2020

Physiological performance characteristics of Universal Tennis Rating (UTR)

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PHYSIOLOGICAL PERFORMANCE CHARACTERISTICS OF UNIVERSAL TENNIS RATING (UTR)

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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University of Northern Iowa

December 2020

ABSTRACT

The purpose of this study was to create a physiological profile based on UTR through a series of tests to aid coaches in improving the performance of their athletes of any UTR level and to prepare the athletes physiologically for the level above. The UTR patent details skill and tactical development of players at each level as well as a few psychological skills. Physiological skills are only vaguely mentioned and not quantified creating a desire for a physiological profile. It has been previously agreed upon that high capabilities in linear speed, agility, power, anaerobic, aerobic, and strength are correlated with high-level tennis athletes so testing in these areas was used. Upon arrival to the testing facility, participants were provided a verbal explanation of the study and asked to complete an Informed Consent document before beginning. Athletes then began height, and weight measurements followed by an active warm-up. Administration of tests was conducted in the following order: Grip Strength, 20m Sprint, Modified 5-0-5 Agility, Vertical Jump, 10x20 Repeat Sprint Ability, and Multistage Shuttle Run. Means and standard deviations were created for each metric to determine effect size. The calculated z score was used to visualize standard differences. All four subjects struggled with single-leg strength and power which may hinder serve and stroke power production. All subjects also struggled with aerobic capacity, indicating difficulty in longer formatted matches or full third set play. Three of the four subjects were weak in anaerobic capacities, which causes a decrement to their strong acceleration abilities throughout a match. With corrections in these areas, athletes will strengthen another style of play for themselves and have another set of abilities to fall back on when their preferred style doesn't work

against opponents, thus potentially raising their UTR. A physiological profile can help to highlight group or team strengths and weaknesses. In a collegiate or academy setting where strength and conditioning coaches are often training small groups of tennis athletes together, this can help to guide the focus of a new macrocycle and the mesocycles within it.

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This Study by: Savanna Hunt

Entitled: PHYSIOLOGICAL PERFORMANCE CHARACTERISTICS OF UNIVERSAL TENNIS RATING (UTR)

has been approved as meeting the thesis requirements for the

Degree of Master of Arts

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ACKNOWLEDGEMENTS

Throughout the design and writing of this thesis I have received an incredible quality of support and assistance.

Firstly, I would like to thank my committee chair, Dr. Jacob Reed, for his assistance from the pre-conception of this research to the very end. His expertise was invaluable in stepping me through my first research study as well as his supportive, teaching attitude, which helped me to learn in a way that was manageable throughout my graduate career.

I would also like to thank my readers, Dr. Fabio Fontana and Dr. Mickey Mack for offering their expertise when I needed additional support. Each always greeted and taught me with a smile over my six years at UNI.

I would like to acknowledge my friends and classmates for dedicating time to participating in my pilot testing in the evenings. I would particularly like to thank Nick LaPointe for staying extra hours after pilot testing to help engineer an eventual smooth and efficient test day with the tools at my disposal.

In addition, I would like to thank my parents and brothers for their support through not only my entire life of schooling, but especially my graduate career which I could not have completed without their support and sympathetic ears.

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CHAPTER 1

INTRODUCTION

Tennis began in France in the 12th and 13th centuries, evolving greatly over the following centuries with rule changes and changes in the shape and size of the court (Gillmeister, 1998). In 1877, the All England Croquet Club held a tennis tournament with rules similar to the modern game. From here, tennis quickly spread to the rest of the world, and since the late 1800's evolutions in racket material and strategy can be noted (Crego, 2003). The sport has become increasingly popular and large tournaments such as Grand Slams are spectated worldwide.

Tennis is characterized by long duration matches constructed from fast-paced points interrupted with short periods of rest. In a match, each point is begun with a service; a rally ensues between opponents until one player hits the ball out or misses into the net. A single point can range from 3 to 15 seconds and an average match will last about 1.5 hours (Kovacs, 2007). Typically, a match is played to the "best of three" sets to 6 games with a tiebreaker at 6-6, although other legal formats are sometimes played due to time constraints or convenience.

Each match won or lost in verified tournaments counts toward a players' ranking on various platforms. As players are ranked across the world and top-ranked players' income and benefits increase, competition for a top-ranking also increases. In tennis, total ability is comprised of a variety of factors including skill, tactical, psychological, and physiological abilities. Differences in ability are evident among athletes to the naked eye as well as through wins and losses in competitions. To quantify these differences, rating

systems such as Universal Tennis Rating (UTR) exist to determine a hierarchy of tennis ability.

Universal Tennis Rating is a global tennis rating system in which all players that meet the criteria (playing verified matches), regardless of age, gender, location, or skill level are rated on the same 16-point scale. This rating system is objective, based on competition, score, and history. Any competing player can have a UTR rating, however, for it to be a "verified UTR" an athlete must have match results from at least five verified tournaments and events. Casual or practice matches reported will not impact a verified UTR score (Howell & Cancado, 2013).

The original UTR patent provides a detailed description of the skill and tactical development of an athlete at a given level as well as some psychological developments that will impact ability at higher levels. A description of a skill that a level 1 player must have is, "The player must be able to serve from the baseline." A tactical development seen in level 2 is, "They are able to recover behind the baseline more frequently." Psychological developments are not seen until later levels. A level 7 is described as not having the ability to hold up some part of their game under pressure (Howell & Cancado, 2013).

Although the physiological facet is eluded to, there are underlying physiological constructs that are not discussed or quantified. Vague phrases such as "court coverage is well developed", "have few skills, but make up for it with athleticism", and "can sustain long rallies" are used. To develop a more complete description, a physiological profile can be created using previously determined valid and reliable tests for tennis athletes.

In the literature, a physiological profile assessment (PPA) allows for quick identification of an older adult's physiological strengths and weaknesses through a series of tests (Lord, Menz, & Tiedemann, 2003). Extrapolated to sport, a physiological profile includes an assessment through a series of tests resembling demands in an athlete's sport which indicates physiological strengths and weaknesses. It has been previously agreed upon that high capabilities in linear speed, agility, power, anaerobic, aerobic, and strength are correlated with high-level tennis athletes (Pugh et al., 2003; Reid & Schneiker, 2008; Kovacs, 2007; Fernandez-Fernandez, Ulbricht & Ferrauti, 2014; Kovacs, 2006).

In a high-level tennis match, an athlete will have to chase down balls greater than the length or width of the court when scrambling for an angle, drop shot, or lob, requiring speed and acceleration. A tennis athlete will also need the ability to make 3-5 direction changes per point, requiring agility (Fernandez-Fernandez et al., 2014). To get to the ball quickly, hit a powerful groundstroke, serve with high velocities, or reach a high lob, both horizontal and vertical acceleration is required, demanding high capabilities to produce power. Additionally, because tennis is a short-burst, high-intensity sport followed by similarly short rest periods, anaerobic capacity needs to be well trained to produce energy without oxygen as well as the aerobic capacity to endure 1-5 hour matches. Finally, high levels of strength are needed to produce force in the lower body and to stabilize the racket upon contact with the ball in the upper body.

With the growing competition for success in tennis, appreciating a player's ranking is key to qualifying for upper-level tournaments. UTR is a universally understood measure of success that quantifies abilities such as skill, tactical, psychological, and

physiological. For a coach to enhance their athlete's rating, one section to improve may be the physiological facet.

Purpose Statement

The purpose of this study is to create a physiological profile based on UTR through a series of tests to aid coaches in improving the performance of their athletes of any UTR level and to prepare the athletes physiologically for the level above.

Research Question

How can athletes improve their UTR through physiological training?

Delimitations

The study was delimited to the following:

1. All participants must have a verified UTR
2. All participants must be healthy and asymptomatic

Limitations

The following limitations were identified for this study:

1. All tests can be affected by player motivation.
2. The vertical jump test can be affected by athlete technique, timing and coordination.
3. The repeat sprint ability test can be affected by the athletes trying to pace themselves.

4. The multistage shuttle run test can be affected by running and turning technique as well as the athlete's knowledge of how to push themselves to their physiological limit.

Operational Definitions

Rally - a sequence of back and forth shots between players, within a point.

Service box - the box near the net on the opponent's side of the court that the serve should land in.

Baseline - a line that runs parallel to the net and defines the furthest boundary or back of the court from the net on both sides.

Angle – a shot executed cross court which bounces off the side of the court at a severe angle

Dropshot - a shot in which the ball lands just over and close to the net.

Approach shot - an offensive shot that allows a tennis player to transition from the baseline to the net using a groundstroke.

Lob - a shot in which the ball high and deep into the opponent's court.

Groundstroke - a forehand or backhand.

Forehand - a one-handed stroke using the dominant hand to hit a ball on the dominant side of the body.

Backhand - a one or two-handed stroke using the dominant hand or both hands to hit a ball approaching the non-dominant side of their body.

Volley - a return of the ball before it touches the ground

Overhead - a shot that is hit above the hitter's head with a serve-like motion.

Slice - backspin that causes the ball to stay low.

Topspin - a spin that rotates forwards causing the ball to drop quickly due to the Magnus effect.

Weapon - skills developed beyond the others that can be used to set up points or win points directly.

Winner - a ball hit by a player that wins the point without being touched by the opponent.

Flat - a ball hit without spin.

CHAPTER 2

REVIEW OF LITERATURE

From the beginning of tennis history, changes have been made in every aspect of the game to become tennis as seen today. Beginning in France, spreading to England, and eventually the rest of the world, crowds now gather worldwide to watch athletes compete for the best of three (or five) sets (Gillmeister, 1998; Crego, 2003). The victor of a match is typically superior to their opponent in a combination of factors such as: skill, tactical, psychological, and physiological abilities. Universal Tennis Rating (UTR) rates all competitors that have played at least 1 verified match on a single, global 16 point scale. The algorithm takes into account two major components: predicted outcome and actual outcome, weighting an unpredicted outcome more heavily than a predicted outcome (Howell & Cancado, 2013). The original UTR patent details skill and tactical development of players at each level as well as some psychological skills. Physiological skills are only briefly or vaguely mentioned and not quantified creating a desire for a physiological profile.

Universal Tennis Rating

Universal Tennis Rating was patented in 2013 by David Howell and Alexandre Cancado in Norfolk, Virginia. Virtually all prior ranking systems split rankings by gender, geographical location, age, or skill level (amateur/professional), so as a player might move from one category to another, their ranking could not be transferred because of various algorithms and data usage. Alternative systems rated players subjectively, with a certified coach observing practice or play and assigning a ranking; others gave the same

weight to all matches regardless of format, competitiveness, reliability, and time degradation.

UTR rates every player on a singular 16 point scale. Each player's score is calculated using the 30 most recent matches within a 12 month period. Each match is broken into two components that factor into a final formula: match rating and match weight.

Match rating uses the UTR Oracle Algorithm to predict a scored outcome of a match based on both player's UTR scores. An athlete's rating is impacted in a positive direction if the actual score is higher than the algorithm predicted and negatively impacted if the actual score is lower than expected. For example, Player A might be predicted to beat Player B 6-3, 6-3, but if Player B loses 6-4, 6-4, or wins the match, Player B's UTR will be positively impacted.

Each match is weighted differently based on several factors: format, competitiveness, reliability, and time degradation. Matches are weighted heavier if the format is longer, for example, a single eight-game pro-set would be less weight than a three-set match with a full third set or a best of five-set match. The closer the competitive level, the higher the weight of the match. To make it clear, if opponents have a difference of one UTR (UTR of 8 and 9), the match will be weighted more heavily than opponents with a difference of four (UTR of 8 and 12). Additionally, the more reliable the opponent's UTR or the more matches an opponent has played, the higher the weight of the match. Lastly, time will degrade the weight of the match, so a more recently played match will be weighted more heavily than a match played nine months prior.

Tennis Skills

The many skills seen in tennis have been developed throughout the sport's history to meet demands from opponents. In order to conform to the rules and play a tennis match, an athlete must be able to start a point. Two skills are necessary to begin a point: the ability to serve from the baseline and to return a serve hit from the baseline. A third requirement to be level 1 UTR includes the ability to continue the point following the serve and serve return (Howell & Cancado, 2013). Increasing competence in skills such as groundstrokes, volleys and overheads, spins, and weapons will all aid in point continuation and eventually the loss or victory of a point.

Serve and Serve Return

The serve is the most important stroke of a tennis match for two reasons: a point cannot begin without it and it is the only stroke that is a closed skill, meaning an athlete has total control over the outcome without opponent interference (Bahamonde, 2000). A legal serve requires the ball to be tossed and struck in the air as well as land in the service box diagonal to the server on the opponent's side of the net. This typically overhand motion is one of the most difficult strokes to learn, however, once an athlete becomes proficient, it can become a useful weapon. In professional tennis, 58-64% of points are won on the service (Norton & Clarke, 2002).

Groundstrokes

The importance of the groundstroke is such that the point cannot often be continued beyond the service without it. A level 2 UTR athlete will develop groundstrokes and begin to be able to sustain a rally, most often on their more developed

forehand side (Howell & Cancado, 2013). Groundstrokes, more specifically called forehands or backhands are typically hit from near the baseline, however, another type of groundstroke called an approach shot is hit from further inside the court. The forehand is a one-handed stroke using the dominant hand to hold the racket and hit a ball on the dominant side of the body. For example, a right-handed player that hits a ball coming to their right side has just performed a forehand groundstroke. Because a forehand is executed on and uses the dominant side, it is generally the first to develop and develops at a faster pace than the backhand. A backhand, however, is a one or two-handed stroke using the dominant hand or both hands to hold the racket and hit a ball approaching the non-dominant side of their body. As an example, a right-handed player that hits a ball on the left side of their body has performed a backhand groundstroke. Groundstrokes will continue to develop in strength as UTR increases to levels 6 and 7 (Howell & Cancado, 2013).

Volleys and Overheads

The remaining strokes such as volleys and overheads emerge around level 4 UTR as they are less utilized in beginner tennis players. Both of these are implemented near the net and are more aggressive types of strokes. A volley is typically a non-swinging shot taking the ball out of the air, meant to be effective when a quick reaction is required or when the athlete wants to take time away from their opponent's recovery. For example, a player standing near the net will have less time to react to an opponent's shot compared to a player standing back at the baseline and such, will not have time to prepare and execute a full groundstroke. That ball will also make it back to the opponent's side of

the net faster than if struck from the baseline, giving the opponent less time to recover from the previous shot. Volleys are performed and developed in a similar manner to groundstrokes where a forehand and backhand volley exist. On the other hand, overheads are only executed on the dominant side, and contact is made above the head when an opponent hits a lob. Although these more aggressive strokes begin to develop later, they will also typically be finished with development once a player reaches level 7 UTR.

Spins

Around level 5, spins such as slice or topspin will develop (Howell & Cancado, 2013). Slice, sometimes called backspin, spins the ball backward, keeping it low and potentially making it drop short as it moves toward the opponent's court. Topspin, however, spins the ball forward and causes the ball to drop quickly and kick up after contacting the ground. This becomes a useful tool when players become stronger and hit the ball harder allowing them to keep the ball in play. A kick (topspin) and a slice will be developed on an athlete's serve for similar purposes.

Weapons

Once the basic skills are well learned, a few skills will advance beyond the rest. These more advanced skills called weapons are shots that will put the athlete in a strong position to win points, or possibly even win the point directly. For example, if an athlete has a high level, flat forehand, they might choose to run around their backhand to access this strong shot. This athlete may often hit winners off this forehand or easily return an opponent's shots.

Tennis Tactics

Tactics can be implemented once skills are moderately developed. Strategies in tennis are endless, however, three broad groups are common among the higher level tennis players: anticipation, consistency, and skill compensation.

Anticipation

Moving to the area the ball will land early enough to be balanced and prepared is essential in stroke execution. Because of increasing ball speeds as the level of tennis increases, these athletes need to have exceptional anticipatory skills. In a non-sport environment, Overney, Blanke, and Herzog (2008) found that tennis players were not necessarily faster, but more accurate in detecting dot movement than triathletes and non-athletes. In a sport setting, high-level tennis players have been shown to be more skilled in ball flight tracking than less skilled tennis players (Williams, Singer, & Weigelt, 1998). Singer et al. (1996) showed players video recordings of other tennis players executing strokes and found that highly skilled players were faster and more accurate in their anticipation of the intended location of strokes than less-skilled players. These highly skilled tennis athletes were also less likely to look to the head for cues than their lower-level counterparts. Players exceptionally strong in anticipation will likely develop into great net attackers or serve and volley players.

Consistency

Fundamentally, the player that hits the most balls in play in a given point is the player that wins the point. Since this is the case, tennis athletes may choose to use consistency to win matches. Often at the lower UTR levels, taking less risk and putting

the ball in play multiple times will be enough to win points. At higher levels, consistency may appear in a more difficult form than simply putting the ball in the court, such as the ability to be consistent in hitting a specific spot on the court or in putting the ball in play at a faster pace. Tennis athletes exceptionally consistent will likely develop into aggressive baseliners or counterpunchers. These players will be more trained and suited for long points and matches.

Skill Compensation/Weakness Masking

Just as weapons emerge beyond other skills, for many UTR ratings, there will certainly be skills that are not as well developed, called weaknesses. A tactic for prevailing in a match when an athlete has a weakness is called skill compensation or weakness masking. For example, if player A continually aims at player B's weak backhand, player B may choose to compensate for this weakness by running around the backhand and taking this ball as a forehand. Weakness masking at a higher level when all skills are well developed might be in the form of masking a shoulder injury or compensating for another type of injury by using healthy limbs or serving underhand as opposed to overhand.

Psychological Tennis Demands

Unlike other sports, tennis, with the exception of collegiate, is played alone without the help of a coach or a team. This unique aspect creates a need for strong psychological skills. Mental toughness is a comprehensive term used by sports psychologists and defined by Jones, Hanton, and Connaughton (2002) as the generic ability to cope better than an opponent with the training and performance demands as

well as performance pressure placed on athletes. In tennis, specific mental toughness skills such as confidence, the ability to perform under pressure, and motivation are key to advancing.

Confidence

Sport confidence can be described as an athlete's belief in their ability to compete successfully in sport (Vealey, 1988). Jones et al. (2002) found that two forms of self-belief ranked number one and number three in their study on mental toughness attributes. One form of self-belief was in the ability of one's self to accomplish their goals, while the other was in unique qualities and abilities that make one better than their opponent. Athletes typically perform successfully when perceptions of confidence are high (Hays et al., 2009), and to follow, Howell and Cancado (2013) indicate that confidence levels may be one of the key differences between UTR ratings of 6, 7, and 8.

Performance Under Pressure

Of the psychological performance characteristics in Jones' et al. study (2002), five attributes emerged that indicate the importance of performance under pressure including "bouncing back from performance setbacks"; "remaining fully focused in the face of competitive distractions"; "regaining psychological control after uncontrollable events"; "not being adversely affected by the performance level of others"; and very specifically, "thriving on the pressure of competition". High-level tennis players were found to have high levels of mental toughness related to resilience (Cowden, Fuller, & Anshel, 2014). Coupled with their description of resilience as coping, maintaining performance, and achieving despite adversity, pressure, setbacks, or stress, this indicates

high-level tennis players have a corresponding ability to perform well under pressure. Howell and Cancado (2013) imply that this ability is a difference between a level 7 and a level 8 UTR.

Motivation

The fourth-ranked mental toughness attribute by Jones et al. (2002) is the desire and internalized motives to succeed. Howell and Cancado (2013) mention motivation in every UTR level from 9 to 16 suggesting that talent alone is not enough to break through these levels. Levels 9 and 10 are described as being motivated by the love of the game while levels 11 and above may also be motivated by tournament prize money since they are likely playing at the professional level. Phrases such as "internalized motives" and "love of the game" indicate intrinsic motivation, a desire for self-development not in comparison with others, or using outside sources to judge ability. Prize money, on the other hand, is an extrinsic motivator and while levels 11 and beyond may also have intrinsic motivation, Howell and Cancado (2013) suggest that levels 13 and above may play tennis as their main source of income, causing prize money to be a strong motivator.

Physiological Tennis Demands

Every tennis match must begin with a serve, typically near-maximal efforts in the highest level players (130 mph for males). During a point, an elite tennis player will also need to generate high ball speeds on groundstrokes for 3 to 15 seconds dependant on court surface, playing style, environmental conditions, strategy, and motivation (Pugh et al., 2003; Reid & Schneiker, 2008; Kovacs, 2007; Fernandez-Fernandez et al., 2014; Kovacs, 2006). These high-intensity points followed by short recovery periods make up

the games of a match which, as they progress to changeovers, will trend toward an increase in VO2 and heart rate. These combined elements total an average match time of 1.5 hours, some lasting for more than five (Kovacs, 2006). During Wimbledon 2010 John Isner and Nicolas Mahut competed for more than 11 hours, as an extreme example.

Given this nature of the game, a match will have a work to rest ratio between 1:3 and 1:5, and athletes will travel 1300 to 1600 meters per hour of match play (Fernandez-Fernandez et al., 2014). As discussed, tennis requires many skills beyond the physical, however, an athlete's full potential may not be able to be reached without well-developed physiological fitness.

Anthropometrics

Anthropometrics are the physical measurement of the size, shape, and composition of the human body. Size in tennis athletes is typically measured by height. Some studies have found the height of female tennis players to be positively related to performance level, but no significant findings in males (Sanchez-Munoz, Sanz, & Zabala, 2007). In contrast, others have found the height and weight of male tennis players to be positively related to performance level, with no significant findings in their female groups (Ulbricht et al, 2015; Perry, Wang, Feldman, Ruth, & Singnorile, 2004). These findings suggest that higher level tennis players may be taller than lower-level athletes.

Speed

In a tennis match, high-level athletes will have to run across more than the width or length of the court, including backcourt and out areas, to chase down a short ball, a lob, or scramble for a groundstroke. A maximum estimated distance for these efforts

would be approximately 20 meters. In accordance, Girard and Millet (2009) found a 5 m, 10 m, and 20 m sprint to be indicative of tennis performance.

Speed is defined as the rate of change of distance over time, whereas acceleration is the rate of change of speed over time. Since tennis players are not ever likely to achieve maximal running speeds, high-level acceleration over a short distance is important for the tennis athlete. Fernandez-Fernandez et al. (2014) as well as the Australian Institute of Sport (2012) suggest a 20m sprint test with splits at 5 and 10 m to measure acceleration and speed. Shorter distances of 5 and 10 m are specific to a distance that might be covered in a given point throughout a match. Therefore, a linear sprint would not need to be longer than 20 m based on maximum distances that would be run on one half of the court (Kovacs, 2006).

Agility

Because of inconsistency in the literature, the Australian Institute of Sport defines agility as, "a rapid whole-body movement with change of velocity or direction in response to a stimulus". In sports such as tennis where a quick pre-planned or un-planned change of direction is required, it is generally accepted that agility is an important skill (Sattler & Sajber, 2015). Little and Williams (2005) tested soccer players in maximum speed, acceleration, and zig-zag direction change tests. They concluded that these three elements are specific qualities and relatively unrelated to one another. In addition to forward linear speed, tennis players need to be exceptional movers in lateral, diagonal, and backward movements. This would allow an athlete to have more time to make decisions as well as execute well balanced, high-quality shots. High-level players will

average 3-5 direction changes in reaction to an opponent in a given point (Fernandez-Fernandez et al., 2014).

Fernandez-Fernandez et al. (2014), as well as the Australian Institute of Sport (2012) suggest the 5-0-5 test as one of the tests for use in intermittent sports. In the common 5-0-5 test, an athlete sprints a predetermined number or yards to make one turn and sprint back to the 5 m line. A typical test requires an athlete to sprint 15 meters before changing direction, but a more tennis-specific 5-0-5 test starts the athlete at the 5 m line rather than having a 10 m lead-in (Australian Institute of Sport, 2012). Finally, because of the bilateral nature of tennis, it would be important to run this test on both sides, testing direction changeability on each leg (Australian Institute of Sport, 2012).

Power

Modern tennis has become fast-paced and explosive with a near maximal effort serve and powerful groundstrokes all in a 3 to 15-second time frame. Powerful unilateral and bilateral limb movements are essential for quality stroke and movement production (Reid & Schneiker, 2008). One of the most common tests of power is the vertical jump. The vertical jump is closely related to acceleration and game-related dynamic movements. Strong correlations between sprint times and vertical jumps in previous research demonstrate the importance of strength and power in the lower body (Fernandez-Fernandez et al., 2014). Because of the unilateral and bilateral nature of tennis, both a double leg and single leg vertical jump should be measured.

Anaerobic

A tennis match consists of powerful strokes and 3-5 direction changes in a 3-15 second period followed by short recoveries, thus creating a work to rest ratio range of 1:3 to 1:5. Although the average metabolic response in a tennis match coincides with moderate-intensity exercise, high-level tennis is not a moderate intensity sport (Kovacs, 2007). A calculation of average metabolic output underemphasizes the high power-output tennis movement and strokes. As games progress to a changeover, an increase in VO2 and heart rate occur. In addition, to produce near maximum velocity serves (130mph for men) and nearly equivalent groundstrokes, the anaerobic system must be well trained (Kovacs, 2007).

To have the ability to recover and repeat prior sprint performance is an important capability for tennis athletes to possess. The repeat sprint ability test (RSA) is a specific approach to test anaerobic capacity. Typical running protocols of RSA are 6–10×5–6 s or 20–40 m followed by brief recovery periods of 10 – 30 seconds. For tennis players, the Australian Institute of Sport (2012) recommends 10x20 meters with 20 seconds between the start of each sprint.

Aerobic

Although high-level male tennis athletes perform well on VO2max tests and record values between 44mL/kg/min and 69mL/kg/min, these values would classify these individuals as highly anaerobically trained as opposed to aerobically trained (Kovacs, 2007). To train these anaerobic athletes for the aerobic component of a 1.5 hour or longer match, repeated short-duration sprints with adequate rest would more accurately train

their energy system for the aerobic challenges they will encounter (Kovacs, 2007). A great majority of high-level tennis players have VO2max values greater than 50mL/kg/min, thus it is generally suggested that high-level players achieve this value to train and compete at the appropriate level (Kovacs, 2006). Total distance traveled (1300 to 1600 meters per hour, ~1 mile) in a match could potentially total up to five miles, this suggests a well-developed level of aerobic fitness is required. Traditional aerobic conditioning methods have been shown to increase team sports performance substantially (Stone & Kilding, 2009).

An aerobic test for tennis players should include a physical workload profile as seen in competition. The 20 m multistage shuttle test (MSST) is composed of 20 m shuttle runs performed at increasing speeds, until exhaustion. Similar to the 20 m sprint test, a linear sprint would not need to be longer than 20 meters based on maximum distances that would be run by an athlete on one half of the court (Kovacs, 2006). An MSST has been found to be an accurate, easily measured, and inexpensive estimate of aerobic fitness (Leger & Lambert, 1982; Ramsbottom, Brewer, & Williams, 1988).

Strength

Maximal strength is defined as the result of force-producing muscles performing maximally, either in isometric or dynamic patterns during a single voluntary effort of a defined task (Cronin & Henderson, 2004). Since strength determines force production, it is also a major component of power production, which may be important in determining athletic success. Strength development in a tennis athlete can improve explosive power of the upper body and trunk, which can develop racket speed, postural strength-enhancing

movement economy, and eccentric leg strength to improve speed and direction changeability on-court (Australian Institute of Sport, 2012). Kovacs, Roetert, and Ellenbecker (2008) attribute a large percentage of injuries in tennis athletes to a lack of eccentric strength in both the upper and lower body.

Upper body strength in tennis is required to create ball velocity via solid ball contact. This is influenced by grip strength which helps to prevent the racket from breaking away from its intended path when under the influence of high angular velocities and torques. Multiple studies have found grip strength in the dominant limb to be a significant predictor of tennis performance (Girard & Millet, 2009; Groppel & Roetert, 1992)

The relationship between maximal strength and performance is supported by vertical jump test results as well as sprint times over 10-30 meters in other intermittent sports (Baker & Nance, 1999; Svensson & Drust, 2005). Both the vertical jump and sprint tests demonstrate the importance of lower body strength. Vertical power abilities such as the vertical jump were found to be a significant predictor of tennis performance (Girard & Millet, 2009).

CHAPTER 3

METHODS

Participants

Currently competing male and female tennis athletes of various UTRs from northern, central, and eastern Iowa were recruited to participate in this study via emailed opt-in forms. Prior to being included in the study, athletes were asked about their injury status (questions of this nature were included on the opt-in form). Athletes were excluded if they had current symptoms of pain or discomfort that would prohibit the completion of the study. Players were not excluded based on any previous history of injuries as long as they were not currently manifested.

Procedures

Athletes were scheduled to come to a local facility for testing. Upon arrival, participants were provided a verbal explanation of the study and asked to complete an Informed Consent document before beginning. Athletes then began height, and weight measurements using a stadiometer (Shorr Productions, Olny, MD) and calibrated scale (Seca, Chino, CA) followed by an active warm-up which included whole-body dynamic movements followed by jogging to striding intensely for 5 minutes in addition to 2 sprints of 15-20 meters. An explanation of each test was given during the inter-test rest period (3-5 minutes). Administration of remaining tests was conducted in the following order: Grip Strength, 20m Sprint, Modified 5-0-5 Agility, Vertical Jump, 10x20 Repeat Sprint Ability, and Multistage Shuttle Run. Athletes were instructed to take a five-minute period to cool down before exiting the facility.

20 m Sprint

For tennis, this test was conducted over 20 m with intermediate distances of 5 and 10 m. Twenty meters was measured with a measuring tape. Care was taken to ensure there were no twists in the tape and a straight line was used to lay the measuring tape along. Each interval (5 and 10 m) was marked with tape including a start line (0 m) and a finish line (20 m) as well as a 24 m distance where two cones were set. Dashr (Dashr Systems, Lincoln, NE) tripods were set with lasers across the 5, 10, and 20m markers.

Athletes were instructed to start the sprint with their front toe just touching the start line (0 m) and with their body mass over their front foot as well as with their front leg blocking the Dashr laser. Shoulders and hips were instructed to be square in a crouched tennis "ready" position and the rear heel elevated. Once the athlete was in the ready position, all following movement occurred in the forward direction. Athletes were instructed to sprint as fast as possible and take care to not decelerate until they passed the cones four meters after the finish line.

Each athlete began on their own time once the Dashr system sounded the ready "beep". Split and final times were recorded for three trials to the nearest hundredth of a second (.01). The best time from each split and final time was used, even if they came from separate trials.

Acceleration scores were determined as the fastest split time measured from the 0 m mark to the 5 m and 10m mark. The combined acceleration/speed scores were determined by the fastest time recorded from the 0 m to 20 m mark.

Modified 5-0-5 Agility

A tape measure and masking tape were used to mark the points of the course. Athletes began with their front toe close to the start line and front leg interfering with the Dashr system laser. After the Dashr "beep", athletes began on their own time. Each subject sprinted from the 5m mark (modified from the 10m lead-in) to the pivot line (0m) turned 180 degrees and sprinted back to the 5m line. For the trial to count, one foot must have been on or over the 0m line at the turn. The time taken to cover the 10m distance was recorded to the nearest hundredth of a second. Six repeats were performed, three pivots on each foot and the best times from each foot were recorded.

Vertical Jump

The athletes were instructed not to use an arm swing counter movement with arms at their sides or on their hips and jump as high as possible on the jump mat (Just Jump Probotics, Huntsville, AL). The takeoff for the double leg jump must have been from two feet with no preliminary steps or shuffling, but feet were allowed to be comfortably placed apart. Each athlete completed at least two trials and was allowed to continue as long as improvements were being made. The best trial (highest jump) was recorded as jump height.

The single-leg vertical jump test was also performed and with the same protocol as the double leg vertical jump except takeoff was from one leg with no preliminary steps or shuffling. The highest jump was taken from each leg.

10 x 20 m Repeat Sprint Ability

The repeat sprint ability test (RSA) required athletes to perform 10 maximal effort 20m sprints departing every 20 seconds for both males and females. Twenty meters was measured along a straight line, with a clear line made at the start and finish. Pre-test preparation included an active warm-up of jogging to striding intensely for 3 minutes in addition to 2 sprints of 15-20 meters. A recovery period of 5 minutes was given before the test commenced. The starting position for the RSA was instructed to be the same as the 20 m sprint test except the athlete was to start just behind the Dashr sensor before each sprint. Each sprint was instructed to be maximal. A five-second warning was given and the athlete assumed the starting position to await the go command for each sprint. The tester started a stopwatch in line with the commencement of the first sprint. If the athlete did not obtain 95% or more of their individual 20m sprint conducted previously, the test was terminated immediately, and a subsequent attempt was performed after an appropriate rest. Athletes start each subsequent sprint every 20 seconds (20s, 40s, 60s). Each split was also recorded individually. The start position was resumed in preparation for the tester's countdown and "go" command. Athletes only needed to return to the line where the preceding sprint finished. This test produced two scores: the absolute (total time) and relative (percent decrement) scores.

Percent decrement was calculated by taking the best 20m sprint time multiplied by the number of repetitions, dividing that by total sprint time, multiplying by 100, and subtracting that number from 100.

$$\text{Percent Decrement} = 100 - (100 \text{ X } ((\text{BST X } n) / \text{TST}))$$

Multistage Shuttle Run

The 20m distance was measured and marked clearly with tape. The athletes lined up on the start line, ready to begin. The audio was played while participants listened (Boxing Workout Ideas, 2015). The commentary provided a brief explanation of the test leading to a five-second countdown before the test began. Each test was started at level 1. The audio emits a single tone at various intervals. The participants must have been at the opposite end of the 20 m track by the time each following beep sounded. After approximately every minute, the time interval between beeps decreased, and running speed increased accordingly. The first level is called “Level 1” and the final level is “Level 21”. Each athlete was required to place one foot on or over the 20 m mark at the sound of each beep. If the athlete arrived at the line before the sound of the beep, they were instructed to turn and wait for the beep before continuing to the next line. If the athlete failed to reach the line at the sound of the beep, a warning was given that they would be eliminated if not at the opposite end of the track by the sound of the subsequent beep. When near exhaustion, subjects that did not meet the line twice in succession (one warning and subsequently missed line) had their test terminated and the score recorded. The score is the level and number of shuttles immediately prior to the beep on which they were eliminated. After completing this test, the athlete was instructed to cool down by walking followed by stretching.

Grip Strength

Grip strength was assessed using a hand dynamometer (Lafayette Instrument Co., Lafayette ,IN). Each athlete was asked to perform a maximal contraction, standing with

the dynamometer held at the athlete's side (elbow extended) and gripping as hard as possible for three seconds. Each athlete performed at least three trials on each hand and was allowed to continue as long as improvements were being made.

Statistics

Means and standard deviations were created for each metric to determine effect size. The calculated z score was used to visualize standard differences. Z score was calculated by taking the raw score of each participant minus the population mean and dividing that by the population standard deviation. All tests were run in Microsoft excel. Radar plots plotted the z score against zero to visually depict if participants were above or below the norm.

CHAPTER 4

RESULTS

Means and standard deviations for each participant are shown in table 1. Table 2 represents the Australian Institute of Sport norms and standard deviations for the age group appropriate for all subjects. Table 3 shows each participant's best result in all tests as a z score compared to the norm.

Table 1

Participant Test Results

Metric	1	2	3	4
Age	23	20	20	22
UTR	9	10.4	8.8	9
Height (cm)	180.30	188.00	186.70	167.6
Weight (kg)	75.6	76.30	64.6	64.60
Grip R (kg)*	60 ± 0	55 ± 0	38 ± 1.7	29.2 ± 0.3
Grip L (kg)*	57.5 ± 0.9	54 ± 0	34.3 ± 0.3	24 ± 0
Grip diff*	2.5 ± 0.9	1 ± 0	3.7 ± 1.4	5.2 ± 0.3
5m*	1 ± 0	1 ± 0	1 ± 0	1.2 ± 0
10m*	1.7 ± 0	1.8 ± 0	1.7 ± 0	2 ± 0
20m*	3 ± 0	3.1 ± 0	3 ± 0	3.4 ± 0
5-0-5 R (s)*	2.5 ± 0	2.5 ± 0	2.4 ± 0.1	2.6 ± 0.1
5-0-5 L (s)*	2.5 ± 0	2.4 ± 0	2.4 ± 0	2.8 ± 0
5-0-5 diff*	0.02 ± 0.03	0.02 ± 0.03	0.08 ± 0.05	0.2 ± 0.1
Vert DL(cm)*	66.2 ± 0.6	58.8 ± 0.2	56.6 ± 1.1	40.3 ± 2
Vert-R(cm)*	34.3 ± 4	36.8 ± 1.4	30.3 ± 1.3	25.1 ± 1.5
Vert-L(cm)*	34.5 ± 1.5	37.5 ± 1	35.2 ± 0.9	27.2 ± 0.5
Vert diff*	1.9 ± 1.1	0.7 ± 0.5	4.9 ± 2.2	2.1 ± 1
RSA Total	33.64	33.73	32.75	37.69
RSA % Dec	5.47	3.94	5.04	2.1
MSRT Total	8.64	8.27	9.18	10.64

* = Data presented as mean ± SD

Table 2

Performance Testing Norms

Metric	F 16+	M 16+
Height	170.6 ± 6.4	183.6 ± 6.7
Weight	62.7 ± 7.3	76.5 ± 8.8
Sprint 5m	1.2 ± 0.1	1.1 ± 0.1
Sprint 10m	2 ± 0.1	1.8 ± 0.1
Sprint 20m	3.5 ± 0.1	3.1 ± 0.1
5-0-5 R	2.8 ± 0.1	2.5 ± 0.1
5-0-5 L	2.8 ± 0.1	2.5 ± 0.1
5-0-5 diff	0.1 ± 0.1	0.1 ± 0.1
Vert CMJ	40 ± 6	54 ± 6
Vert SL -R	30 ± 3	38 ± 5
Vert SL -L	29 ± 4	38 ± 7
Vert SL diff	2 ± 1	4 ± 3
RSA Total	38.5 ± 2.4	32.9 ± 1.2
RSA % dec	4 ± 1.7	3.5 ± 1.3
MSRT Lvl	11 ± 1	13 ± 1
MSRT S#	2 ± 2	4 ± 0
Grip D (kg)	34.7 ± 11.8	48.4 ± 9
Grip ND (kg)	30.7 ± 5.1	21.5 ± 7
Grip diff	4 ± 0	26.9 ± 0

Data presented as mean ± SD

Table 3

Participant Best Trial

Metric	1	2	3	4
Height	-0.49	0.65	0.46	-0.46
Weight	-0.11	-0.02	-1.35	0.25
Sprint 5m	1.58	1.08	2.25	0.80
Sprint 10m	0.88	0.56	1.38	0.21
Sprint 20m	1.35	0.05	1.30	0.54
5-0-5 R	0.00	0.83	1.89	1.67
5-0-5 L	-0.07	1.05	1.45	-0.13
5-0-5 diff	1.53	0.93	1.67	4.00
Vert CMJ	2.03	-2.47	-2.71	0.05
Vert SL -R	-0.74	-0.23	-1.54	-1.65
Vert SL -L	-0.51	-0.07	-0.40	-0.46
Vert SL diff	0.71	1.11	-0.30	-0.12
RSA Total	-0.62	-0.69	0.12	0.34
RSA % dec	-1.52	-0.34	-1.18	1.12
MSRT Lvl	-5.00	-5.00	-4.00	-1.00
MSRT S#	0.00	0.00	0.00	2.50
Grip D (kg)	1.01	0.73	-1.16	-0.47
Grip ND (kg)	5.50	4.64	1.83	-1.31

Data presented as best trial (Z-score)

CHAPTER 5

DISCUSSION

This study sought to physiologically compare four athletes to norms from high level counterparts in an effort to find strengths and weaknesses as well as describe how to improve on those weaknesses. For each athlete, strengths and weaknesses are outlined, and general as well as specific suggestions for improvement are given. These suggestions are meant to act as a map for strength and conditioning coaches to use in these athletes training. Additionally, for each athlete, details are given on how the physiological corrections will impact the athletes' play as well as potentially improve UTR.

Subject 1

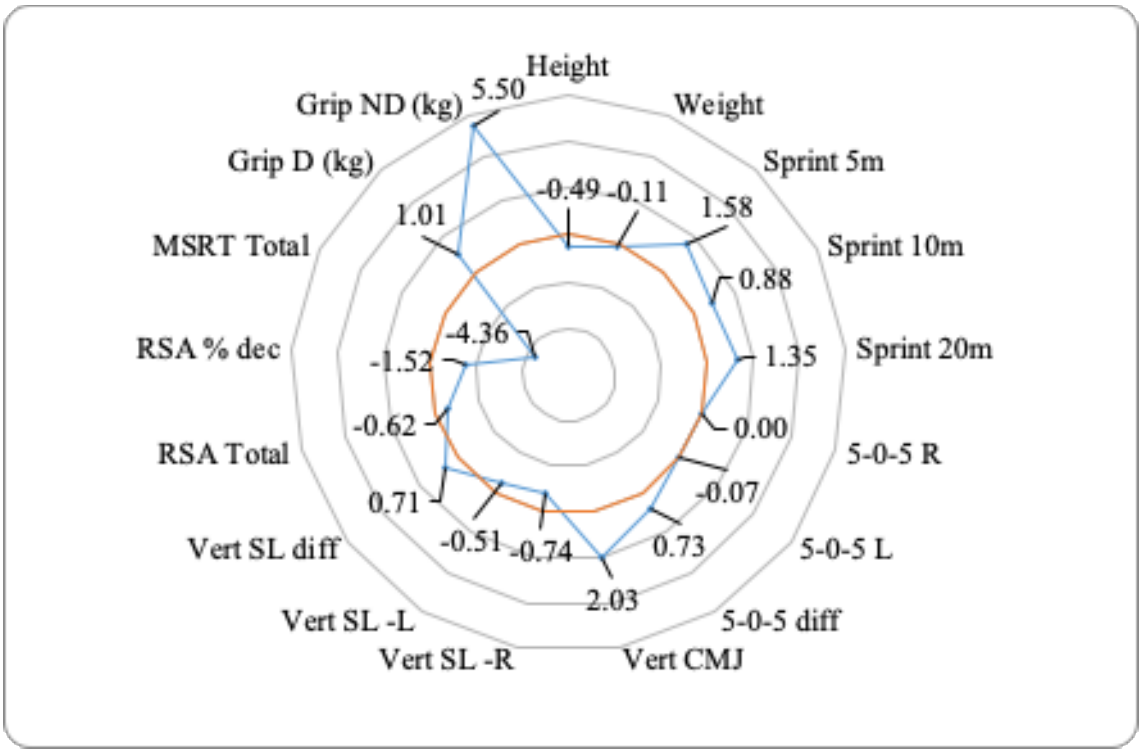

Figure 1. Radar plot of Subject 1's results compared to the norm represented as z score

Subject 1 is strong in linear speed with z-score values above the norms in 5, 10, and 20m sprint times (1.58, 0.88, 1.35). This is also positively correlated with lower body horizontal strength and power. He was the strongest in the 5m sprint, which indicates an advantage in his ability to cover ground quickly when running after a ball. Subject 1 was also notably strong in his vertical jump (2.03) which is an indication of vertical lower body strength and power as well. Additionally, this athlete was very strong in dominant as well as non-dominant handgrip strength (1.01, 5.50) which helps with repetitive solid ball contacts and creating as well as controlling high ball velocities.

His weaknesses lie in single-leg vertical strength and power as well as anaerobic and aerobic capacities. Single leg vertical strength and power are indicated by his single leg vertical jumps which are below the norm (R: -0.74, L: -0.51). Low levels of vertical strength and power can indicate some trouble creating powerful serves and groundstrokes and potentially low deceleration abilities. Weaknesses in single leg strength and power specifically, can negatively influence lateral movement and change of direction as well. The athlete's anaerobic weakness can be seen in this low RSA percent decrement score (-1.52) compared to the norm. With low scores in anaerobic capacity, this athlete likely struggles to retain quickness and power production in long points and changeovers. This also means any strengths he has decrease throughout a match and weaker, but more anaerobically trained opponents may begin to challenge him. His aerobic weakness was shown in his MSST level z-score (-5.00). Below average aerobic fitness indicates challenges with longer formatted matches and full third set play.

Although Subject 1 was above the norm in bilateral symmetry, he was lacking in single leg strength and power. This indicates he would benefit from focusing on single leg lower-body strength and power. He should also add aerobic and anaerobic systems training to his programs. Lower body strength improvements may come from progressive overload or hypertrophy in single leg or split squats, while lower body power improvements may come from single leg plyometric training. This will help him to raise his strength and power ceiling, so anaerobic decrement will not be as impactful. Aerobic training may come in the form of slow long-distance or interval training and anaerobic improvements could mean 300-yard shuttle training. These types of training will help this athlete retain his abilities in long, strenuous matches.

This athlete would benefit the most from spending his first block of training on his greatest weakness, aerobic fitness. As an example, he may spend 4-8 weeks training slow long distance and interval aerobic exercise. Using the principle of specificity, this should be done running and possibly with changes of direction. Following that block, 4-8 more weeks should be spent on anaerobic training. Three hundred-yard shuttles could be implemented in a way that mimics the distance an athlete may run on a tennis court, such as 15 yards between direction changes. During this 8-16 week period, Subject 1 should add focus on single leg exercises during strength training. At the very beginning of a lift, single leg plyometrics in the form of box jumps, small depth jumps, or single leg hops, should be implemented as well as some single leg strength training later on in the workout. This could come in the form of pistol squats, step-ups, or rear-elevated split squats.

The UTR patent characterizes levels nine and ten together with “very advanced games”, “strong weapons”, and “ability to cover up their weaknesses”. For Subject 1, strong weapons are obvious in the form of power, strength, and quickness. However, his weaknesses in anaerobic and aerobic capacities cause him to use his “weakness masking” skills to go for the early finish in a point and avoid fatigue. Enhancing this athlete’s ability to recover anaerobically and aerobically during rest periods will allow him to play longer points with higher level opponents when he cannot end points early. This raises his level of play by opening up another playing style during match play.

Subject 2

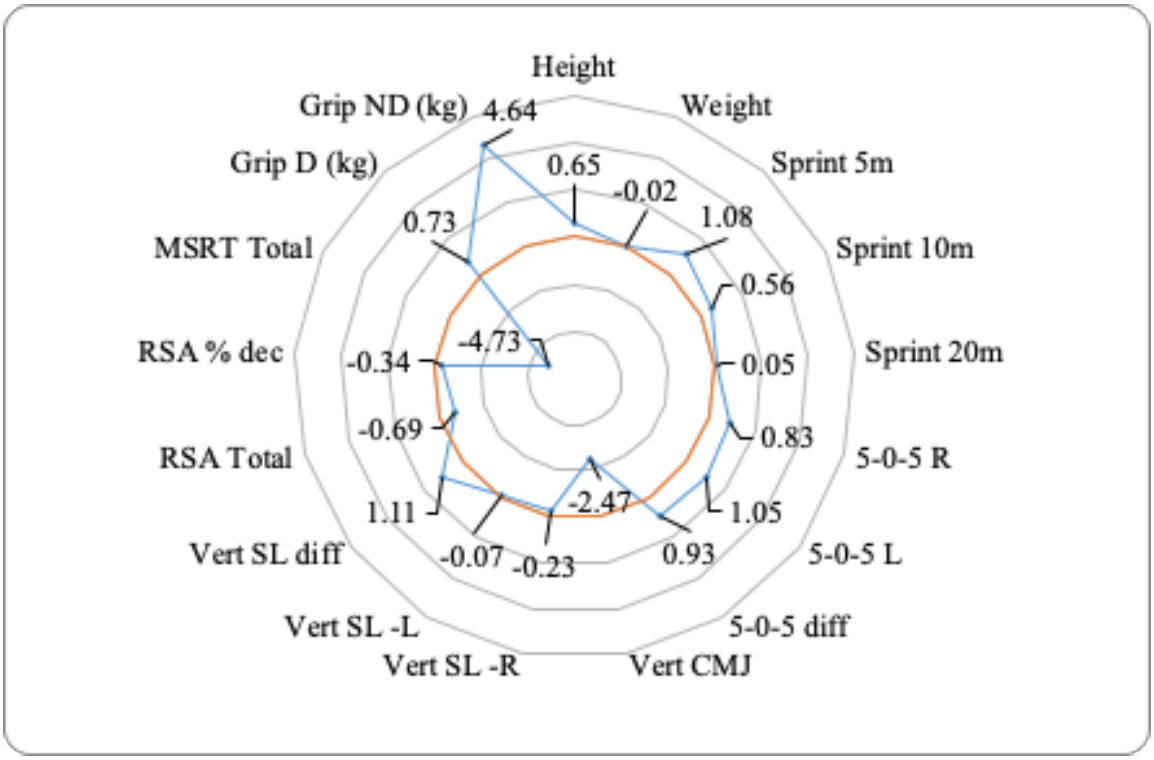

Figure 2. Radar plot of Subject 2’s results compared to the norm represented as z score

Subject 2 is strong in early linear acceleration at 5 meters (1.08) and agility in both of his 5-0-5 tests (R:.83, L:1.05). He is also strong in horizontal strength and power based on his fast sprint times (5m:1.08, 10m:0.56, 20m:0.05). This is helpful for him to be able to cover ground quickly and potentially get to balls early. This athlete is strong in dominant and non-dominant handgrip strength as well (.73, 4.64) which allows him to maintain solid contact with balls imposing high angular forces and torques on his racket.

His weaknesses are in his aerobic and anaerobic capacities. The athlete's aerobic weakness can be seen in his MSST level z score (-5.00). Below average aerobic fitness indicates challenges with longer formatted matches and full third set play. His low anaerobic fitness is shown in his RSA percent decrement (-.34) and could negatively impact his strengths in acceleration throughout a game when rest periods are short.

This athlete would benefit the most from spending his first block of training on his greatest weakness, aerobic fitness. As an example, he may spend 4-8 weeks training slow long distance and interval aerobic exercise. Using the principle of specificity, this should be done running and possibly with changes of direction. Following that block, 4-8 more weeks should be spent on anaerobic training. Three hundred-yard shuttles could be implemented in a way that mimics the distance an athlete may run on a tennis court, such as 15 yards between direction changes. During these two training blocks, subject two may add single leg exercises during strength training to improve his single leg jumps to the level of his double leg jump. At the very beginning of a lift, single leg plyometrics in the form of box jumps, small depth jumps, or single leg hops, should be implemented as

well as some single leg strength training later on in the workout. This could come in the form of pistol squats, step-ups, or rear-elevated split squats.

In the UTR patent, levels nine and ten are characterized together as having, “very advanced games”, “strong weapons”, and “ability to cover up their weaknesses”. For this subject, strong weapons include power, strength, and short distance quickness. However, his weaknesses in anaerobic and aerobic capacities cause him to use “weakness masking” to keep points short and avoid fatigue. Enhancing this athlete’s ability to recover anaerobically and aerobically during rest periods will allow him to play longer points with more advanced opponents that do not allow him to end points early. This will raise his level of play by opening up another playing style during match play.

Subject 3

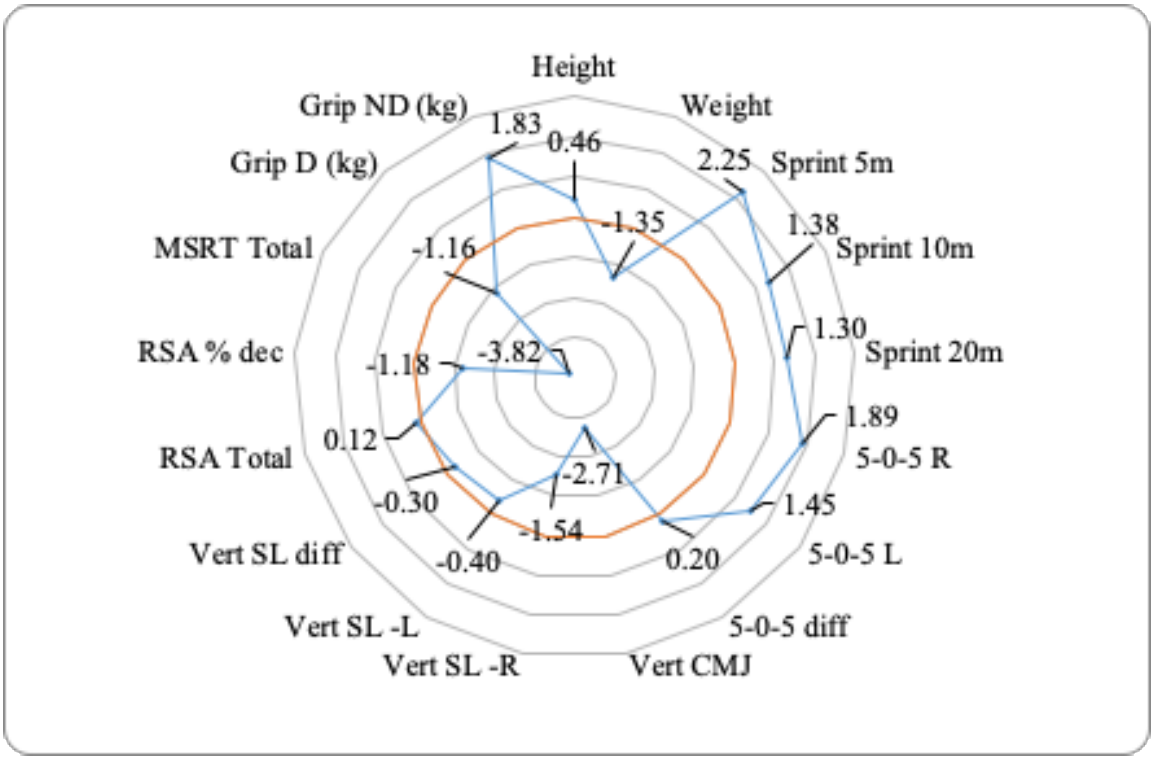

Figure 3. Radar plot of Subject 3’s results compared to the norm represented as z score

Subject 3 was very strong in all lengths of linear speed (5m:2.25, 10m:1.38, 20m:1.30) as well as agility (5-0-5 R: 1.89, 5-0-5 L:1.45) meaning he has a high ability to cover ground quickly from anywhere on the court. He is also strong in horizontal strength and power because of his fast sprint times.

His weaknesses can be found in his single leg vertical strength and power and are indicated by his single leg vertical jumps which are below the norm (R:-1.54), L:-0.40). Low levels of vertical strength and power can indicate some trouble creating powerful serves and groundstrokes and potentially low deceleration abilities. Weaknesses in single leg strength and power specifically, can have negative implications on lateral movement and change of direction as well. There was also weakness in his upper body or dominant handgrip strength (-1.16) making it difficult to transfer any lower body forces to his racket as well as controlling hard-hit balls from his opponents. He is also weak in anaerobic (-1.18) as well as aerobic (-4.00) capacity implying that he may be weaker in points and matches that are long duration, longer formatted, or full third set play.

This subject would improve from single-leg lower body strength and power training as well as aerobic and anaerobic system training. Lower body strength improvements may come from progressive overload or hypertrophy in single leg or split squats, while lower body power improvements may come from single leg plyometric training. This will help him to raise his strength and power ceiling, so anaerobic decrement will not be as impactful. An upper body strength program would be advisable as well including large muscle group progressive overload or hypertrophy as well as

some grip strength training. Aerobic training may come in the form of slow long-distance or interval training and anaerobic improvements could mean 300-yard shuttle training.

Subject 3 would benefit the most from spending his first block of training on his greatest weakness, aerobic fitness. As an example, he may spend 4-8 weeks training slow long distance and interval aerobic exercise. Using the principle of specificity, this should be done running and with changes of direction. Following that block, 4-8 more weeks should be spent on anaerobic training. Three hundred-yard shuttles could be implemented in a way that mimics the distance an athlete may run on a tennis court, such as 15 yards between direction changes. During this 8-16 week period, this subject should add focus on single leg exercises during strength training. At the very beginning of a lift, single leg plyometrics in the form of box jumps, small depth jumps, or single leg hops, should be implemented as well as some single leg strength training later on in the workout. This could come in the form of pistol squats, step-ups, or rear-elevated split squats. In addition to adding single leg training, an element of grip strength training should be added as well. This may be as simple as switching from machine weights to free weights so that the athlete must grip every weight he lifts and being diligent to not use a hook grip or alternated grip on the barbell. More specifically, the athlete may add pinch grip exercises or dumbbell wrist pronation and supination exercises.

The UTR patent states, “for an Adult Level 8 to move beyond this level often takes a tremendous commitment to fitness, practice and play.” For this athlete, his strengths are apparent in his linear speed and agility. However, with low scores in vertical strength and power, grip strength, and anaerobic and aerobic capacities, it is apparent that

his fitness is below the norm. With strengths in quickness and agility, he can likely get in position as well as recover in time for most balls. His weaknesses though, prevent him from creating power for his serve and groundstrokes as well as transferring any power created. Any strengths he does have will decrement throughout a match and even more severely in long matches. From the training suggested, this athlete will be able to add power to his serves and groundstrokes and retain that power throughout a match.

Subject 4

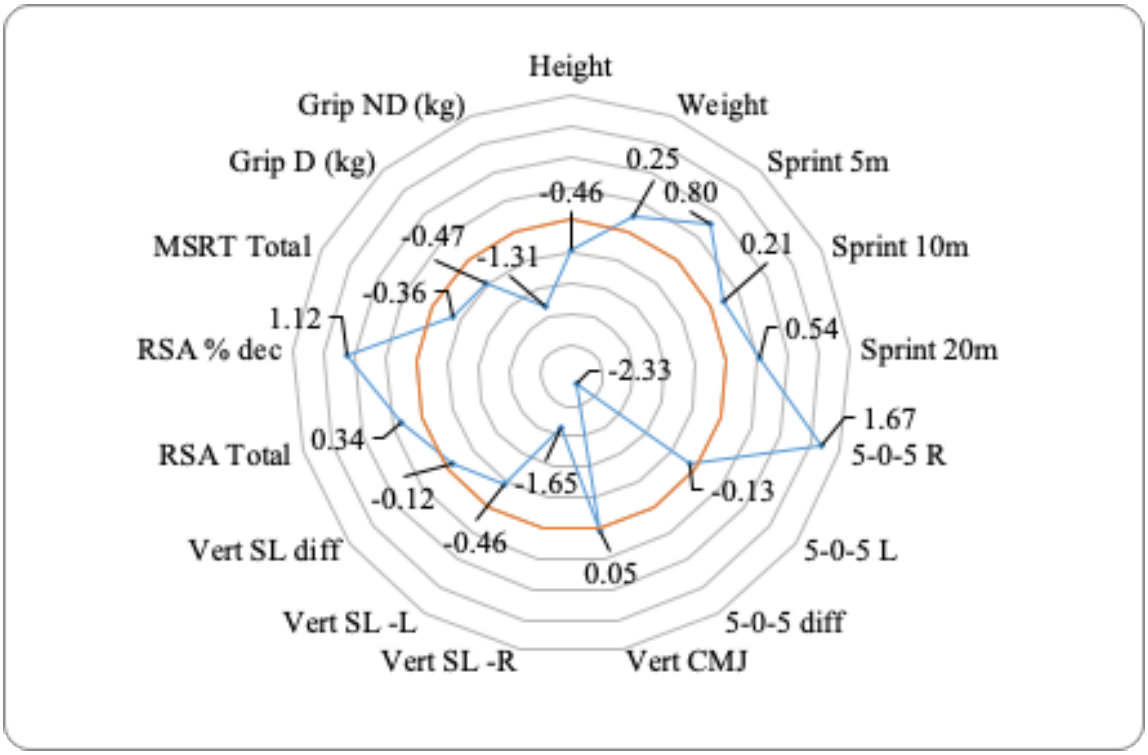

Figure 4. Radar plot of Subject 4's results compared to the norm represented as z score

Subject 4 was strong in all acceleration sprints, but especially her 5m linear sprint (.80) as well as her right-sided 5-0-5 (1.67) which indicates she can cover ground quickly, as well as recover quickly, though especially on her forehand side. Overall, she has strong horizontal strength and power because of her above the norm sprint times

(5m:0.80, 10m:0.21, 20m:0.54). She is also quite strong anaerobically, meaning in a long point or changeover, she will likely retain her quickness in court coverage.

For this subject, weaknesses include her vertical strength and power single-leg (R:-1.65, L:-0.46) vertical jumps as well as a slightly below average dominant handgrip strength (-.47). This suggests she may have a difficult time producing high-velocity balls and handling hard-hit balls from her opponents. Weaknesses in single leg strength and power specifically, can negatively influence lateral movement and change of direction as well. Her aerobic capacity is slightly below the norm as well (-0.36) which may indicate some trouble in longer formatted matches.

Subject 4 will benefit most from single-leg vertical strength and power training as well as upper body and grip strength training. Aerobic capacity may also be included. Lower body strength improvements may come from progressive overload or hypertrophy in single leg or split squats, while lower body power improvements may come from single leg plyometric training. An upper body strength program would be advisable as well including large muscle group progressive overload or hypertrophy as well as some grip strength training. Aerobic training may come in the form of slow long-distance or interval training.

Subject 4 will benefit the most from focusing a training block of 4-8 weeks on single-leg exercises during strength training. At the very beginning of a lift, single leg plyometrics in the form of box jumps, small depth jumps, or single leg hops, should be implemented as well as some single leg strength training later on in the workout. This could come in the form of pistol squats, step-ups, or rear-elevated split squats. Single leg

training will also help to clear up her bilateral asymmetries. In addition to adding single leg training, an element of grip strength training should be added as well. This may be as simple as switching from machine weights to free weights so that the athlete must grip every weight she lifts as well as avoiding using a hook grip or alternated grip on the barbell. More specifically, the athlete may add pinch grip exercises or dumbbell wrist pronation and supination exercises. During this training block, it would be advisable to add an aerobic training program in the form of slow long distance or intervals to bring her aerobic capacity up to the norm.

In the UTR patent, levels nine and ten are characterized together as having, “very advanced games”, “strong weapons”, and “ability to cover up their weaknesses”. For this subject, strong weapons are obvious in sprint times and anaerobic capacity. However, weaknesses in aerobic fitness, grip strength, and single leg strength and power indicate this athlete may weakness mask by using her ability to recover quickly from fast-paced and long rallies to best her opponents by forcing them to fatigue and would prefer to win in two sets. Enhancing this athlete’s aerobic capacity as well as grip strength and single leg strength and power will allow this subject to hit more powerful serves and groundstrokes, and to be more comfortable in long two set matches or a full third set. This will raise her level of play by opening up another playing style during match play as well as allowing her to use all her strengths through the end of a long match.

Conclusion

All four athletes were very strong in their 5m acceleration time, indicating good quickness in getting to most balls hit by opponents. All were also above average in all

sprint times, indicating good horizontal strength and power, which has some implications in high stroke power production. However, all subjects struggled with single-leg strength and power which may hinder serve and stroke power production. All subjects struggled with aerobic capacity as well, indicating difficulty in longer formatted matches or full third set play. Three of the four subjects were weak in anaerobic capacities, which causes a decrement to their strong acceleration abilities throughout a match.

All subjects were current or recently graduated former college tennis players and within 1.6 UTR levels of each other. The similar level and arena of play is consistent with the group overall group strengths and weaknesses as they are high-level tennis players, which requires powerful strokes and short distance quickness, but doesn't often play Ad scoring, or three full sets. Many college tennis conferences clinch matches, meaning not everyone gets to finish two full sets. This could explain the weakness in aerobic conditioning.

However, their performance in general would be improved with training in the areas of single leg vertical strength and power and performance as well as aerobic capacity. Improvements in these areas will raise the athlete's ceiling of potential, meaning decrement over time affects performance less. With corrections in these areas, athletes will strengthen another style of play for themselves and have another set of abilities to fall back on when their preferred style doesn't work against opponents, thus potentially raising their UTR.

Practical Application

The physiological profile created for each participant is a useful process for strength and conditioning professionals. Testing an athlete's physiological characteristics against normative values in that athlete's sport, gender, and age group can help strength and conditioning professionals understand the areas where athletes under their supervision may need to improve as well as understand how it may help improve their level of sport performance.

Specifically, the creation of a physiological profile can help to highlight group or team strengths and weaknesses. In a collegiate or academy setting where strength and conditioning coaches are often training small groups of tennis athletes together, this can help to guide the focus of a new macrocycle and the mesocycles within it. This study depicted four tennis athletes within two UTR levels of each other, common on any collegiate tennis team and in groups that train together at academies. Supposing these athletes were on the same team or in the same academy group, the focuses of their new macrocycle would include aerobic and anaerobic capacity training, single leg strength and power training, and upper body and grip training.

Anecdotal Evidence

Anecdotally, as per the author's interpretation and experience with these four individuals on the tennis court this testing logically demonstrates the strengths and weaknesses of these individuals and is demonstrating reality in the game styles described.

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