionally, Nagelkerke  $R^2$  witnessed an increase in explained variance with a large effect size demonstrated ( $R^2 = 1.00$ ; Hopkins et al., 2009), and observed power was  $1-\beta = .99$  (Yuan & Maxwell, 2005). The combination of SJ Impulse-Momentum maximum and SJ Peak Velocity variability demonstrated 90% accuracy in predicted Starter vs Non-Starter group membership with one member in each group misclassified; thus, improving predictive utility of the independent models by 10% and 15%, respectfully.

## Discussion

The purpose of Aim 3.B. was to examine the predictive utility of GAP maximum, in conjunction with intra-set variability, for distinguishing starters and non-starters in an NCAA DI beach volleyball team. Additionally, Aim 3.B. attempted to cross-validate recent studies that identified impulse-momentum and peak velocity as demonstrating predictive utility to SP rank and outcomes (Baker & Newton, 2008; Garcia-Ramos et al., 2016; Magrini et al., 2017); however, none of these studies examined intra-set variability of these non-traditional GAP markers. Furthermore, Aim 3.B. included pertinent research from the motor control literature, particularly involving impulse-variability theory, provided results from recent studies that have examined multijoint

ballistic skills related to SP (e.g., kicking and throwing; Urbin et al., 2011; Urbin et al., 2012; Molina, 2015; Chappell et al., 2016; Molina et al., 2019).

In agreement with Aims 1.C<sub>2</sub> and 2.C<sub>2</sub>, these data indicate SJ Peak Velocity (maximum), Impulse-Momentum (maximum), and SJ Peak Velocity (intra-set variability) demonstrate strong predictive utility to Starter vs Non-Starter group membership in NCAA DI beach volleyball. Vertical Jump Height (maximum) failed to improve model fit and failed to demonstrate strong predictive utility to Starter vs Non-Starter Membership. Conversely, SJ Peak Velocity variability improved model fit for both models, thus provided greater predictive utility to each model compared to independent contribution from SJ Peak Velocity maximum and SJ Impulse-Momentum maximum (see Aim 1.C<sub>2</sub> and Table 3.10.).

These data indicate a robust GAP foundation is necessary for recruitment and inclusion in NCAA DI beach volleyball (i.e., domain specific criteria; Ericsson et al., 1993), but how they are expressed during multijoint ballistic actions (i.e., peak velocity and variable error) provide better discriminatory utility to SP group memberships (e.g., starter vs non-starter status on the same team, professional vs developmental status in the same sport, high vs low-skill performers in the same tasks; Stodden et al., 2001; Baker & Newton, 2008; Urbin et al., 2011; Magrini et al., 2017; Molina et al, 2019). Variability observed via GAP markers have been largely overlooked in the sport science literature but may provide relevant information when examining similarities and differences among homogenous groups of athletes. Additionally, these results provide

merit for further exploration into motor control implications in the high performance sport setting.

These data provide logical validity of the assumption that Sport Performance is the result of the combined effects of ballistic strength (i.e., peak velocity) and consistency of that output (i.e., exhibiting less variable error). Additionally, these data provide construct validity provided differences were observed between groups (i.e., starter vs non-starter) among a homogenous cohort, as well as casual-comparative design where group membership was considered the critical value. Aim 3.A. provides a basis of external validity in regard to future research to examine GAP maximum and variability and their implications on SP outcomes among skilled sport athletes and teams (i.e., golf, tennis, baseball, indoor volleyball, basketball, etc.). Given results of Aim 3.B., and recent research related to IVT and SP related multijoint ballistic skills (e.g., kicking and throwing; Urbin et al., 2011; Molina, 2015; Chappell et al., 2016; Molina & Stodden, 2017), these data provide a foundation for further research to examine the generalizable application of GAP maximal output and GAP variability to SP outcomes in skill based sports.

### **Limitations**

See Aim 1.A. for general limitations and Aim 2.A. for limitations specific to Aim 3.A.

Table 3.1. Descriptive Statistics for Demographic and Anthropometric Markers

Demographic and Anthropometric Markers	Team		Starters		Non-Starters	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Age (years)	19.75	1.52	19.70	1.57	19.80	1.55
Height (cm)	173.32	6.49	172.47	7.33	174.17	5.80
Standing Reach (cm)	223.71	7.70	223.90	7.94	223.52	7.88
Weight (kg)	66.91	7.75	69.42	8.24	64.40	6.70
Fat Mass (%)	20.35	4.06	20.68	3.58	20.02	4.66



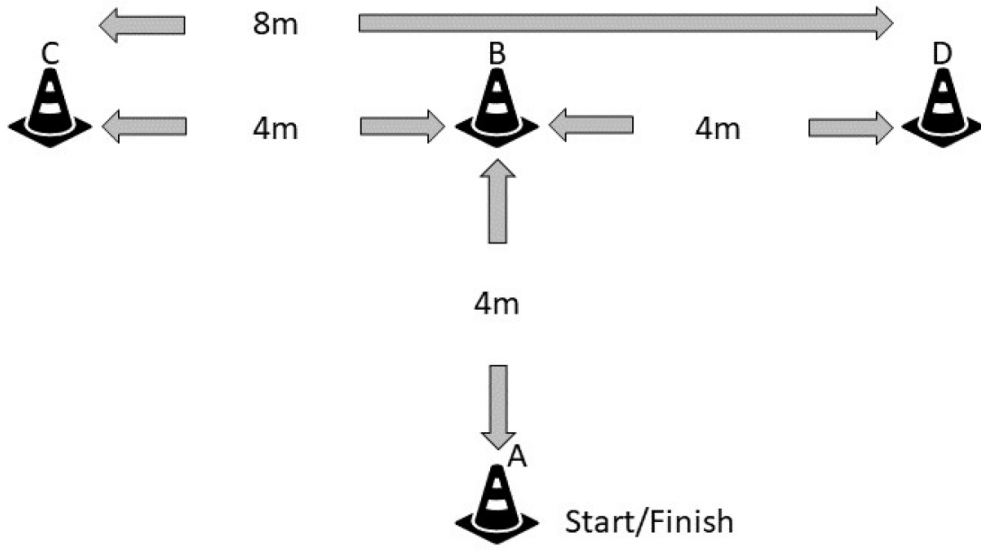


Figure 3.1. Modified T-Test Agility Assessment

Table 3.2. Descriptive Statistics for GAP Maximum, Demographic, and Anthropometric Markers (raw scores)

GAP, Demographic, and Demographic Markers	Starters		Team		Non-Starters	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Age (years)	19.70	1.57	19.75	1.52	19.80	1.55
Height (cm)	172.47	7.33	173.32	6.49	174.17	5.80
Standing Reach (cm)	223.90	7.94	223.71	7.70	223.52	7.88
Weight (kg)	69.42	8.24	66.91	7.75	64.40	6.70
Fat Mass (%)	20.68	3.58	20.35	4.06	20.02	4.66
VJ Height (cm)	61.98	4.93	58.80	5.62	55.63	4.47
Approach VJ Height (cm)	68.45	4.95	65.60	5.30	62.74	4.07
MedBall Toss (m)	10.57	.69	10.11	.86	9.65	.78
1RM Power Clean (kg)	63.18	14.08	57.05	14.78	50.91	13.39
T-Test Agility (secs)	5.40	.12	5.45	.14	5.51	.14
1RM HB Deadlift (kg)	112.27	22.55	100.00	24.30	87.73	20.08
1RM Front Squat (kg)	89.09	18.86	78.86	18.84	68.64	12.71
SJ Peak Velocity (m/s)	2.57	.15	2.44	.18	2.31	.10
SJ Impulse-Momentum	229.98	25.93	212.39	27.21	194.81	14.25

Table 3.3. Pearson's Correlational Matrix for GAP Maximum Marker Associations

GAP Markers	1	2	3	4	5	6	7	8	9
1. VJ Height (cm)									
2. Approach VJ Height (cm)	.88**								
3. MedBall Toss (m)	.43	.42							
4. 1RM Power Clean (kg)	.50	.56	.43						
5. T-Test Agility (secs)	-.42	-.33	-.44	-.45					
6. 1RM HB Deadlift (kg)	.45	.54	.55	.79**	-.51				
7. 1RM Front Squat (kg)	.49	.60*	.47	.84**	-.41	.95**			
8. SJ Peak Velocity (m/s)	.81**	.77**	.53	.50	-.49	.61*	.60*		
9. SJ Impulse-Momentum	.53	.60*	.54	.74**	-.48	.88**	.89**	.72**	

Note. \*  $p \leq .006$ , \*\*  $p \leq .001$

Table 3.4. Kendall's and Spearman's Correlations Among Expert Raters

Expert	1	2	3	4	5
1. ER1		.89	.86	.95	.92
2. ER2	.78		.74	.93	.82
3. ER3	.69	.64		.84	.87
4. ER4	.63	.79	.51		.94
5. ER5	.78	.83	.68	.73	

Note.  $p \leq .001$

tau-b

rho

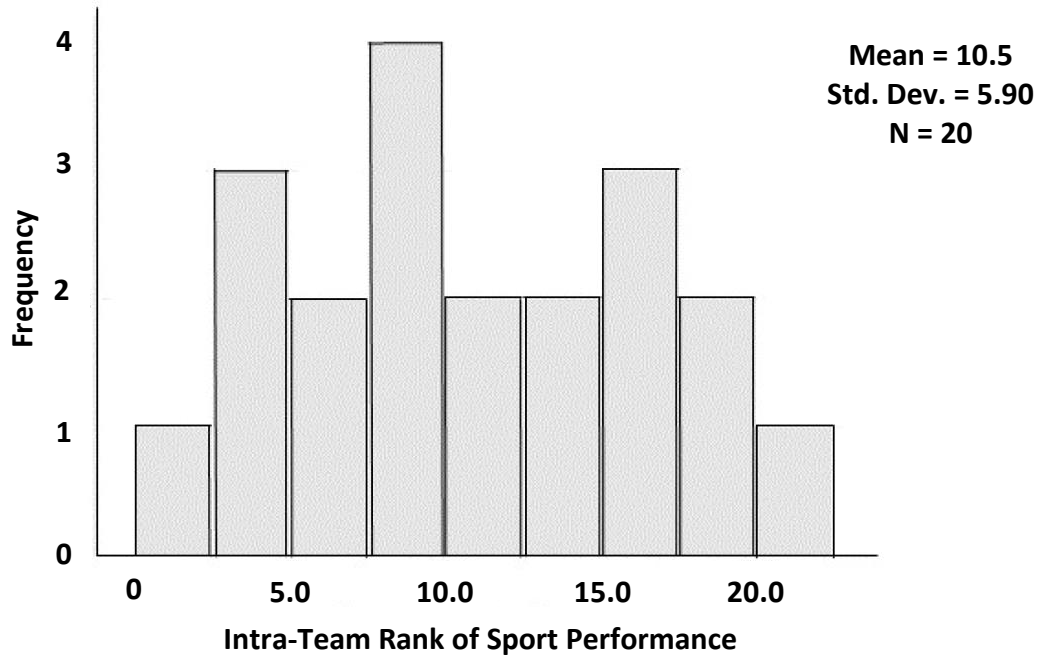


Figure 3.2. Test of Normality for Intra-Team Rank of Sport Performance

Table 3.5. Spearman's Correlations for GAP Maximum, Anthropometric, and Demographic Markers to Intra-Team Rank of Sport Performance

Order of Association	<i>r</i>
SJ Peak Velocity (m/s)	-.71**
SJ Impulse-Momentum (kg·m/s)	-.71**
1RM Front Squat (kg)	-.66*
VJ Height (cm)	-.64*
Approach VJ Height (cm)	-.63*
1RM HexBar Deadlift (kg)	-.63*
MedBall Toss (m)	-.60
1RM Power Clean	-.49
Body Mass (kg)	-.45
T-Test Agility (secs)	.44
Fat Mass (%)	-.31
Age (years)	.16
Standing Reach (cm)	-.08
Height (cm)	.04

Note. \*  $p \leq .003$ , \*\*  $p \leq .001$

Table 3.6. Descriptive Statistics for GAP Maximum Markers (t-scores)

GAP Markers	Team	
	<i>M</i>	<i>SD</i>
VJ Height	50.00	10.00
Approach VJ Height	50.00	10.00
1RM HexBar Deadlift	50.00	10.00
1RM Front Squat	50.00	10.00
SJ Peak Velocity	50.00	10.00
SJ Impulse-	50.00	10.00

Table 3.7. Ordinal Logistic Regression Analysis for GAP Maximum Markers and Intra-Team Rank of Sport Performance

GAP Markers	$\chi^2$	$p$	$R^2$	$1-\beta$	Wald $\chi^2$	OR [95% CI]	$p$
<b>SJ Impulse-Momentum and VJ Height</b>							
Overall Model	13.10***	.001	.48	.98			
SJ Impulse-Momentum					4.86	-.89 [-.80 to -.99]	.027*
VJ Height					2.58	-.92 [-.84 to -1.02]	.108
<b>SJ Peak Velocity and 1RM HexBar</b>							
Overall Model	10.41**	.005	.41	.93			
SJ Peak Velocity					3.71	-.90 [-.81 to -1.01]	.050*
1RM HexBar Deadlift					1.15	-.95 [-.85 to -1.05]	.284
<b>Approach VJ Height and 1RM Front</b>							
Overall Model	11.06**	.004	.43	.94			
Approach VJ Height					2.29	-.92 [-.83 to -1.02]	.130
1RM Front Squat					3.06	-.91 [-.82 to -1.01]	.080

Note. \* $p \leq .05$ , \*\* $p \leq .005$ , \*\*\* $p \leq .001$



Table 3.8. *Point-Biserial Correlations for GAP Maximum, Anthropometric, and Demographic Markers to Starter vs Non-Starter Group Membership*

<b>Order of Association</b>	<b><i>r</i></b>
<b>SJ Peak Velocity (m/s)</b>	.71**
<b>SJ Impulse-Momentum (kg·m/s)</b>	.66**
<b>VJ Height (cm)</b>	.58
<b>1RM Front Squat (kg)</b>	.56
<b>Approach VJ Height (cm)</b>	.55
<b>MedBall Toss (m)</b>	.55
<b>1RM HexBar Deadlift (kg)</b>	.52
<b>T-Test Agility (secs)</b>	-.44
<b>1RM Power Clean</b>	.43
<b>Body Mass (kg)</b>	.33
<b>Height (cm)</b>	-.14
<b>Fat Mass (%)</b>	.08
<b>Age (years)</b>	-.03
<b>Standing Reach (cm)</b>	.03

Note. \* $p \leq .003$ , \*\* $p \leq .001$

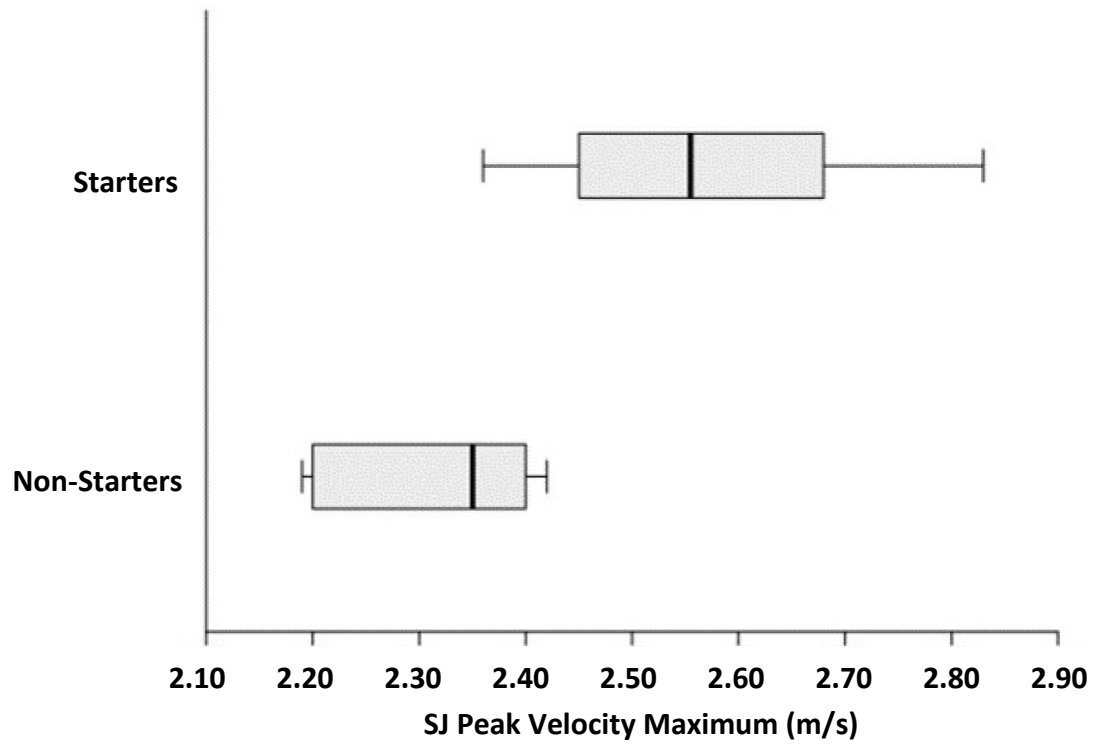


Figure 3.3. Comparison of SJ Peak Velocity Maximum (m/s) in Starter vs Non-Starter Group Membership

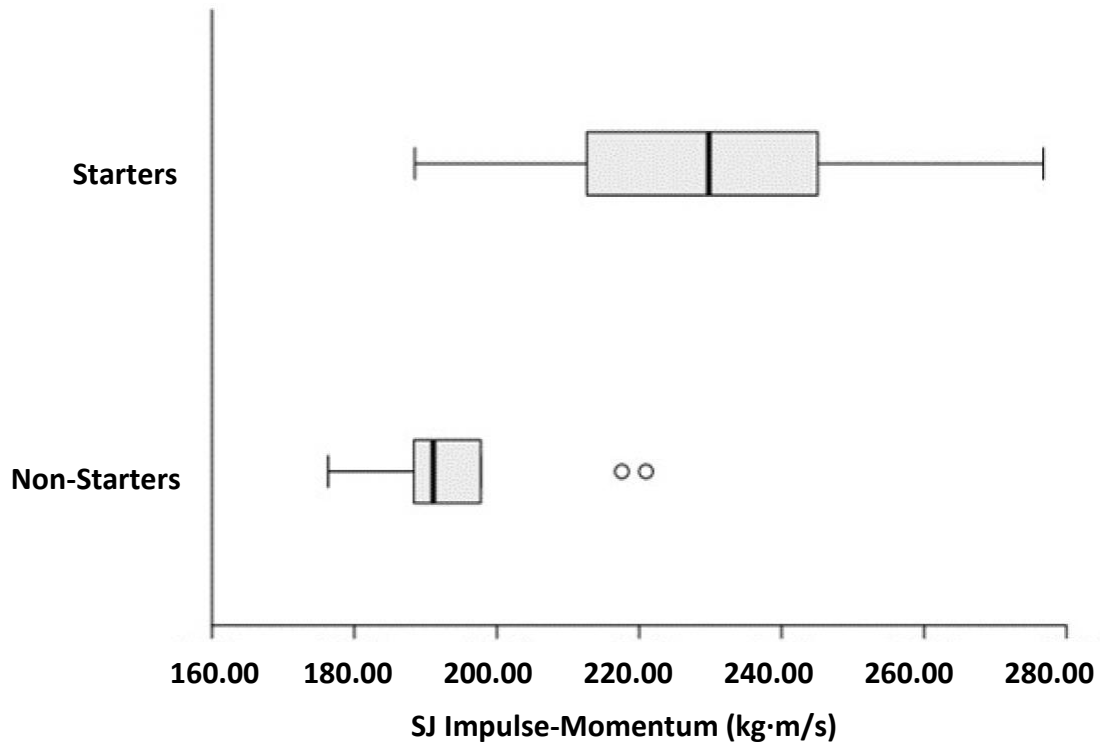


Figure 3.4. Comparison of SJ Impulse-Momentum Maximum (kg·m/s) in Starter vs Non-Starter Group Membership

Table 3.9. Descriptive Statistics of Starters vs Non-Starters for GAP Maximum Markers (t-scores)

GAP Markers	Starters		Team		Non-Starters	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<b>SJ Peak Velocity</b>	57.22	8.13	50.00	10.00	42.78	5.39
<b>SJ Impulse-</b>	56.46	9.53	50.00	10.00	43.54	5.24
<b>Vertical Jump Height</b>	55.65	8.77	50.00	10.00	44.35	7.95

Table 3.10. Binary Logistic Regression for GAP Maximum Markers to Starter vs Non-Starter Group Membership

GAP Markers	$\chi^2$	$R^2$	$\beta$	$SE(\beta)$	Wald $\chi^2$	OR [95% CI]	$p$	1- $\beta$
<b>Starters vs Non-SJ Peak Velocity</b>	17.53**	.78	.63	.34	3.29	1.87 [.95-3.67]	.035*	.99
<b>Starters vs Non-SJ Impulse-</b>	11.55**	.59	.25	.25	5.45	1.28 [1.04-1.58]	.010**	.98
<b>Starters vs Non-VJ Height</b>	7.78**	.43	.16	.16	4.87	1.18 [1.02-1.36]	.014*	.90

Note. \*  $p \leq .05$ , \*\*  $p \leq .01$

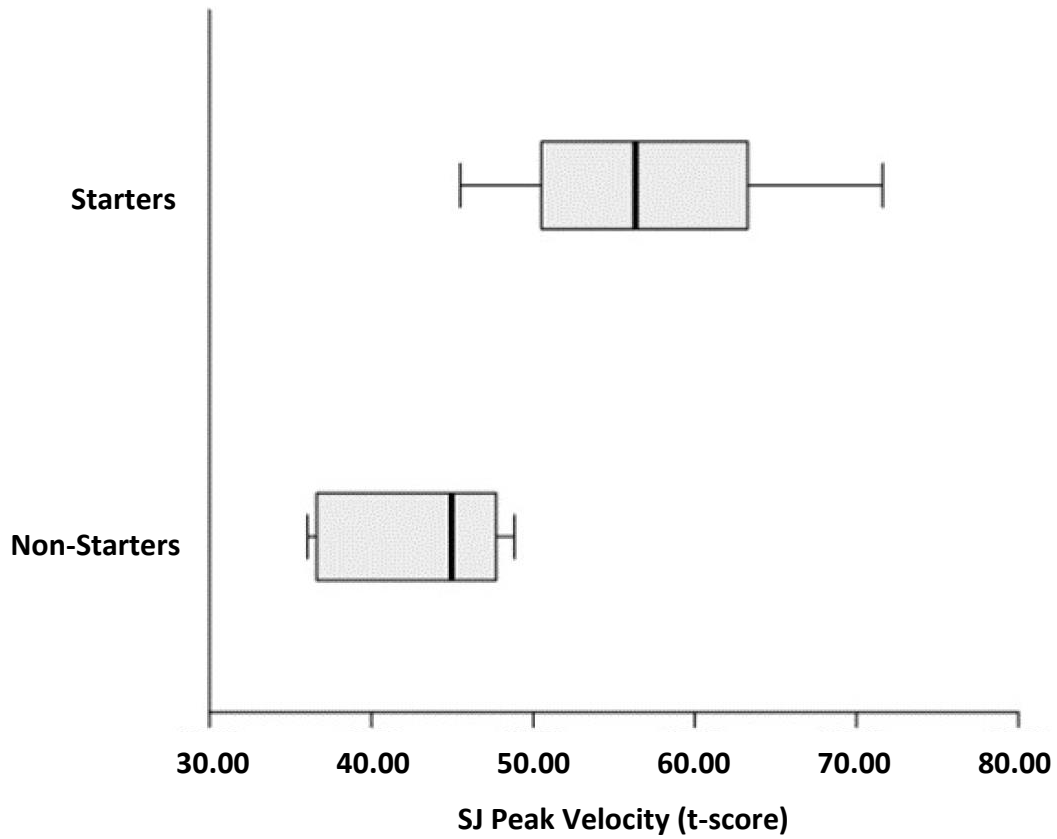


Figure 3.5. Comparison of SJ Peak Velocity Maximum (t-score) in Starter vs Non-Starter Group Membership

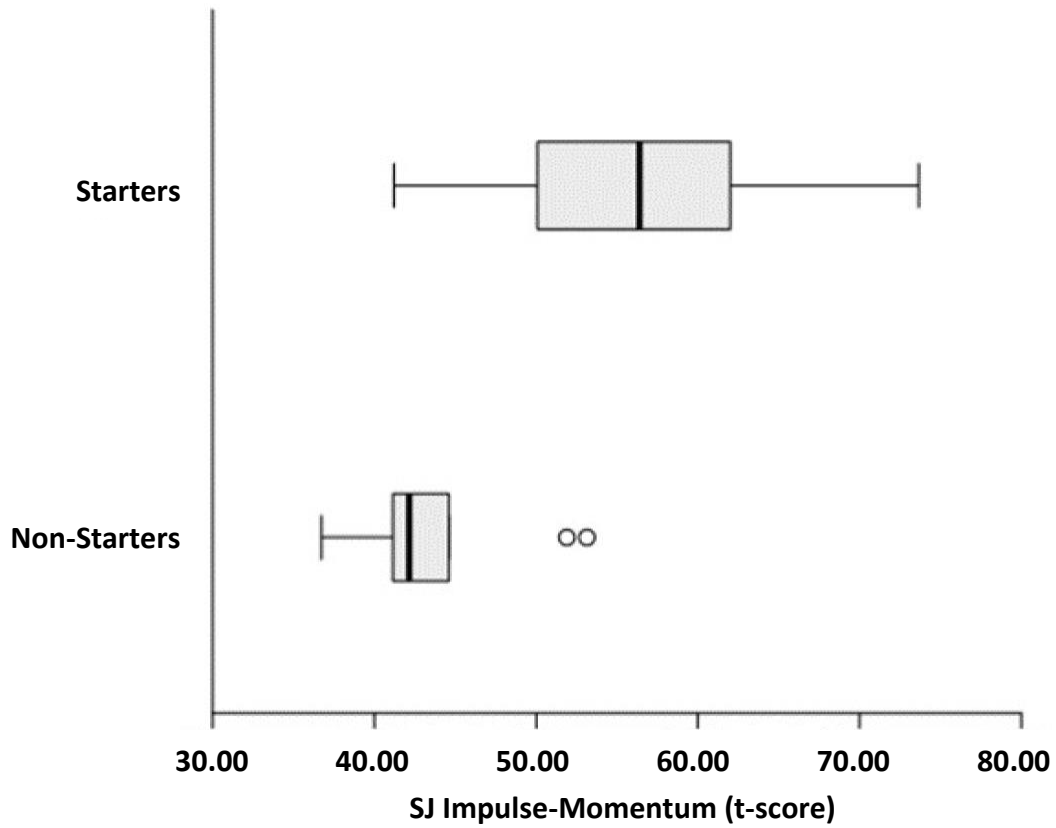


Figure 3.6. Comparison of SJ Impulse-Momentum Maximum (t-score) in Starter vs Non-Starter Group Membership

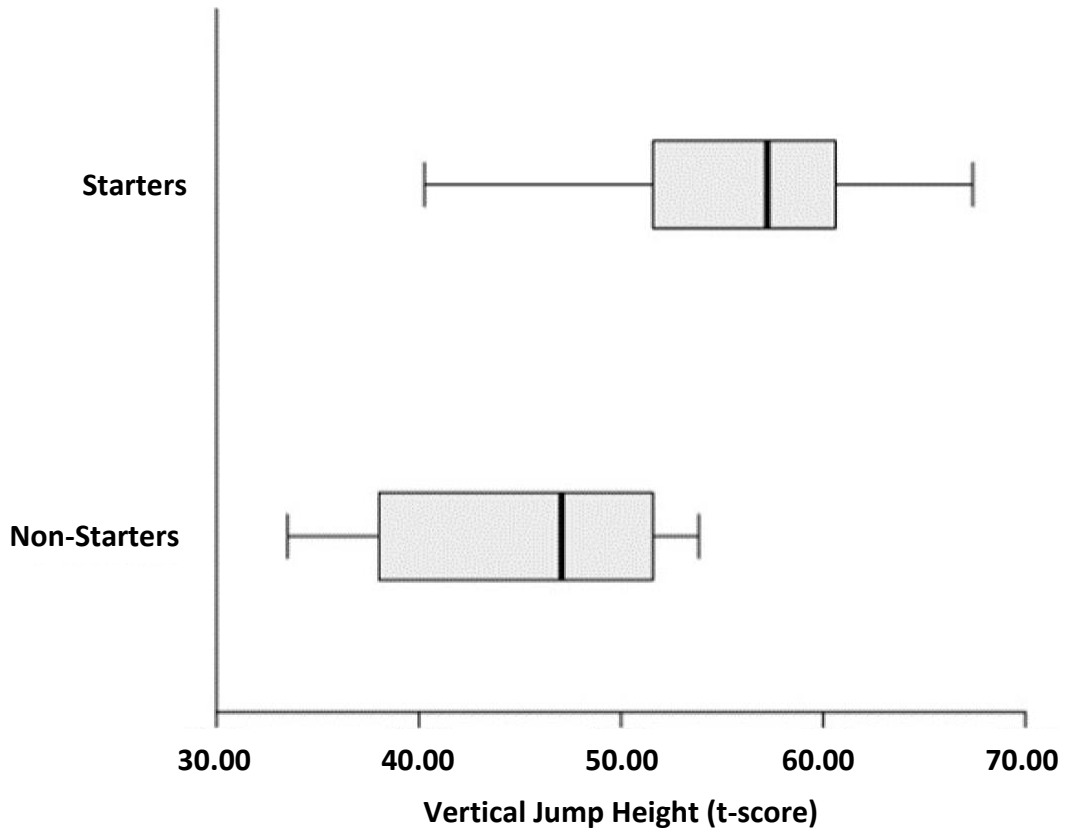


Figure 3.7. Comparison of Vertical Jump Height Maximum (t-score) in Starter vs Non-Starter Group Membership



Table 3.11. *Descriptive Statistics for Jump-Based GAP Variability*

GAP Variability	Raw Scores		t-Scores	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
VJ Height	1.02	.65	50.00	10.00
Approach VJ Height	1.61	.76	50.00	10.00
SJ Peak Velocity	.05	.02	50.00	10.00
SJ Impulse-Momentum	4.03	1.36	50.00	10.00

Table 3.12. Spearman's Correlations for Jump-Based GAP Variability to Intra-Team Rank of Sport Performance

GAP Markers	<i>r</i>	<i>p</i>
SJ Peak Velocity Variability	.43	.057
SJ Impulse-Momentum Variability	.29	.201
Approach VJ Height Variability	.23	.368
VJ Height Variability	-.14	.603

Note. \* $p \leq .01$

Table 3.13. Descriptive Statistics for Starter vs Non-Starter Jump-Based GAP Variability

GAP Variability	Starters				Non-Starters			
	Raw Scores		t-Scores		Raw Scores		t-Scores	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
VJ Height	1.08	.79	50.89	11.92	.96	.55	49.11	8.21
Approach VJ Height	1.29	.27	45.89	3.47	1.93	.99	54.11	12.71
SJ Peak Velocity	.04	.02	43.92	6.60	.06	.02	56.08	9.24
SJ Impulse-Momentum	3.30	1.08	44.73	7.72	4.77	1.33	55.27	9.48

Table 3.14. *Point-Biserial Correlations for Jump-Based GAP Variability to Starter vs Non-Starter Group Membership*

<b>GAP Markers</b>	<b><i>r</i></b>	<b><i>p</i></b>
<b>SJ Peak Velocity Variability</b>	-0.62	.003
<b>SJ Impulse-Momentum Variability</b>	-0.54	.014
<b>Approach VJ Height Variability</b>	-0.42	.064
<b>VJ Height Variability</b>	.09	.701

Note. \* $p \leq .01$

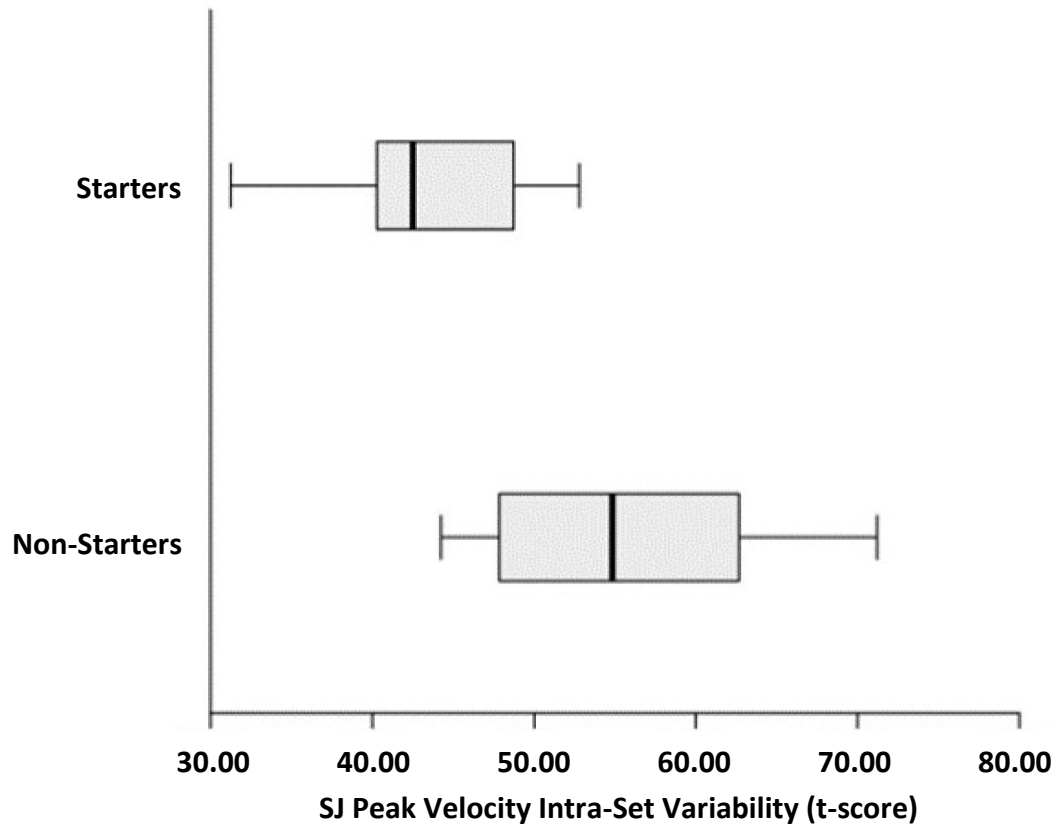


Figure 3.8. Comparison of SJ Peak Velocity Variability in Starter vs Non-Starter Group Membership

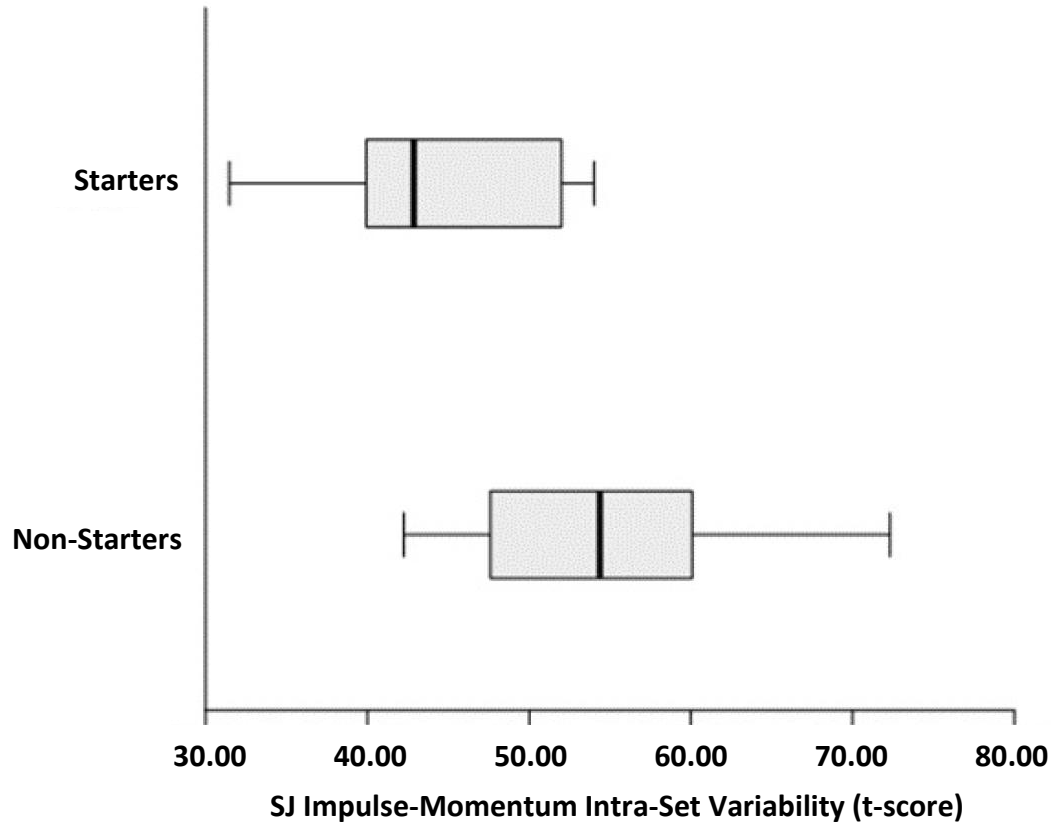


Figure 3.9. Comparison of SJ Impulse-Momentum Variability in Starter vs Non-Starter Group Membership

Table 3.15. Binary Logistic Regression for Jump-Based GAP Variability to Starter vs Non-Starter Group Membership

GAP Markers	$\chi^2$	$R^2$	$\beta$	$SE(\beta)$	Wald $\chi^2$	OR [95% CI]	$p$	1- $\beta$
<b>Starters vs Non-Starters (1)</b>								
SJ Peak Velocity Variability	10.10**	.53	-.23	.11	4.49	.79 [.64-.98]	.017*	.95
<b>Starters vs Non-Starters (2)</b>								
SJ Impulse-Momentum	6.96**	.39	-.16	.08	4.19	.85 [.73-.99]	.020*	.84

Note. \* $p \leq .05$ , \*\* $p \leq .01$

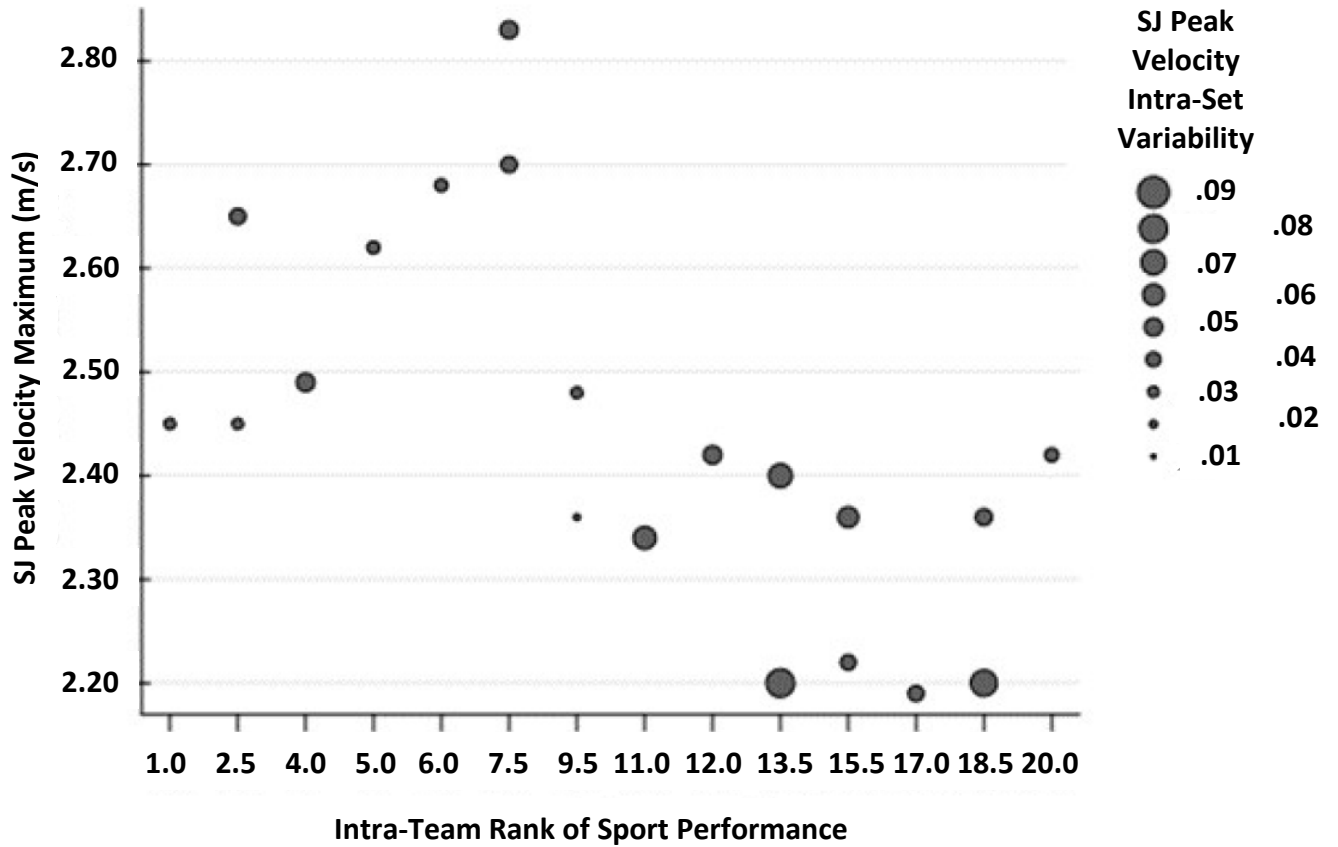


Figure 3.10. Combination of SJ Peak Velocity Maximum and Variability to Intra-Team Rank of Sport Performance



Table 3.16. *Descriptive Statistics for GAP Markers in the Binary Logistic Regression Analysis (t-scores)*

GAP Markers	Starters		Team		Non-Starters	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<b>SJ Peak Velocity Maximum</b>	57.22	8.13	50.00	10.00	42.78	5.39
<b>SJ Impulse-Momentum</b>	56.46	9.53	50.00	10.00	43.54	5.24
<b>Vertical Jump Height</b>	55.65	8.77	50.00	10.00	44.35	7.95
<b>SJ Peak Velocity Variability</b>	43.92	6.60	50.00	10.00	56.08	9.24

Table 3.17. Binary Logistic Regression for GAP Maximum and Jump-Based GAP Variability to Starter vs Non-Starter Group Membership

GAP Maximum and GAP	$\chi^2$	$R^2$	$\beta$	$SE(\beta)$	Wald $\chi^2$	OR [95% CI]	$p$	1- $\beta$
<b>SJ Peak Velocity Maximum and</b>								
<b>SJ Peak Velocity Variability (1)</b>								
Overall Model	27.73**	1.00						.99
SJ Peak Velocity Maximum	17.53**	.78	.63	.34	3.29	1.87 [.95-3.67]	.035*	.99
SJ Peak Velocity Variability	10.10**	.53	-.23	.11	4.49	.79 [.69 - .98]	.017*	.95
<b>SJ Impulse-Momentum</b>								
<b>Maximum,</b>								
<b>VJ Height Maximum, and</b>								
<b>SJ Peak Velocity Variability (2)</b>								
Overall Model	19.71**	.84						.99
SJ Impulse-Momentum	11.55**	.59	.25	.25	5.45	1.28 [1.04-1.58]	.010**	.98
VJ Height Maximum	7.78**	.43	.16	.16	4.87	1.18 [1.02-1.36]	.014*	.90
SJ Peak Velocity Variability	10.10**	.53	-.23	.11	4.49	.79 [.69 - .98]	.017*	.95

Note. \* $p \leq .05$ , \*\* $p \leq .01$

Table 3.18. Classification Results for Predicted Starter vs Non-Starter Group Membership for SJ Peak Velocity Maximum and SJ Peak Velocity Variability

<b>Predicted Starter vs Non-Starter Group Membership</b>				
	<b>SJ Peak Velocity Maximum and SJ Peak Velocity Variability</b>		<b>SJ Impulse-Momentum Maximum, VJ Height Maximum, and SJ Peak Velocity Variability</b>	
	<b>Starters</b>	<b>Non-Starters</b>	<b>Starters</b>	<b>Non-Starters</b>
<b>Starters</b>	10	0	9	1
<b>Non-Starters</b>	0	10	1	9
<b>Total / %</b>	<b>10 / 100%</b>	<b>10 / 100%</b>	<b>9 / 90%</b>	<b>9 / 90%</b>

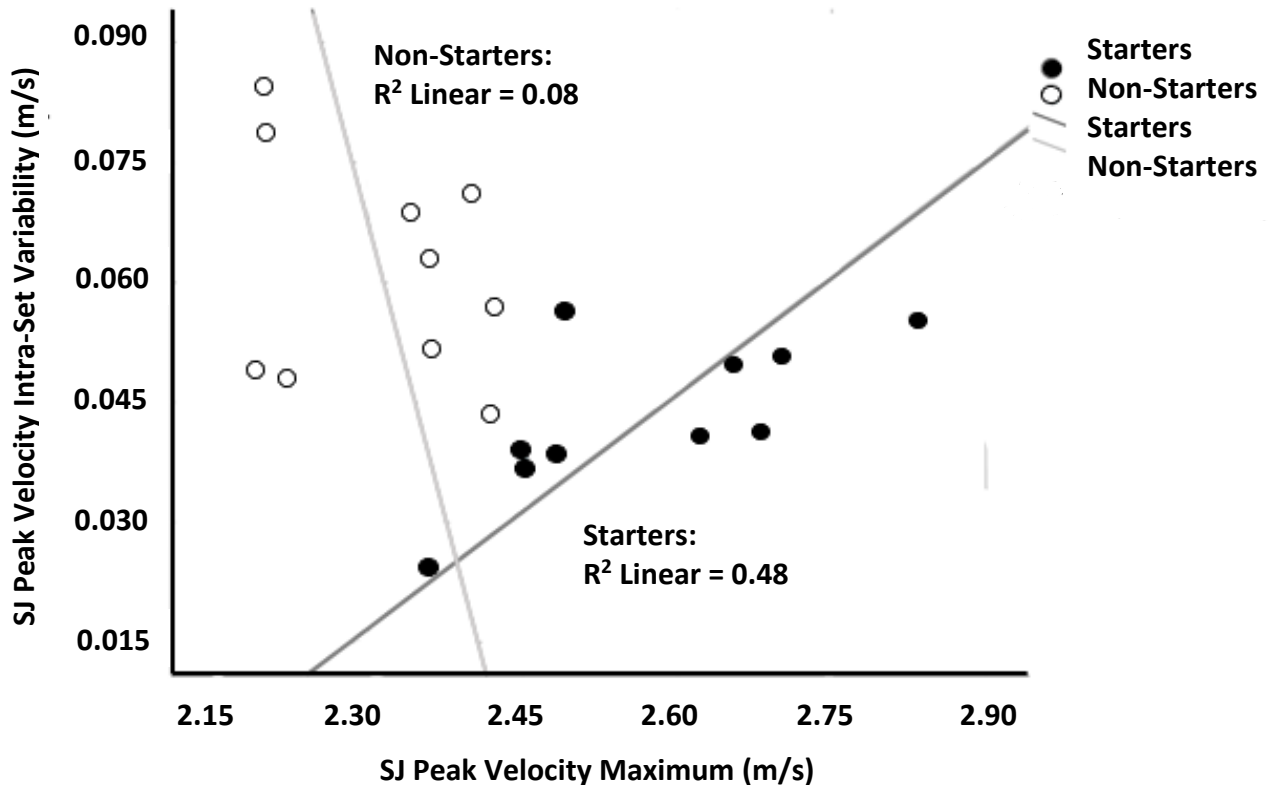


Figure 3.11. Scatterplot of SJ Peak Velocity Maximum and SJ Peak Velocity Variability to Starter vs Non-Starter Group Membership

## CHAPTER 4

### SUMMARY

Advanced evaluations of talent identification need to be explored in order to distinguish between or predict SP outcomes and group memberships. Sport coaches commonly state that “consistency is key” in regard to SP; however, sports science has failed to listen to, nor integrate, this concept in athlete monitoring strategies and research methods. Data observed from these Aims indicate that maximal output SJ Peak Velocity not only associates well with traditional GAP markers, but also demonstrates strong predictive utility to Starter vs Non-Starter group membership in an NCAA beach volleyball team (see Aim 1.C<sub>2</sub>). Furthermore, the observed consistency (e.g., intra-set variability) of SJ Peak Velocity provides utility to predicted Starter vs Non-Starter group membership (see Aim 2.C<sub>2</sub>) and commensurate with maximal output GAP markers (see Aim 1.C<sub>2</sub> vs Aim 2.C<sub>2</sub>). When examined together SJ Peak Velocity maximal output in conjunction with SJ Peak Velocity variability demonstrate the strongest predictive utility to SP group membership. Future research should consider examining these markers in other speed and power based sports, and longitudinally assess these non-traditional GAP markers to examine changes across a collegiate career.

Variability observed via squat jumps may also provide predictive utility to non-contact injury risk (i.e., ACL tears) among athletes, especially if examined unilaterally. Further examination may provide a basis for further implications of impulse-variability theory on SP, GAP development, as well as in the athletic training and rehabilitation realms (Schmidt et al., 1979; Carlton & Newell, 1993; Bobbert et al., 2008; Maffiuletti et al., 2016). Additionally, tenants of impulse-variability theory need to be further explored in childhood development and physical education as both play a role in future SP outcomes and GAP development (i.e., transferability of fundamental motor skills to GAP, specific sport skill execution, and SP outcomes) in youth physical development as well as in high level sport performance arenas.

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## APPENDIX A.

### SPORTS SCIENCE RESEARCH COMMITTEE APPROVAL LETTER

June 15, 2020

Dear Keith Scruggs:

Thank you for reaching out regarding your interests in proposing a research project titled *Relationship of General Athletic Performance Markers to Intra-team Ranking of Sport Skills* with the Department of Athletics at the University of South Carolina. The University of South Carolina Sports Science Committee, comprised of Athletics Administrators, Sports Medicine, Sports Performance and Coaching staff, completed review of the requested protocol.

After review of this request for retrospective analysis of historic data by the Committee, this research request is approved. Under our current policy, only research projects which directly impact the student-athlete experience will be considered for approval.

Our apologies for the delay in responding to this request. This research approval process is new, and we are working to make it more efficient. We wish you the best of success as you continue to pursue your academic and professional goals.

Sincerely,

Sports Science Research Committee

cc: Billy Anderson, Director of Sports Performance  
Jay Patel, Director of Performance Science  
Judy Van Horn, Deputy Athletics Director for Internal Operations & Risk Management