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THE RELATIONSHIP BETWEEN PHYSICAL FACTORS TO AGILITY PERFORMANCE IN COLLEGIATE TENNIS PLAYERS

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By

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ABSTRACT

THE RELATIONSHIP BETWEEN PHYSICAL FACTORS TO AGILITY PERFORMANCE IN COLLEGIATE TENNIS PLAYERS

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Tennis players change direction numerous times within a tennis match and game making agility an important skill for them to possess. The purpose of this study was to investigate the significance of physical factors as they relate to agility performance in collegiate tennis players. The physical factors looked at were anthropomorphic measurements; isometric peak force, rate of force development, countermovement jump, and squat jump performance. The participants were seventeen (Male: N = 8, Female: N=9) NCAA Division I collegiate level tennis players. Anthropomorphic measurements included height, body mass, and body fat percentages were also considered. Strength and power were measured by an isometric mid-thigh pull, and power was measured by vertical jumps. Significance was set at 0.05 for statistical analysis. Correlation analysis showed that isometric rate of force development from isometric mid-thigh pull was significant ($p = 0.033$). In conclusion both anthropomorphic measurements and vertical jump performance have very small relationship with agility performance but the rate of force development in the isometric mid-thigh pull test has statistically significant relationship to agility performance in tennis players, indicating agility movement is influenced by how fast you can develop force against ground.

INTRODUCTION

In collegiate tennis there were 10,018 men and 10,648 women in play across all division during the 2013 season, for a total of 20,666 athletes during this season (retrieved from scholarshipstats.com). As well as being widely played sport, tennis is a unique sport that involves various movements to complete many quick starts and stops (i.e., acceleration and deceleration), repetitive overhead motions, and many different types of strokes. Additionally this game can be characterized by shifts from brief periods of maximal or near maximal work to longer periods of moderate or low intensity activity. The duration of a tennis match is often more than an hour and in some cases more than five hours even though rallies typically only last around five to seven seconds, and within this time frame a tennis player will on average run three meters per shot and a total of eight to twelve meters per point. Along with this intense aerobic activity players will often complete three hundred to five hundred high intensity efforts during a best of three sets match. During an average match a tennis player will complete around four directional changes per point, (Fernandez et al, 2006). These directional changes can be further broken down into three categories as tennis players move 1) forward forty-seven percent of the time, 2) sideways forty-eight percent of the time, and 3) backwards five percent of the time, (Parson & Jones, 1998). Within a regular match of two sets there is generally forty-eight points scored and during a Grand Slam match with three sets there are seventy-two points scored. This results in around one hundred and ninety-two directional changes in a regular match and around two hundred and eighty-eight directional changes in a Grand Slam match. These directional changes are in addition to the roughly three hundred and eighty-four five hundred and seventy-six meters that players will be likely to run during a regular match and the five hundred and seventy-six to eight hundred and sixty-four meters that are run in a Grand Slam. Therefore this information implies that agility is a very important component for tennis players to develop to improve the quality of their play.

In light of this information the purpose of this study was to investigate physical factors that relate to agility performance for competitive level of collegiate tennis players. The hypothesis going into these tests is that the power and speed of force production variables will have significance to the superior agility performance of the tennis players since there is a more directional changes over a shorter distance than in sports like soccer so the ability to decelerate and then reaccelerate again in a new direction is important for performance.

REVIEW OF THE LITERATURE

Agility Movements

Agility is an important aspect for athletes across a broad range of sports and can often be used to separate elite athletes from sub-elite athletes. However to begin to understand the aspects of agility and how to test and train this component one must be able to define what is agility. Such a definition is made difficult though by how many different components that agility can include or be defined as depending on the perspective of the author. For example agility has been simply defined as the ability to quickly and accurately change direction (Young, et al., 2005). While this is the most simple and widely used definition for agility this fails to recognize some the cognitive aspects involved in agility. Further conflicting the goal of a common definition has been the relatively recent use of the term quickness in addition or as a replacement to agility. Quickness has come to be defined as a multiplanar or multidirectional skill that encompasses acceleration, explosiveness, and reactiveness (Parsons & Jones, 1998). Despite being used interchangeably for agility and even recommended training drills to increase this specific skill it must be noted that quickness can be seen as a component of agility itself since the common definition for it does include changing of direction or deceleration (Young, et al., 2002). Because of all of these interrelated components agility could only be described as the physical qualities it takes to be able to rapidly change direction or as the visual, processing, and decision-making abilities it takes to appropriately react and change direction to a stimulus. The previously mentioned process could also be expanded to include the technique and learning and retention process an athlete needs to be able to agile.

Agility Movement Used in Sports

In light of all of these interrelated components that can make up agility some very comprehensive definitions of agility have been proposed. One example of this comprehensive definition for agility was done by Chelladurai (1976). Chelladurai (1976) proposed a definition that would capture the perceptual and decision-making components involved in many competitive sports and thus defined four different categories that agility tasks could be placed. The first of the four categories are simple agility tasks, which he defined as being a pre-planned activity that is initiated by the athlete; therefore in this category the stimulus is the athlete's environment and own movement. Second, is the temporal category of agility performance which consists of an athlete's pre-planned response to an uncertain stimulus; such as a starter's pistol or the referee's whistle. The next category is spatial agility where the athlete has spatial uncertainty but temporal certainty. What these spatial and temporal confidence and lack of confidence translates into is that the athlete has a lack of knowledge about their action in response to a known stimulus. For example, this type of scenario can be seen in tennis where an athlete is receiving a serve and has knowledge of the time frame that serve will be completed but does not know where the serve will be directed on the court. Lastly, Chelladurai (1976) set out a universal category of agility in which there is both spatial and temporal uncertainty. This type of scenario can be seen in many team sports where during the plays the athletes cannot predict with certainty where or when the other players will move on the field. From this comprehensive definition it is easy for one to infer that both the spatial component of rapidly changing direction and the temporal component in which athletes go through perceptual factors and decision making occurs. However these two main components can be even further broken down into the factors that can relate to agility performance. This level of division is where factors like anthropometry, technique, sprint speed, muscle qualities, visual scanning, pattern recognition, and anticipation reveal their connections to agility skill.

Agility Performance

Since agility is related to so many different factors the term is used by many to describe any action that requires a rapid change of direction. Therefore agility has been used to describe sprints with planned directional changes but at the same time reactive evasion drills for team sports are also referred as agility drills. Such a liberal use of agility in describing these different actions can lead to further confusion. This time the confusion is due to inability to differentiate and specifically target the training factors that relate to agility performance. To try and alleviate some of this confusion Sheppard and Young (2005) attempted to develop a new and simpler definition that focused on the reaction to a stimulus component of agility performance. The new definition by Sheppard and Young (2005) defines agility as a rapid whole-body movement with change of velocity or direction in response to a stimulus, and in this way removes the classification system that Chelladurai created (1976). According to this new definition closed skills that involve a pre-planned action to a stimulus would be excluded from being called agility tasks. Additionally cone drills that are used many times for agility tests do not meet this definition of agility since there is no stimulus that the athlete is reacting to in this scenario. As a result this new definition requires the completed action to be an open skill to be counted as an agility task.

As a result of the difficulty in finding a common definition and use for agility there tend to be two main types of agility tests. These two testing types are planned agility and reactive agility tests. From the above information one can infer that while the planned agility tests have been the most commonly used test type they carry a specific weakness in that they lack a reaction to a sport specific stimuli. Therefore these tests are better predictors of change of direction speed for an athlete rather than the full definition of agility previously found.

Agility as a Reactive Action

Due to the emphasis of a reaction to a sport specific stimulus for agility performance more research and testing has been done for reactive agility tests. Reactive testing was created as reaction to the traditional agility tests that had previously excluded a perceptual component as part of the testing procedure that were counterproductive in testing motor expertise (Farrow, et al., 2005). One of the more popular ways of creating a more realistic testing environment has been to use life-size projections of a sport specific stimulus. For example, the Australian Institute of Sport used a life-size projection of a netball player hitting a ball towards the testing athlete as the stimulus to move either left or right. These projections require the athlete to use similar visual cues and information processing that they would require during a competition setting as their stimulus on where to go during the agility test. The use of these scenarios has continually shown that the more elite players possess quicker response times, movement initiations, and both faster and more accurate decision making abilities than sub-elite athletes, (Farrow, et al., 2005). These tests have shown the ability to successfully discriminate elite and sub elite Australian football players better than their pre-planned change of direction test counterparts (Gabbet & Benton, 2009). In addition to being able to discriminate athlete level in Australian football, Farrow et al. (2005) showed that a reactive agility test developed by the Australian Institute of Sport was able to develop a reactive agility test for netball players, that was able to successfully discriminate elite athletes from club level netball athletes.

Connecting Agility Performance to Tennis

All the above factors are especially important for elite level tennis players to posses due to the speed of the ball and the relatively short distance between the two players. Therefore the faster tennis players can read and then accurately react to the stimulus would reduce time stress and have the potential to improve performance (Shim, et al., 2005). In one study by Shim et al (2005) the purpose was to test if there was a significant difference in both perception and response times versus elite and sub-elite levels of tennis players. This study was conducted in two parts with the first experiment being mainly concerned with the perceptual and predictive abilities of different level tennis players. The results from this first experiment showed that expert level tennis players were able to correctly anticipate a shot from the visual information given during the experiment. In addition, the more information that the testers presented the subjects with the better the elite level players anticipation of the shot was while the novice's scores decreased. The second part of the experiment focused on the decision-making skills of the players and the ability to translate perceptual abilities into an appropriate action to the stimulus. As expected, the results from this experiment revealed that the more skilled players were able to translate their greater perceptual abilities into a dramatically faster shorter response delay time to their novice counterparts. In this experiment the elite level tennis players were more than twenty-five percent faster when provided visual cues of the hitter and thus resulted in a fifty-millisecond faster response delay time. While this may seem like too short of a time frame to make much of a difference those extra fifty-milliseconds allow skilled players to increase their court coverage by 1.2 meters or half that in coverage of the forehand and backhand sides (Shim, et al., 2005).

Biomechanics of Agility Patterns

Another important factor when looking at agility performance is the level of technique that the player has when executing the change of direction maneuver. Two of the most common ways that this change of direction is achieved is through the open maneuver and the cross maneuver. The first of these, the open maneuver, is completed by the athlete using the foot opposite of the direction they wish to change direction to with foot planted further away from the body. After this plant the opposite foot is then used to accelerate in the new direction. The crossover maneuver is completed by using the foot on the same side as the new direction and then crossing the other leg in front of this plant leg to achieve acceleration (Rand, et al., 2000; Green, et al., 2011).

It is also important to understand that there are three proposed different phases to these cutting maneuvers. These three phases are preliminary deceleration, plant and cut, and takeoff. During the preliminary deceleration phase the muscles of the lower extremities provide the necessary power. Upon entering the plant and cut phase, the hips are flexed, and the knee of the pivot leg is fully extended. After the pivot foot is planted, the femur and knee are flexed. Lastly, during the take-off phase plantar flexion occurs and is followed by knee and hip extension that allows for acceleration in the new direction (Andrews et al., 1977). Even during these phases there is good technique to ensure a more efficient change of direction maneuver. The better an athlete can take advantage of the stretch-shortening cycle during the deceleration phase the better the athlete's muscles will be loaded for acceleration in the new direction. This muscle loading can be achieved by maintaining a lower stance through squatting and thus lowering the body's center of mass. This lowered stance is also important during the deceleration phase to reduce the forward torque about the base of support by lowering the body's center of gravity.

It is interesting to note here that this lowered stance is commonly seen in many field sport athletes even though this contradictory to a proper sprinting posture. Yet many of the sprinting with change of direction tests have the athletes abandon this posture for a more upright and sprint available posture (Sayers, 2000). This especially applies to tennis athletes since there is no way to play tennis without carrying a racquet, which will affect the player's running efficiency. This same article by Sayers (2000) also attempted to highlight the effects of carrying a ball or stick can have on running efficiency. While running the arm swing, when done efficiently, can help increase stride rate and the ground contact forces. At the same time the arm swing can counteract the body rotation caused by the pelvis, which increases balance during the maneuver. Therefore carrying a ball or stick type of equipment will reduce these benefits on the side of the body that the athlete is carrying said equipment. So as a result the athlete may be forced to reduce their stride length, change their landing distance, or adjust their pelvic rotation (Sayers, 2000). Another factor that can help the athlete during the deceleration phase is their stride frequency. When stride frequency is increased during this phase it allows the athlete to make minor adjustments and lower the absolute force require from each leg.

On going with biomechanics of agility patterns

Alignment of the on the lower extremities will also ensure a greater efficiency and muscle loading during the deceleration phase. When the foot, shin, and thigh of the braking leg are pointing in the direction that the athlete is trying to slow down in it ensures that the muscles of the hip, thigh and leg are used for the braking force. However when braking a side shuffle type of movement, like that seen in tennis, the forward lean of the athlete and hip architecture requires the braking alignment of the lower extremities to be at a forty-five degree angle in the direction of the braking movement. Misalignment of the lower extremities likely loads the ligaments at the ankle, knee, and hip (Goodman, 2008).

Another reason why the lower extremity alignment and muscle loading is so important is that a faster stretch shortening cycle of the leg extensors to result in a fast change of direction because of the shorter ground contact time and small flexion at the hip, knee, and ankle joints. This is due to the leg extensor muscles lengthening during the action of planting the leg. This initial lengthening is then followed by leg extension, an active push-off, due to the shortening of these same muscles. This type of cycle of quickly moving an eccentric action to a concentric action has been termed reactive strength and has been hypothesized to be important for agility performance (Young, et al., 2002).

METHODS

Participants

Seventeen (Male: N = 8, Female: N=9) NCAA Division I collegiate level tennis players were participants for this study. All the players were familiar with all testing procedures in order to investigate the research question. The all tests used in this study are a part of an ongoing athlete monitoring program. Based on review from the East Tennessee State University Institutional Review Board (IRB), all data were considered as retrospective and analyzed without the approval from the IRB.

Procedures

Testing sessions took place over a period of past years through the aforementioned athlete monitoring program. Out of all tests, the following tests were considered specifically for this study; static jump (SJ), and countermovement jump (CMJ), isometric mid-thigh pull (IMTP), and Agility test. All testing procedures listed below consisted throughout the years of athlete monitoring program and no alternatives have been applied up to investigator's knowledge. SJ, CMJ, IMPT were tested in the Exercise and Sport Science Laboratory, and agility test was conducted in indoor test court at the Memorial Center on the campus of East Tennessee State University.

Anthropometric measures

Anthropometric Measures were obtained for the male and female tennis players (see Table 1).

Table 1. Anthropometry data for both genders.

	Male (N = 8)	Female (N = 9)
Height (cm)	176.38 ± 7.50	165.40 ± 6.14
Mass (kg)	76.35 ± 10.38	61.44 ± 8.49
Body fat (%)	20.58 ± 9.84	24.91 ± 4.46

Jump Testing

A warm-up was done prior to testing consisted with 1) 25 jumping jacks, 2) a set of five mid-thigh clean-pulls with 20 kg, and 3) three sets of five mid-thigh clean pulls with 40 kg for the female players or 60 kg for the male players, with 3 minutes rest between sets prior to beginning the vertical jump tests. Both SJ and CMJ were performed with a 1 kg PVC pipe holding with both hands on upper back to eliminate the arm swing effect so that jump performance can be measured solely on lower extremity force output. All participants stood on a 0.91 m x 0.91 m force plate (Rice Lake, WI). The sampling rate of the force plate was 1,000 Hz to display force-time curve to calculate jump height (from air time) and peak power output (from force and velocity).

Each participant performed two jumps on SJ and CMJ with 1 minute rest between jumps. During the SJ test the participants were instructed to squat down to approximately 90° knee flexion (confirmed by a handheld goniometer prior to the jumps). They held the position for 3 seconds in order to eliminate the utilization of the stretch shortening cycle of lower extremity muscles. Test conductor gave a verbal cue of countdown “3, 2, 1, jump”. The CMJ initiated the jump from standing position, as the countdown was given, the participants performed in one fluid movement downward movement to upward thrust to jump as high as they can.

All jump trials were recorded and analysed using LabView^{TM} software (National Instruments Co., Austin, TX) throughout the years of testing for athlete monitoring program. Specifically, 1) jump height (cm), and 2) peak power output (W) were quantified from each trial of all participants. All jumps were analysed using previously established methods, and previously established test-retest reliability for jump height in our lab was CMJ, ICCα = 0.98 (n = 63) and SJ, ICCα = 0.96 (n = 63) (Kraska, et al. 2009).

Isometric Mid-Thigh Pull Measures

Following the jump tests, the isometric mid-thigh pull was tested on a force plate (Rice Lake, WI, USA) in a custom-designed power rack. The test procedure was established based on previously published study protocol (Haff et al., 1997). Bar heights for each individual were set at a height specific to the individual and a knee angle at 125 ± 5°. The participants' hands were wrapped tightly to the bar using weightlifting straps and standard athletic tape to prevent their hands from slipping (Haff et al., 1997).

Each participant performed two practice trials at self-determined intensities of approximately 50% and 75% of maximal effort. The test consisted of two trials at the maximum effort with 1-minute rest between trials. The participant was instructed to "pull as hard and as fast as possible". With the verbal instruction of "3, 2, 1, pull", each participant pulled the immovable bar at the maximum effort.

Just like all jump trials, the LabView^{TM} software (LabView^{TM} 8.5.1, National Instruments Co., Austin, TX) was used to analyze the trials. The variables (peak force (PF) and rate of force development (RFD)) from both trials were averaged for overall data analysis purpose. Previous testing in our lab (n = 63) has established a test-retest reliability of: PF, ICCα ≥ 0.98, and RFD, ICCα ≥ 0.95 (Kraska, et al. 2009).

Agility Test

Agility test times were recorded to the nearest 0.01 second using the same infrared timing system (Brower Timing Systems, Draper, Utah, USA). The agility test was administered to evaluate agility performance. The electronic timing gates were placed at the Start/Finish line of the course. After an appropriate dynamic warm-up, each participant was allowed to go through the course at 50% and 75% of their maximum speed. The participants were given approximately 5 minutes rest between trials. Before each trial, the participants were instructed to use a standing start 0.5 meters behind the start timing gates as marked by athletic tape. The participants completed two trials and those are averaged for overall data analysis.

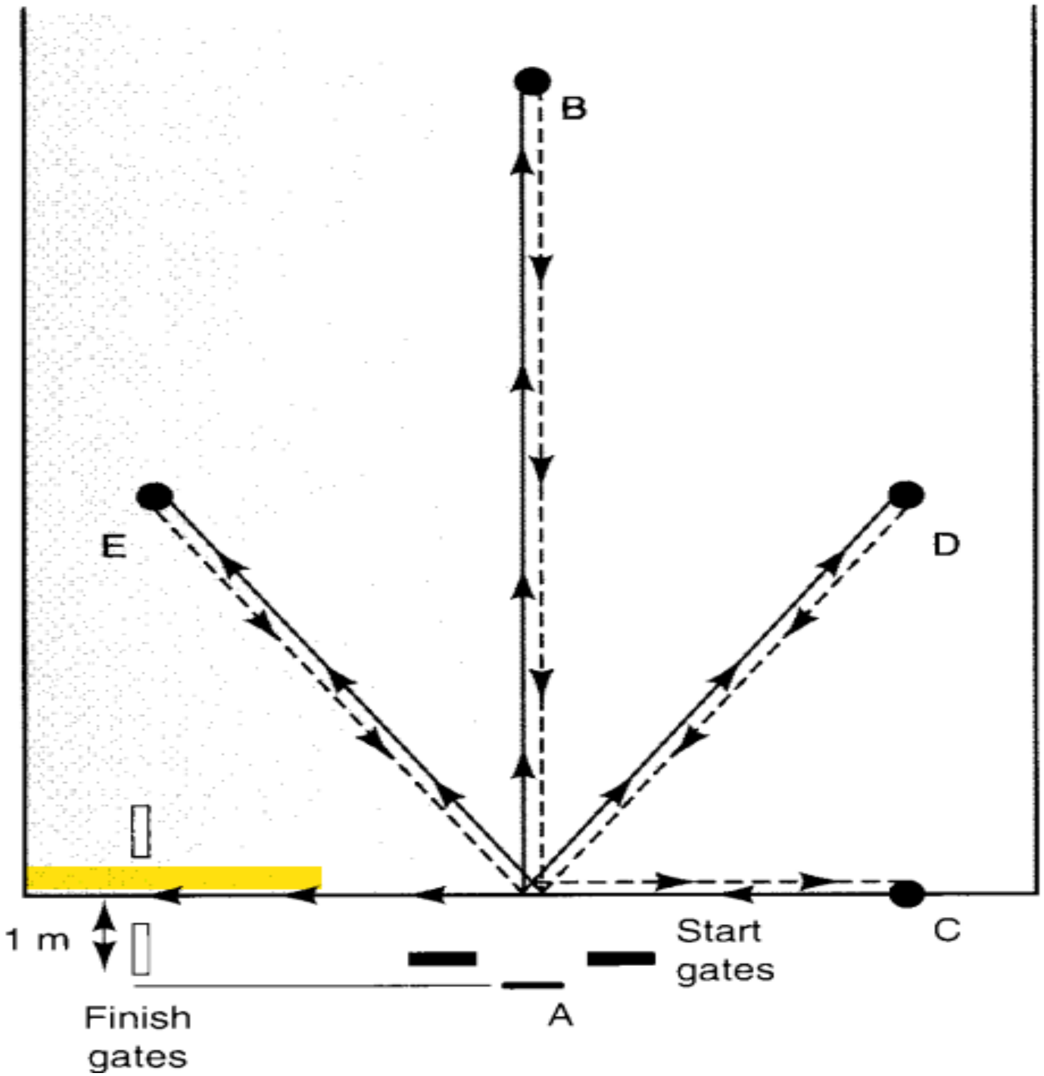

Figure 1. Agility test layout
***Backpedal from B to start
***Face to the net
**Do not give a count of how many completed or have left
***Start gates are 1m behind baseline
***Start line is 30 cm behind timing gates

Data Analysis

As mentioned above, all participants' data were gathered in the data sheet to calculate mean and standard deviation on all measured variables including anthropometrics, jumps, IMTP, and agility test using Microsoft Excel. Data were then used for Pearson correlation analysis to identify the relationship between strength and power variables to agility test performance. Significance was set for 0.05.

RESULTS

The means and standard deviations of all tested variables are listed in table 2. Correlation was defined as significant if the p-value of two-tailed test was at or below 0.05. Out of all of these tested variables the only one that was significant according to the data analysis was RFD from IMTP with a p value of 0.033 with $r = -0.518$ indicating that greater the RFD values equals to faster agility time. The rest of the tested variables show non-significant relationship with agility performance with r values ranging from -0.023 (height) to -0.344 (CMJ height).

Table 2. Means and standard deviations of all tested variables.

Test Measures	Mean & Standard Deviation
IMTP PF (N)	3135.45 ± 836.98
IMTP RFD (N/s)	4995.46 ± 1789.25 N/s
CMJ height (cm)	26.66 ± 6.41
CMJ peak power (W)	3364.25 ± 1052.61
SJ height (cm)	23.92 ± 4.96
SJ peak power (W)	3194.49 ± 1014.49
Agility time (s)	16.90 ± 1.21

DISCUSSION

The purpose of this experiment was to test several physical factors (strength and power) to see their significance towards collegiate tennis players' agility performance. Of the training factors tested more were to be significant than just the IMTP RFD. From previous studies the anthropomorphic measurements, while having been hypothesized to be correlated with change of direction tests, have not shown significance. In one study looking at collegiate soccer players this same result was seen with body fat percentage being the closest to have significance (Young, et al., 2005). Strength and power variables did not show a strong correlation in previous studies as well. A study done by Young, et al. (1996) determined that both a loaded and an unloaded CMJ had a low and non-significant correlation to a sprinting with change of direction tests. In another study, Young, et al. (2002) showed that concentric power had a non-significant relationship to sprint with change of direction test that was used. However the same study also showed that reactive strength did have a significant and negative correlation to the sprint with change of direction tests (2002), indicating that higher power output in concentric phase is likely to lead faster speed with change of direction test. Therefore this quick change from an eccentric to a concentric action might be a better indicator of the athlete's deceleration and reacceleration abilities.

Additionally the other tested variables not being significant to the agility performance of the athletes can possibly be explained by the size of the tennis court, such that by the time the players have built up enough speed to have more factors to influence the athletes in order to change direction and thus reduce their speed. However the IMTP RFD having significance does make sense when applied to this scenario.

The ability to produce develop force quickly would be important in reaccelerating in the new direction after the athletes have decelerated. As a result coaches can use this data in their building a workout routine to create more agile athletes through incorporating exercises to specifically target increasing the athlete's IMTP RFD. This can even be applied for coaches in charge of programs other than tennis. For example softball and baseball coaches can focus on building their athletes IMTP RFD since similar to tennis the reacceleration after a directional change is more important than the braking forces based off of the distance the players have run. In essence the significance of the IMTP RFD lies in the athlete's ability to accelerate faster after changing direction. This study reinforces the importance of the ability of higher-level players to reaccelerate faster than their non-elite counterparts. Additionally this concept is applicable to field sports like soccer rugby, because while the braking forces are high in these the ability to accelerate faster is a factor that can separate elite and non-elite athletes.

Lastly, anthropometric data in theory should relate to agility performance but was not seen in this study. This relationship between agility and anthropometric data is hypothesized because given two athletes with the same height and weight the one with less body fat percentage would be expected to be faster. This expectation is based upon the fatter of these two athletes having less lean body mass to contribute to deceleration and acceleration actions required of an agility movement. At the same time the fatter athlete will have more excess fatty tissue and inertia which will require a greater amount of force to complete an agility movement than the other athlete (Young, et al. 2005).

Alongside body fat percentage, limb length has also been hypothesized to have a relationship with agility performance. The relationship of these two is hypothesized based on the athlete's centre of gravity. In theory, between two athletes with similar anthropometric data except for limb length, the athlete with the lower centre of gravity would be able to complete the agility movement faster because they would need less time to lower their centre of gravity in preparation for a lateral direction change (Young, et al. 2005).

Further research could be done in looking at the relationship of a depth-jump test that would look at the speed of which athletes can change from an eccentric to a concentric action and see if this test has a higher significance for agility performance in tennis players than the counter movement and squat jump showed. Additionally, if the athletes could repeat this test but while carrying their racquets during the agility performance it would be interesting to see if there was any more significant variables.

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