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Physical and performance correlates of agility in tennis players

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PHYSICAL AND PERFORMANCE CORRELATES OF AGILITY IN TENNIS PLAYERS

A Master's Thesis presented to the Faculty of the
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Master of Science

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by

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Thesis of

Himani Sood

submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health Sciences and Human Performance at Ithaca College has been approved.

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ABSTRACT

Purpose: The purpose of this study was to evaluate the relationships of body mass index (BMI), years of sport-specific training, power, and reaction time with simple agility measured in tennis players.

Methods: Thirty participants were recruited from local tennis teams and clubs in Ithaca, NY. Participant age ranged from 18 to 39 years ($M = 22.7$, $SD = 5.8$). Participants performed an Agility T-Test, a 505 Agility Test, a Vertical Jump Test and a Reaction Time Test in the Biomechanics Lab at Ithaca College. Participant data including age, height, mass, gender, years of sport-specific training and BMI were recorded for each individual prior to testing. Pearson correlations were used to evaluate bivariate relationships between BMI, years of sport-specific training, power, reaction time, and Agility T-Test and 505 Agility Test. Also multiple regressions were completed to determine the prediction strength of selected variables for agility performance and also prediction strength for all the variables combined together.

Results: A negative and significant correlation existed between power and Agility T-Test ($r = -0.58$, $p < .01$) and power and years of training ($r = -0.40$, $p < .05$). The correlation between power and 505 Agility Test approached significance ($r = -0.30$, $p = .057$). Also, a positive and significant but weak correlation existed between BMI and 505 Agility Test ($r = 0.39$, $p < .05$). Surprisingly, no relationship existed between other variables. Multiple regression analysis revealed that BMI, years of training, PPO and reaction time best predicted agility time for both the 505 Agility Test ($R^2 = 0.48$) and Agility T-Test ($R^2 = 0.64$)

Conclusion: Under the present experimental condition, Agility T-Test and 505 Agility Test scores were best predicted by all variables together. Since agility is related to successful performance, this information may be helpful to coaches, athletes and recreational populations.

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Chapter 1

INTRODUCTION

Agility training is an important component of training for most sports. Agility is defined as the ability to change direction accurately and quickly at the presentation of a stimulus such as the movement of the ball or the movement of the opposing players (Barrow & McGee, 1959; Johnson & Nelson, 1969). Some further distinguish the concept of agility as “simple” or “reactive” agility. Simple agility is defined as a pre-planned change of direction (closed skill), whereas reactive agility is a rapid change in direction to a sport-specific stimulus (open skill) (Gabbett & Benton, 2009; J. Sheppard, Young, Doyle, T. Sheppard, & Newton, 2006). For a sport such as tennis, agility skills are particularly important for success. Strength, power, balance, coordination and reaction time are important components of agility. Of the aforementioned components, power is the most important contributor to agility (Linford et al., 2006; McMillian, Moore, Hatler, & Taylor, 2006; Myer, Ford, Palumbo, & Hewett, 2005; Shultz et al., 2001; Wojtys, Huston, Taylor, & Bastian, 1996).

A majority of research on agility and performance has focused on the relationships of strength, reaction time and power to agility. Negrete and Brophy (2000) reported a moderate but significant correlation of r = 0.61, $p < .05$, between squat strength and agility measured by a lower extremity functional test (in which the participant ran a diamond shaped course). In contrast, Djevalikian (1993) found reactive strength (depth jump from various drop heights) and agility (measured by boomerang run) to have a correlation of only r = 0.42, $p < .05$. Additionally, Pauole, Madole, and Lacourse (2000) reported a significant correlation of r = -0.63, $p < .05$ between power (measured by counter movement vertical jump) and agility (measured by Agility T-Test). Based on their (Pauole et al., 2000) correlation analysis, it appeared that power and agility were more highly related than strength and agility.

Other factors that affect performance on agility tests include reaction time, training and stretching prior to the agility test (McMillian et al., 2006; Shaji & Saluja, 2009; Shultz et al., 2001; Wilkerson et al., 2004). Studies have demonstrated that neuromuscular training can reduce reaction time (Linford et al., 2006) and presumably improve agility. Plyometric training combined with dynamic stretching is perhaps one of the most effective training programs to improve agility (Shaji & Saluja, 2009). This study by Shaji and Saluja (2009) reported that Agility T-Test scores improved the most in a combined dynamic-stretching-plyometrics group (from 11.80 sec to 10.54 sec) as opposed to a dynamic-stretching-only group (from 11.70 sec to 11.10 sec) or plyometrics-only group (from 11.60 sec to 10.88 sec).

Research also suggests that agility score is related to body size. A study by Webb and Lander (1983) reported a weak correlation ($r = 0.21$, $p < .05$) between body fat and agility in rugby players. It is the only study that has examined the relationship between body fat and agility. Cronin, McNair, and Marshall (2003) suggested that the height of an individual can affect agility scores. Other factors in addition to height that might affect agility are relative limb length and height of center of gravity.

While research indicates that agility is affected by many factors including strength, power, reaction time, gender, weight, height and years of sport-specific training; no study has investigated the combined effects of physical attributes (e.g., power, reaction time) and anthropometric characteristics (e.g., mass, height) on agility. For example, it is unknown if power and reaction time alone are the best predictors of agility or if the interaction of power and reaction time combined with height and mass is better. Understanding those factors that enhance agility will help coaches and athletes design more effective training programs to improve agility. This is of chief importance since agility is highly related to successful performance. For example, Paul, Biswas, Shukla, and Sandhu (2011) reported a 34% improvement in agility and a remarkable 61% improvement in serve precision following eight weeks of agility training in tennis players.

Statement of Purpose

The purpose of this study was to evaluate the relationships of power, reaction time, anthropometric characteristics and years of sport-specific training with simple agility measured in tennis players.

Hypotheses

The hypotheses for this study were:

1. Years of sport-specific training are positively correlated with agility scores.
2. Reaction time and agility score are inversely related.
3. Power and agility score are positively related.
4. Body mass index (BMI) and agility score are inversely related.
5. Power, reaction time, BMI and years of sport-specific training together best predict agility scores.

Delimitations

The delimitations of this study were as follows:

1. Tennis players were recruited only from local tennis teams and clubs in Ithaca, NY.
2. Simple agility was measured using Agility T-Test and 505 Agility Test.

Limitations

The limitations of the study were as follows:

1. The results of the study may apply only to tennis players.
2. The results of the study may apply only to the Agility T-Test and the 505 Agility Test. The results are not indicative of what might occur in other types of agility test.
3. Due to age limitation of this sample (15-39 years), the results of this study cannot be extrapolated to an older or younger population.
4. Motivation and stress level may have had an impact upon the internal validity of this research. The above mentioned factors may alter the agility scores.

Assumptions of the Study

For the purpose of this study, the following assumptions were made at the start of the investigation:

1. Participants complied with instructions.
2. The participants responded truthfully to the 24-Hour Health History Questionnaire.
3. Participants gave maximum efforts on all tests.

Definitions of Terms

The following terms are operationally defined for the purpose of this study:

1. Agility - The ability to move and change direction quickly and effectively.
2. Simple Agility - Pre-planned change of direction.
3. Reactive Agility - Rapid change in direction to a sport-specific stimulus.
4. Body Mass Index (BMI) - A measure to quantify body size. BMI is calculated by dividing weight (kg) by the square of height (m).
5. Reaction Time - Time between a stimulus and response to the stimulus.
6. Electromechanical Delay - Time between a neural stimulus and activation of movement.

Chapter 2

REVIEW OF LITERATURE

Introduction

Agility is an important contributor to performance of many types of athletes. Various factors that contribute to agility are training status, movement coordination, decision making, reaction time, strength, power and years of experience. To improve agility, many athletes use neuromuscular training which incorporates power, strength, agility, and balance activities. Therefore, this chapter includes a survey of the research about: 1) agility and sports performance, 2) components of agility and 3) measuring agility.

Agility and Sports Performance

Agility and agility training play important roles in enhancing sport performance. Paul et al. (2011) studied the effects of agility training on tennis and agility performance in 30 collegiate male tennis players. Agility performance was measured using the Illinois Agility Test and tennis performance was assessed by the precision of serves. Agility scores improved by 34%, and precision of serves improved by 61.3% following agility training. This enhancement may be credited to improvement in proprioceptive ability and advanced integration of the neural and muscular systems.

Components of Agility

The most studied contributors to agility are power and strength (Djevalikian, 1993; Myer et al., 2005; Pauole et al., 2000; Sporis, Milanovic, Jukie, Omreen, & Molinuevo, 2010; Young, James, & Montgomery, 2002). Other factors that may also affect agility are years of training, reaction time, electromechanical delay, body size and technique employed in performing an agility task.

Power and Strength

Power is defined as the rate of doing work (Abernethy, Wilson, & Logan, 1995). Strength is the ability to produce maximum force. Muscular strength, in particular, is influenced by the capacity of a muscle to develop active tension (Abernethy et al., 1995). Strength is an important component of power, although the opposite is not true. One can have strength without power, which typically occurs when a person has a poor rate of force development (RFD) and muscle shortening velocity (Halberg, 2001).

Agility and ability to change direction quickly rely on power generation. Power is essential to change directions in an agility test. Most agility drills are comprised of rapid acceleration, deceleration and change of direction; and the ability to accelerate is highly correlated to power generation (Halberg, 2001; Mayhew, Piper, Schwegler, & Ball, 1989). Djevalikian (1993) studied the relationship between power and agility in athletes involved in short distance sports like soccer-goal keeping and badminton. While he reported no significant relationship between power and agility ($r = 0.15$, $p > .05$), Djevalikian (1993) also examined the relationship between reactive strength and change of direction speed and found a moderate correlation ($r = 0.42$, $p < .05$) between reactive strength and change of direction speed for short sprints (20m sprint with three directional changes). Reactive strength is the ability to change rapidly from an eccentric to a concentric contraction. Reactive strength was measured using depth jumps from various drop heights. In a similar study, Young, Hawken, and McDonald (1996) examined the relationship between reactive strength (loaded squat movement) and another agility type task (20m sprint with change of direction) and found no significant correlation (r = 0.36, $p > .05$). In 2002, Young et al. again conducted a similar study and found a non significant correlation (r = -0.47, $p > .05$) between reactive strength (drop jump test) and sprints with changes in direction. These studies suggested that reactive strength might play an important role in change of direction when observed over short distances (Sheppard & Young, 2006).

Most studies that have investigated the relationship of strength and power with agility do so by focusing on different training programs. Shaji and Saluja (2009) examined the effects of both plyometric training and dynamic stretching on vertical jump and Agility T-Test in 45 male collegiate basketball players. These participants were assigned to three groups: group A (dynamic-stretching- group), group B (plyometric group) and group C (dynamic-stretching-plyometric group). Vertical jump and Agility T-Test scores improved in all three training groups but the improvement was greatest in group C, the dynamic-stretching-plyometrics group. Improvement in performance was attributed to possible neural adaptations such as improved motor recruitment or increased rate of force development, thereby increasing speed and power or excitability of fast twitch motor units.

Agility training is also often used to improve both power and agility performance (Sporis et al., 2010). Sporis et al. (2010) examined the effect of agility training on power performance in 80 healthy physically active first year college-aged males. The 10 week agility training was held for 60 minutes, thrice weekly. The study had a one week recovery period after five weeks of training for control testing. The participants were assigned to either a control group or an experimental group. After five weeks the participant's power was measured using nine power performance tests, namely: counter movement jump (CMJ), counter movement jump from the left (CMJ1L), counter movement jump from the right (CMJ1R), standing long jump (SLJ), standing long jump from the left (SLJ1L), standing long jump from the right (SLJ1R), 5-m sprint (SP5), 10-m sprint (SP10) and 20-m sprint (SP20). The CMJ height improved significantly in the experimental group by 5% to 9%. This improvement in power was attributed to the specific task training (agility training) and/or improved muscle coordination. It should be noted that the training programs that improved power and strength in these studies also improved muscle coordination. Thus, it is not possible to attribute the improvement in agility exclusively to power or strength. While all the aforementioned studies suggested that strength and power are essential determinants of agility, and in-turn sports performance, strength and power are not the only components that alter agility scores; for example, neuromuscular delay and reaction time may affect agility.

Electromechanical Delay and Reaction Time

Electromechanical delay may be an important component of agility (Shaji & Saluja, 2009). Electromechanical delay is the delay in muscular activity in response to a neural stimulus. Electromechanical delay can be improved by neuromuscular training and it may predict agility (Grosset, Piscione, Lambertz, & Pérot, 2009). Training programs that include stretching and plyometrics tend to decrease muscular stiffness which is directly related to electromechanical delay (Grosset et al., 2009). Neuromuscular training decreases muscular stiffness, which decreases electromechanical delay, hence decreases time on agility test. Since electromechanical delay is directly proportional to agility time, training programs consisting of strength, power, balance and stretching exercises that elicited improvements in electromechanical delay also show improvements in time on agility test (Myer et al., 2005; Shaji & Saluja, 2009).

Another component of agility, in addition to strength, power and electromechanical delay, is reaction time. Reaction time is the time between a stimulus and a response to a stimulus. Reaction time depends on the rate of signal transmission through the afferent sensory pathways and efferent motor response to the sensory information (Prentice, 2006). For an individual to be agile, the sensory signals and motor responses should be fast. Chelladurai (1976) stated that agility has two components: reaction time and velocity. Reaction time is most important in changing direction, starting and stopping. Velocity refers to athlete's speed during the performance of an agility task. A person's velocity is most directly affected by power.

Interestingly, in a 2012 study, Çankaya found that power (vertical jump) is strongly related to reaction time in wrestlers ($r = 0.62$-0.73, $p < .05$). The author also proposed that more powerful individuals react faster, suggesting that power and reaction time are related to each other, and thus both (power and reaction time) are related to agility.

One can improve reaction time and electromechanical delay with training. Linford et al. (2006) found that six weeks of training comprised of strength, power, balance and stretching exercises improved reaction time and electromechanical delay in 26 physically active, college-age subjects. The subjects were sex matched and assigned to either a treatment group or control group. The improvement in reaction time in the treatment group from $M = 61.9$, $SD = 6.5$ ms to $M = 57.1$, $SD = 7.7$ ms was attributed to the components of the training program: strength, power and agility.

Wojtys et al. (1996) studied neuromuscular adaptations (reaction time, endurance rate, and time to peak muscle torque) to six weeks of knee flexion/extension and ankle plantarflexion/dorsiflexion training in 32 volunteers (16 males and 16 females). Endurance rate was defined as time to fatigue. The participants were randomly assigned to four training groups: isokinetic, isotonic, agility or control. The isokinetic protocol was knee flexion/extension and ankle plantarflexion/dorsiflexion exercises on an isokinetic dynamometer. The isotonic protocol consisted of 3x12 reps each for leg press, hamstring curl and calf raises. The agility protocol comprised of five drills: a) slide-boarding (5x25), b) unilateral bounding (3x10), c) carioca (foot cross-over drill 3x10), d) figure of 8 (3x15) and e) backward runs (3x10). The control group protocol consisted of activities of daily living. Reaction time was measured by spinal reflex, intermediate response and voluntary response. Spinal reflex is a monosynaptic response resembling a tendon tap. Intermediate response is a spinal reflex with interneuronal input from higher centers. Voluntary response is voluntary muscle activity. Spinal reflex times of the lateral and medial quadriceps decreased by 13.8 msec to 15.4 msec in the agility group. The agility group also improved in intermediate response time by 18.1 msec and shortened voluntary response time by 15.7 msec to 34.4 msec. Isotonic and isokinetic groups did not change. No differences in peak muscle torque and endurance rates of knee flexion/extension or ankle plantarflexion were observed within and between groups. Improvements in reaction time in the agility group were attributed to quick quadriceps-hamstring-gastrocnemius muscle contractions needed to stabilize the lower extremity joints during the stop and go activities of agility training.

The aforementioned studies indicate that reaction time and electromechanical delay can be improved by agility training. However, since training programs improved reaction time and electromechanical delay simultaneously with strength, power and balance, it is not possible to attribute the improvement in agility solely to improved reaction time and electromechanical delay.

Body Size, Age and Gender

Body size is another important determinant of agility. Height, weight and BMI fall under the category of anthropometry. Age and gender are other important factors that might affect agility. Mujika, Sanisteban, Impellizzeri, & Castagna (2009) examined the determinants of success in men's and women's football (soccer) in 68 participants (34 females and 34 males). These participants were randomly selected from division I and junior players. The participants were divided into four groups according to gender and competitive standard. Vertical jump, 15-m sprint run, 15-m agility run, 15-m ball dribble and Yo-Yo intermittent recovery tests were compared between groups by gender to assess the impact of fitness on success in men's and women's football. The study showed that agility scores were higher in senior males and females compared to junior males and females by 2.86% - 16.46%. Agility scores were also higher in senior males compared to senior females, and junior males compared to junior females by 1.84% - 20.22% and 6.74% - 20.28%, respectively. Mujika et al. (2009) suggested that the difference in performance was due to differences in fitness of the males and females, and not gender per se. The difference in junior and senior players was attributed to competitive experience or years of training. It stands to reason that improvements in agility could be attributed to years of sport-specific training.

Fitness may not account for all gender differences observed in agility scores. Shultz et al. (2001) evaluated neuromuscular response characteristics in men and women after knee perturbation in single leg, weight-bearing stance in 32 males and 32 females. Using electromyography, this study examined if muscle response time and activation patterns differed in males and females. Results showed that females responded faster than males by 10 milliseconds, whereas no differences in muscle recruitment order were seen across genders. The difference was attributed to a shorter latency in muscle activation in females possibly due to less muscle inhibition compared to men. However it is unknown how this difference would affect agility or performance.

Only two studies to date have examined the relationship between body size and agility. In one study, Nimphius, McGuigan, and Newton (2010) found significant relationships between body weight (BW) and sprint time ($r = 0.93$, $p < .01$), BW and 505 Agility Test ($r = 0.71$, $p < .05$), vertical jump height and relative strength ($r = 0.38$, $p < .05$), vertical jump height and 505 Agility Test ($r = -0.48$, $p < .05$) and peak power and 505 Agility Test ($r = -0.90$, $p < .01$) in 10 female softball players. Nimphius et al. (2010) also reported a non significant relationship between BW and vertical jump height ($r = -0.57$, $p > .05$). Another study by Webb and Lander (1983) reported a weak correlation ($r = 0.21$, $p > .05$) between body fat and speed of change of direction in rugby players. Other factors that might affect agility are height and relative limb lengths which are genetically pre-determined, but may be moderately influenced by nutrition status, particularly during growth spurts. However an athlete can enhance fitness by reducing body fat and increasing lean body mass.

Technique

Yet another factor that plays an important role in determining agility is technique. Technique is defined as a systematic procedure by which a complex or specific task is accomplished (Mann, 1986). Specifically, running technique plays an important role in agility. Francis (1997) reported that a low center of gravity along with forward lean contributed to a more rapid change of direction. It is likely that a lower center of gravity and forward lean affected acceleration and deceleration times, support time/contact time, ground contact forces, stride frequency, knee extension initiation and velocity (Green, Blake, & Caulfield, 2011; Jindrich, Besier, & Lloyd, 2006; Lockie et al., 2011; Murphy, Lockie, & Coutts, 2003).

Murphy et al. (2003) studied kinematic determinants of early acceleration in field sport athletes in 20 healthy active men. Subjects were divided into fast and slow groups based on sprint ability over the first three steps of a 15m sprint. The study revealed significantly shorter foot contact times (11% - 13%) in the fast group compared to the slow group. The reduction in contact times was attributed to decreased knee extension at toe-off. Decrease in foot contact times are associated with increased stride frequency which will result in a faster average sprint velocity if there is not a concomitant change in stride length.

Lockie et al. (2011) studied the biomechanical and performance factors that differentiated sprint acceleration in field sport athletes. Participants were assigned to either the slower or faster groups based on 0 m-10 m velocity. Lockie et al. (2011) reported higher peak ground contact forces for faster group. This was attributed to shorter support time and faster average force generation. Additionally, the faster group had 14% greater counter movement jump (power) and 48% greater reactive strength index (strength). The results suggest that shorter contact time and improved ground force efficiency (ability to develop and use force within a short duration) can improve agility. This study further supports the importance of power and good technique to improve agility scores.

Green et al. (2011) compared cutting techniques in 23 rugby union players. They reported that rapid deceleration on to the plant leg followed by reacceleration of the push-off leg in a new direction are essential components of effective change of direction/cutting technique. They also found that starters (first team players) had shorter contact time during leg plant when cutting on the dominant foot; starters also initiated knee extension of the push-off leg earlier than nonstarters (reserve team player) during both dominant and non-dominant foot cuts.

In addition to cutting technique, foot positioning is another factor that can impact change of direction or agility. Wheeler and Sayers (2010) studied foot positions in straight-line sprinting and change of direction during a rugby agility task in eight highly trained rugby union players. There was greater change in anterior (M = 46.2% leg length, SD = 11.2%) foot positions during change of direction step compared to straight line sprinting (M = 14.9, SD = 8.9). Greater lateral foot displacement was observed at foot-strike (M = 41.4, SD = 5.9) during change of direction step compared to foot-strike at straight line sprinting (M = 8.1, SD = 3.2). Anterior and lateral foot positioning was influenced by the shape of the agility course, as one direction change involved more lateral foot placement and another direction change involved more anterior foot placement. More specifically, the initial change of direction step involved deceleration of running speed and development of lateral movement. This lateral movement was in-turn utilized for forward progression after the direction change. The magnitude of the deceleration was attributed to anterior foot displacement or position and associated braking forces. Jindrich et al. (2006) also reported that braking forces are essential for an individual to decelerate while changing the direction of center of mass (COM). These results illustrate the importance of foot placement and force development during cutting tasks, and suggest that accurate technique developed under the guidance of coaches and trainers can be used to improve performance.

Measuring Agility

Five of the more common tests for measuring agility are: 1) Illinois Agility Test, 2) Agility Shuttle Run Test, 3) 505 Agility Test, 4) Agility T-Test and 5) 3-Cone Shuttle Drill Test. Of these five tests, the two commonly used tests are Agility T-Test (Shaji & Saluja, 2009; McMillian et al., 2006) and 505 Agility Test (Nimphius et al., 2010; Thomas, Duncan, & Philip, 2009). The Agility T-Test is often used for athletes, and includes forward, backward and lateral running while the 505 Agility Test is used to assess 180 degree turning ability. The 505 Agility Test can also be adapted for sport-specific training.

The Illinois Agility Test

This test was described by Getchell in 1979. It involves running through a weaving course after starting from a prone position, with head at the start line and hands by the shoulders. The course is 10 meters long and 5 meters wide. Four cones are used to mark the start, finish and two turning points. Another four cones are placed across the width of the course at the center; each cone at the center is spaced 3.3 meters apart (Figure 1). Time taken to run the entire distance is recorded using a stop watch or timing gates. On the ‘go’ command, the runner gets up as quickly as possible and runs around the course in the direction indicated without knocking over cones (Reiman & Manske, 2009, p. 193). The Illinois Agility Test is simple and easy to administer and requires minimum equipment. The only disadvantage of this test is that it requires a person, in addition to the runner, to administer the test. There is no known reliability or validity data for this assessment.

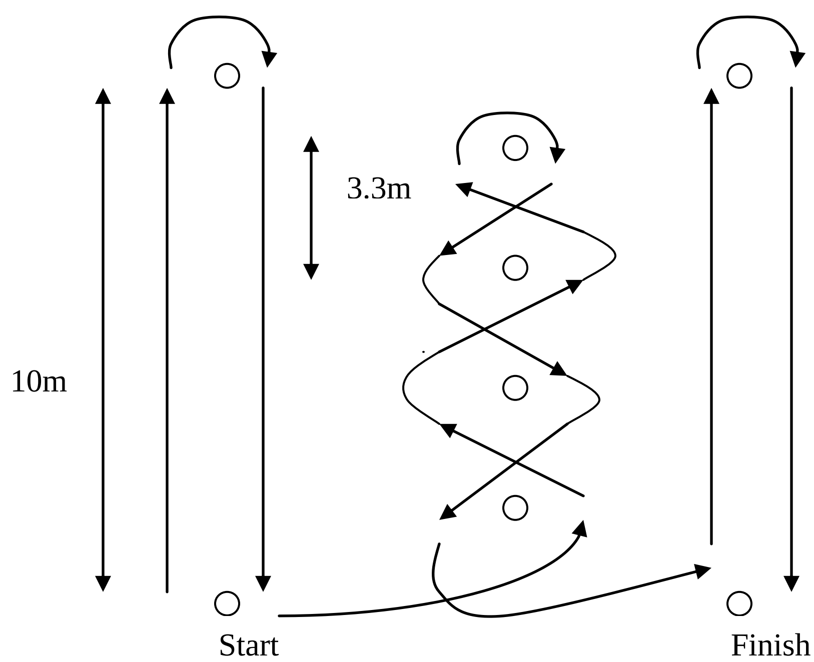

Figure 1. Illinois Agility Test.

<u>The Agility Cone or Compass Drill Test</u>

The Agility Cone Test is most commonly used for basketball and soccer players. This test was once part of the speed, power, agility reaction and quickness (SPARQ) soccer and basketball rating. Five cones are arranged as shown in figure 2; the athlete starts from the center cone and finishes at the cone behind the center cone. The outer cones are 3 meters away from the center cone. On the go command the runner runs from start to point A, back to center, to point B, back to center, to point C, again back to center, and runs to the finish point (Reiman & Manske, 2009, p. 195). It is used for active individuals. Only one individual can perform the test at a time.

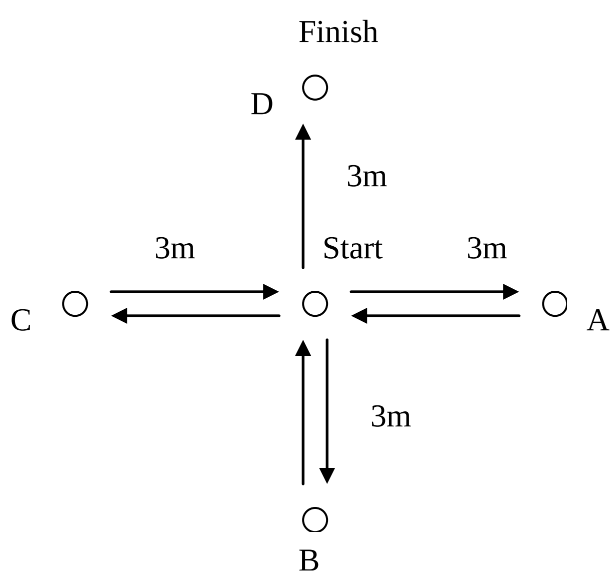

Figure 2. Agility Cone Drill Test.

<u>The 505 Agility Test</u>

The 505 Agility Test was developed by Draper and Lancaster in 1985. This test is used only for active individuals like tennis or soccer players. For this test the athlete runs 15 meters and then makes a 180 degree turn and then runs past the 5 meter mark. A timing system is placed at the 5 meter line (Figure 3). The time taken to cover 5 meters before and after the turn (using a timing system) is recorded. The athlete is not timed for the first 10 meters. The athlete is advised not to overstep the turning point too much, as this will increase their time. This test is easy to setup and administer, and requires minimum equipment. Intraclass correlation coefficient is R= 0.78 (Cochrane, Legg, & Hooker, 2004).

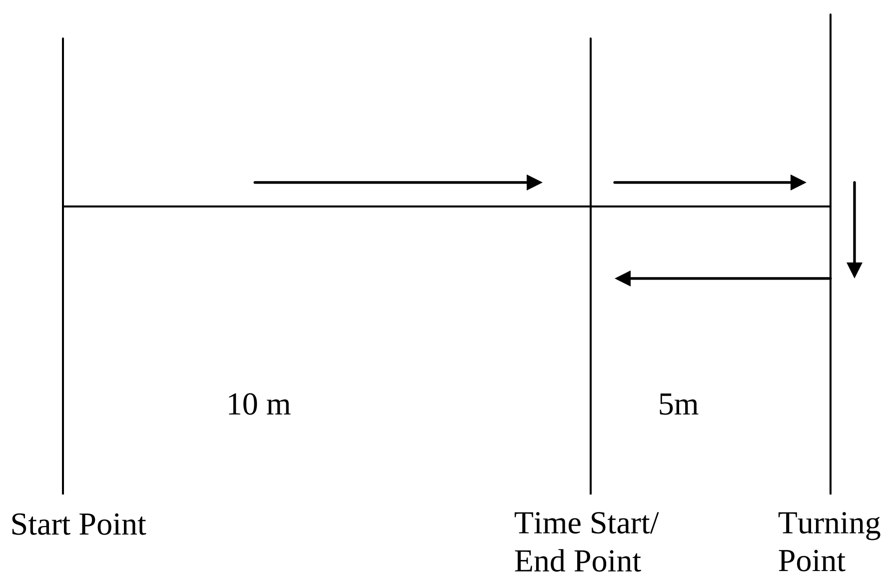

Figure 3. 505 Agility Test.

<u>The Agility T-Test</u>

The Agility T-Test (Semenick, 1990) is used to determine speed and directional change, but unlike other agility tests it focuses on back pedaling and lateral shuffles. Four cones are placed on the ground in a ‘T’ shape as illustrated in figure 4 (5 yards = 4.57 m, 10 yards = 9.14 m). The subject starts at cone A and sprints forward to cone B, laterally shuffles to cone C, laterally shuffles to cone D, laterally shuffles to cone B, then runs backward to cone A. The time taken to run the entire distance is recorded using a timing system or stopwatch. The advantage of this agility test is that it requires minimum equipment and space, and is easy to perform. Intraclass correlation coefficient (ICC) ranges from R= 0.94 to 0.98 (Pauole et al., 2000)

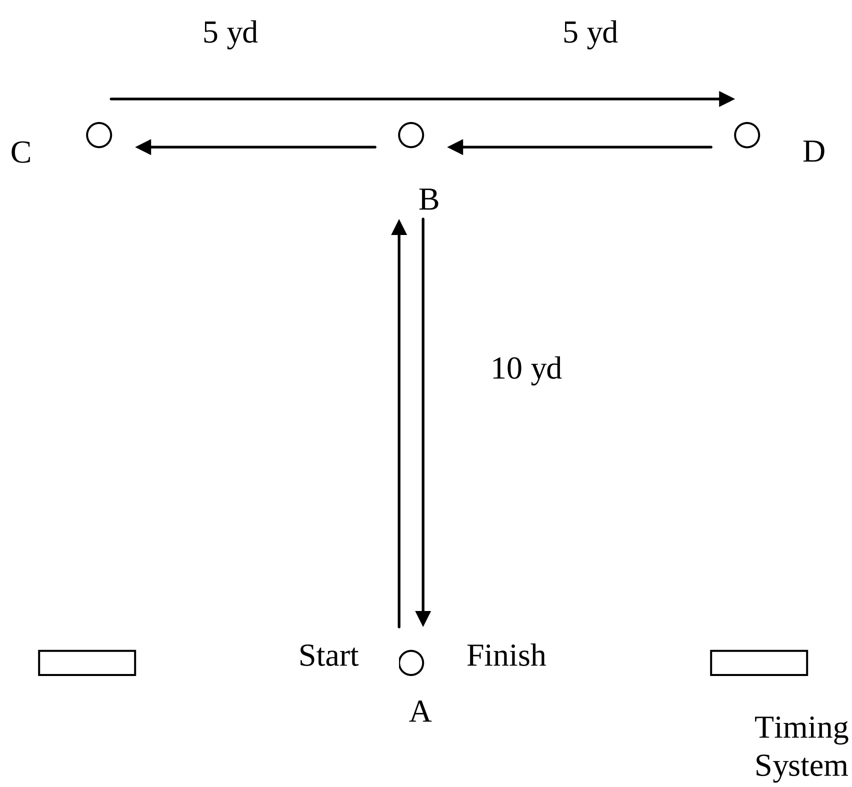

Figure 4. Agility T-Test.

The 3-Cone Shuttle Drill Test

The 3-Cone Shuttle Drill Test is used in the fitness testing battery for the National Football League (NFL). It is also called the L-drill. Three cones are placed in the shape of 'L' as shown in figure 5 (each cone is 5 yards apart). The athlete starts at cone 1 from a three point stance, runs towards cone 2, turns and runs back to cone 1. Next, on the outside of cone 1 the athlete runs to cone 2, then runs to the inside of cone 3, around cone 3 then cone 2 and back to cone 1. The time taken to perform the entire drill is recorded using a stopwatch or timing gates (Reiman & Manske, 2009, p. 196). This test is suitable for team sports like field hockey and rugby since these frequently require change in direction. Intraclass correlation coefficient is R= 0.81 (Lagley, 2011).

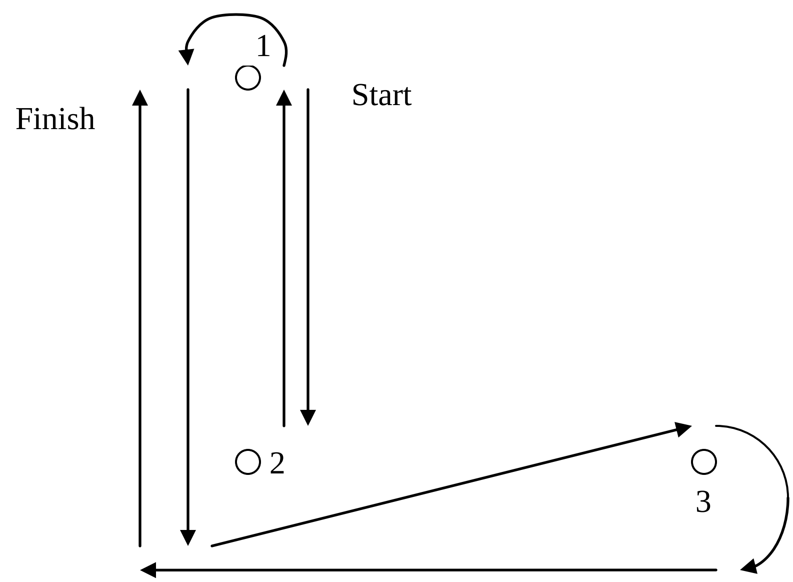

Figure 5. 3-Cone Shuttle Drill Test.

Summary

Based on the research, it is evident that several factors potentially influence agility skill including leg strength (Djevalikian, 1993; Young et al., 2002), leg power (Lockie et al., 2011; Pauole et al., 2000; Sporis et al., 2010) and reaction time (Linford et al., 2006; Chelladurai, 1976; Wojtys et al., 1996). It is believed that power and reaction time together play an important role in determining the agility of an individual, though the results are inconclusive (Linford et al., 2006). In addition, most of the earlier studies focused on individual factors that influenced agility namely: gender, body size and sport-specific training. They found that males are faster than females; agility is dependent on body size and individuals with more sport-specific training have faster agility scores (Mujika et al., 2009). While the research on agility is extensive, studies have yet to examine the combined effects of body size, years of sport specific training, power and reaction time on simple agility in tennis players.

Chapter 3

METHODOLOGY

The present study examined the relationships between body size, training history and performance variables (power and reaction time) and agility. This chapter describes the procedures used to quantify these variables and the statistical analyses to assess these relationships.

Participants

Thirty participants with at least one year of tennis playing experience, between the ages of 18 – 39 years old, were recruited through coaches and meetings with local tennis teams and clubs in Ithaca, NY, of which 22 were males and 8 were females. Each participant read and signed an informed consent form that was approved by the Human Subjects Review Board at Ithaca College, Ithaca, NY.

Experimental Design

Participants completed one test session that began with familiarization or practice trials and were followed by test trials. In the test session, participants first read and signed an informed consent (Appendix A) and also completed a 24-Hour Health History Questionnaire (Appendix B). Age, height, mass, years of sport-specific training and BMI were measured and recorded for each individual. Years of sport-specific training were determined as number of years played under a coach or tennis professional.

During the test session, participants performed three familiarization trials for: 1) Agility T-Test, 2) 505 Agility Test, 3) Vertical Jump Test and 4) Simple Reaction Time Test, with a rest period of one minute between the trials. All tests were administered by the same tester in the Biomechanics Lab at Ithaca College. Familiarization trials were preceded by a 5 minute warm-up, which consisted of low intensity forward, backward and sideways runs. Test trials were performed after a rest of one minute following the familiarization trials. Two test trials of agility were recorded for both the Agility T-Test and 505 Agility Test, with one minute rest in between trials. Lastly, peak power was recorded from the Vertical Jump Test (two trials with one minute rest period between the trials) and reaction time (two trials with one minute rest between trials) was recorded from the Reaction Time Test.

Experimental Procedures

For the purpose of this study the participants were asked to complete the Agility T-Test, 505 Agility Test, Vertical Jump Test and the Reaction Time Test; which are explained in the following paragraphs.

Agility T-Test

For the Agility T-Test, participants sprinted 10 yd forward, to the center cone, shuffled 5 yd to the left, shuffled 10 yd to the right, shuffled 5 yd to the left and then shuffled backwards past the starting cone (Semenick, 1990). Participants did not touch the cones. Time taken to accomplish this entire task (Figure 6) was recorded to the nearest .001 sec using the Smartspeed^{TM} timing system (Fusion Sport, Australia). Participants performed this test twice with a rest period of 1-2 minutes between trials. The fastest time was used for analysis.

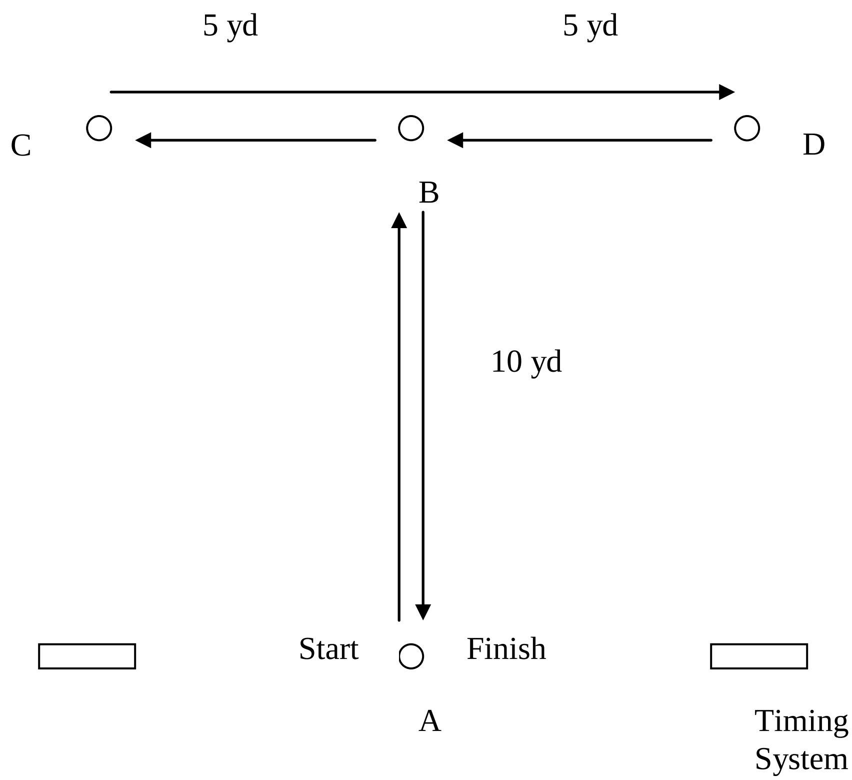

Figure 6. Agility T-Test setup.

505 Agility Test

Following the Agility T-Test, participants recovered for two minutes then performed the 505 Agility Test developed by Draper and Lancaster (1985). For this test, participants ran 15 m from the Start Point to the Turning Point, reversed and ran back past the 5 m End Point (Figure 7). Participants performed this test twice, with a rest period of one minute between trials. The time taken to cover a distance of 10 m (from Time Start to End Point) was recorded to the nearest 100th sec using the Smartspeed™ timing system (Fusion Sport, Australia). The initial 10 m distance was used to increase speed and was not included in timing the test. Both scores were recorded and the fastest time was used for analysis.

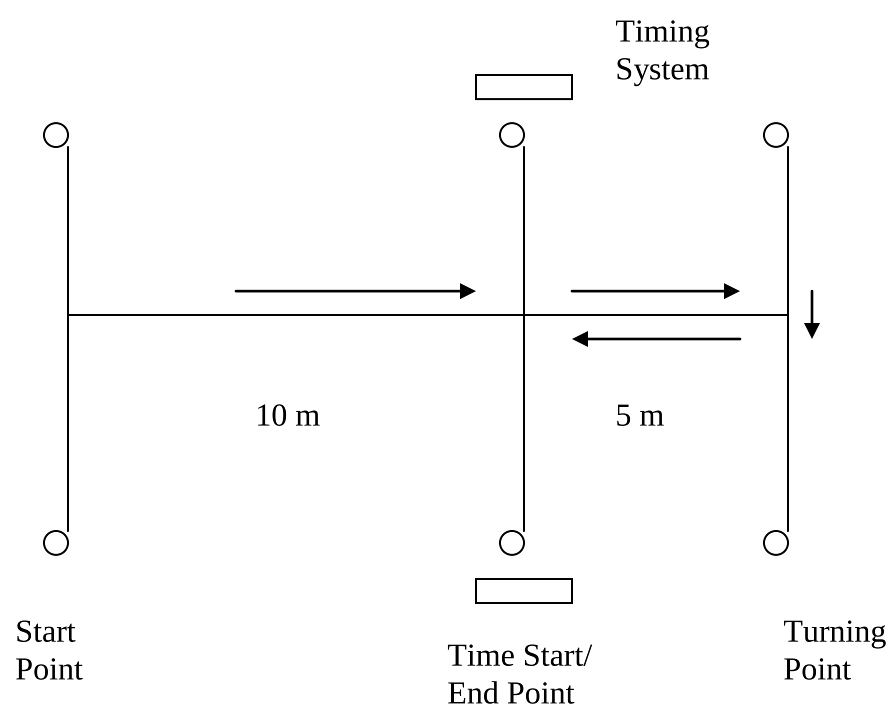

Figure 7. 505 Agility Test setup.

Vertical Jump Test

Participants recovered for two minutes following the 505 Agility Test and then performed the Vertical Jump Test (Sargent, 1921). To perform the Vertical Jump Test, participants began by standing on a force plate (AMTI, Watertown, MA). The force plate sampled at a rate of 1000Hz. On the 'go' command, participants performed a counter movement then jumped vertically as high as possible (using both arms and legs to assist). Labview software version 8.6.1 (National Instruments, Austin, TX) was used to calculate peak power output (PPO). Power output was calculated using the formulas:

$P = \sum F * V$

Where: P = power

V = velocity

$V = \int a$

$a = \sum F / m$

where: a = acceleration

m = mass

$\sum F = GRF - W$

where: $\sum F$ = net force

GRF = ground reaction forces

W = body weight

Participants repeated this test twice separated by one minute of rest, and both scores were recorded. Maximum power output value during the counter movement jump was defined as PPO. The highest PPO was used for analysis.

Reaction Time Test

Two minutes following completion of the Vertical Jump Test, participants performed a simple Reaction Time Test. This test was performed using the force plate and Labview software version 8.6.1 (National Instruments, Austin, Texas). A participant stood on the force plate in a one-forth squat or sports ready position, weight on balls of feet flat and knees slightly bent. At the presentation of combined auditory and visual stimuli, the participant reacted as fast as possible by performing a quick two feet hop motion. Reaction time was defined as an increase in the vertical ground reaction force (GRF) from the baseline. The stimulus was set to occur 1000 msec after initiating the program. To determine the response time, an algorithm was developed to define the onset of GRF production for the two footed hop. Specifically, the algorithm generated a graph and calculated the mean of the vertical force curve obtained from the time of start to 1000 msec (Figure 8). Onset of GRF was defined as the first 10 N fluctuation in the vertical force curve following the stimulus. Each participant performed the Reaction Time Test twice, with a rest period of one minute between trials. Both reaction time scores were recorded, although the fastest time was used for analysis.

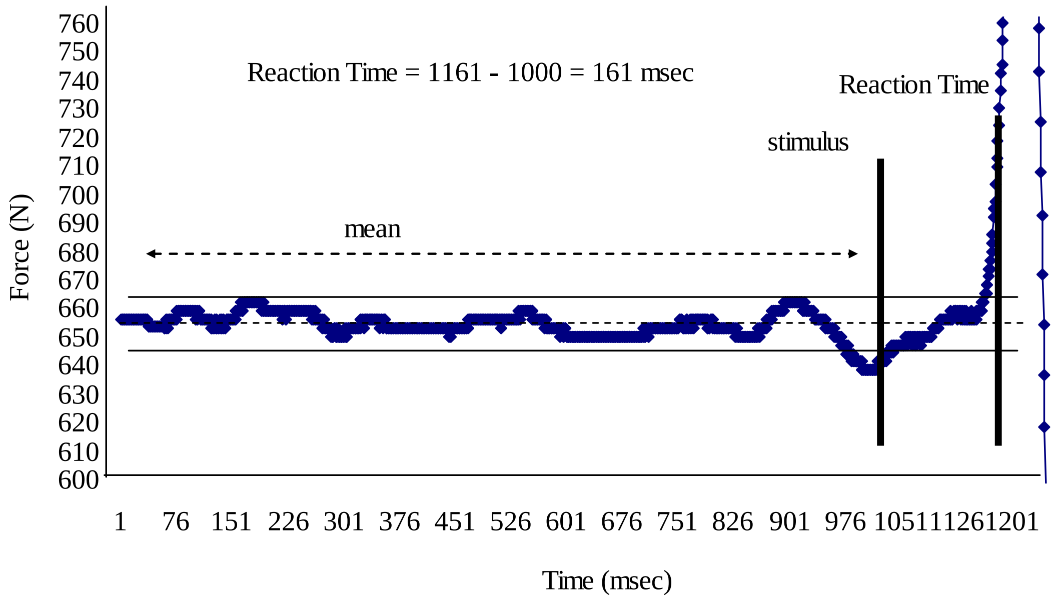

Figure 8. Ground reaction force graph.

Statistical Analysis

It was hypothesized that there were statistically significant relationships between agility test scores and years of sport-specific training, reaction time, power and BMI. The relationships between independent and dependent variables were calculated using Pearson correlations. Two multiple regression analyses using SPSS (Version 17.0, Chicago, IL) were used to identify significant predictors of agility; one for Agility T-Test score and one for 505 Agility Test score. The variables were entered in a hierarchical method. The independent variables were years of sport-specific training, reaction time, power and BMI, while the dependent variables were 505 Agility Test score and Agility T-Test score. Effect size was calculated as r^2 using the Pearson correlation.

Chapter 4

RESULTS

The purpose of this study was to examine the relationship between BMI, years of tennis training, reaction time, power and agility scores that include Agility T-Test and 505 Agility Test. For this, 30 subjects volunteered from local tennis teams and clubs in Ithaca, NY. The dependent variables measured were Agility T-Test and 505 Agility Test. Appendix D contains the raw data for all variables. This chapter includes results and data analyses of subject characteristics and correlates of agility.

Subject Characteristics

Age, height, mass and years of tennis training are reported in Table 1. Participant ages ($M = 22.7$, $SD = 5.8$) ranged between 18 and 39 years.

Table 1

Subject Characteristics (N = 30)

Parameter	Mean ± SD	Range
Age (years)	22.67 ± 5.84	18.00 - 39.00
Mass (kg)	72.48 ± 12.76	49.50 - 98.10
Height (m)	1.75 ± 0.09	1.57 - 1.98
Years of tennis training	6.65 ± 3.63	1.00 - 13.00
BMI	23.45 ± 3.28	18.25 - 31.94

Note. BMI: Body Mass Index.

Correlates of Agility

Summary data of peak power output (PPO), reaction time, Agility T-Test and 505 Agility Test are provided in Table 2. Peak power output was very variable, ranging from 998 W to 3443 W. Reaction time was also quite variable with a 215 msec difference between the slowest and fastest times. Agility T-Test and 505 Agility Test had less variability across subjects. Performance time for Agility T-Test ranged from 8.48 sec to 12.87 sec, and for 505 Agility Test from 2.12 sec to 3.11 sec.

Table 2

Correlates of Agility

Parameter	Mean ± SD	Range
PPO (W)	2116.53 ± 710.77	998.00 - 3443.00
Reaction time (ms)	201.40 ± 60.88	105.00 - 320.00
Agility T-Test (s)	10.69 ± 1.18	8.48 - 12.87
505 Agility Test (s)	2.56 ± 0.26	2.12 - 3.11

Note. PPO: peak power output.

Pearson correlations were calculated to determine the correlations between dependent and independent variables (Table 3). There were statistically significant relationships between BMI and 505 Agility Test (r = 0.394, $p < .05$; ES = 0.155), PPO and Agility T-Test (r = -0.583, $p < .01$; ES = 0.34), PPO and BMI (r = 0.416, $p < .05$; ES = 0.1731) and PPO and years of training (r = -0.395, $p < .05$; ES = 0.156). The relationship between PPO and 505 Agility Test (r = -0.295, $p = .057$; ES = 0.087) approached significance. There were no other statistically significant relationships. There was a strong correlation between Agility T-Test and 505 Agility Test (r = 0.85, p < .01; ES = 0.7225). Correlational data is illustrated in scatter plots for BMI and 505 Agility Test (Figure 9), PPO and Agility T-Test (Figure 10), PPO and 505 Agility Test (Figure 11), PPO and BMI (Figure 12) and PPO and years of training (Figure 13).

Table 3

Correlation Matrix of Physical and Performance Correlates of Agility

	BMI	Years of training	PPO	Reaction Time	Agility T-Test	505Agility Test
BMI	1					
Years of training	-0.156	1				
PPO	0.416*	-0.395*	1			
Reaction time	0.130	-0.174	0.215	1		
Agility T-Test	0.184	-0.023	-0.583**	-0.037	1	
505Agility Test	0.394*	-0.067	-0.295***	0.150	0.850**	1

Note. *p < .05, one- tailed. **p < .01, one- tailed. *** p < .057, one- tailed.

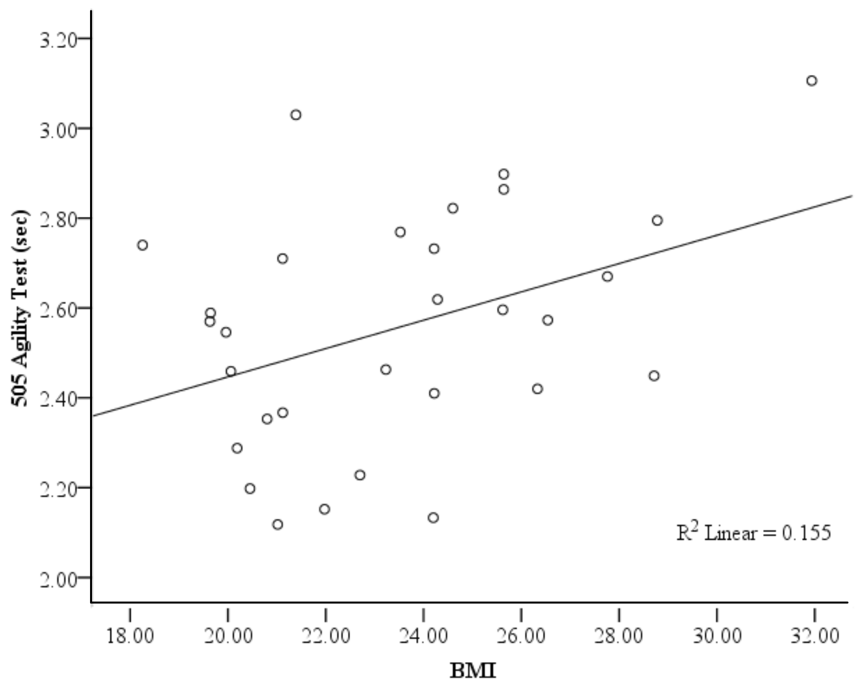

Figure 9. Relationship between BMI and 505 Agility Test (r = 0.394, $p < .05$; ES = 0.155).

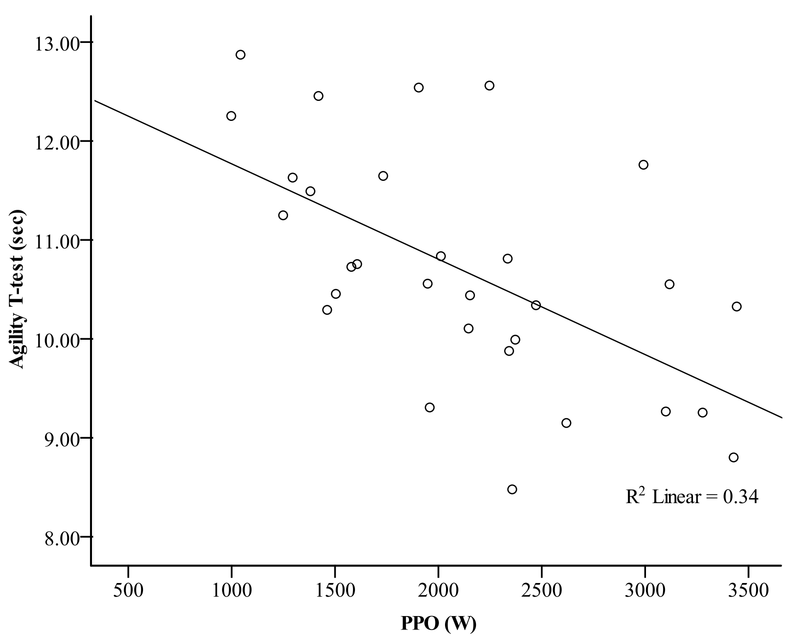

Figure 10. Relationship between PPO and Agility T-Test (r = -0.583, $p < .01$; ES = 0.34).

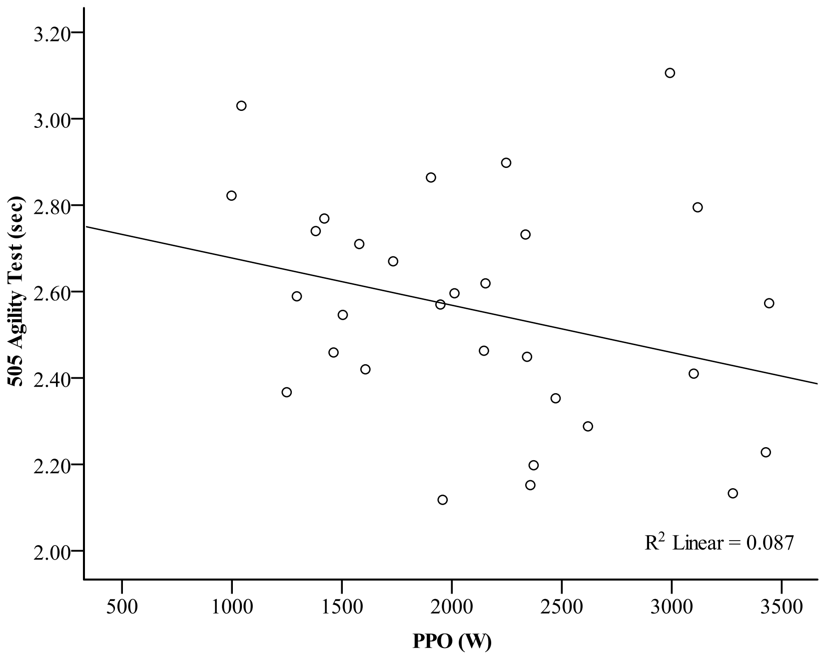

Figure 11. Relationship between PPO and 505 Agility Test (r = -0.295, p = .057; ES = 0.087).

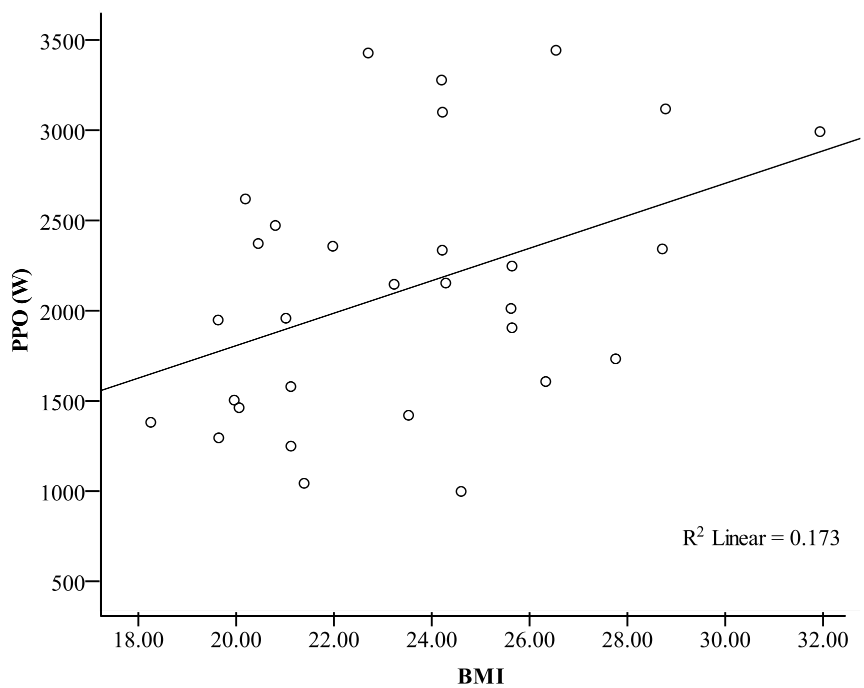

Figure 12. Relationship between PPO and BMI (r = 0.416, p < .05; ES = 0.1731).

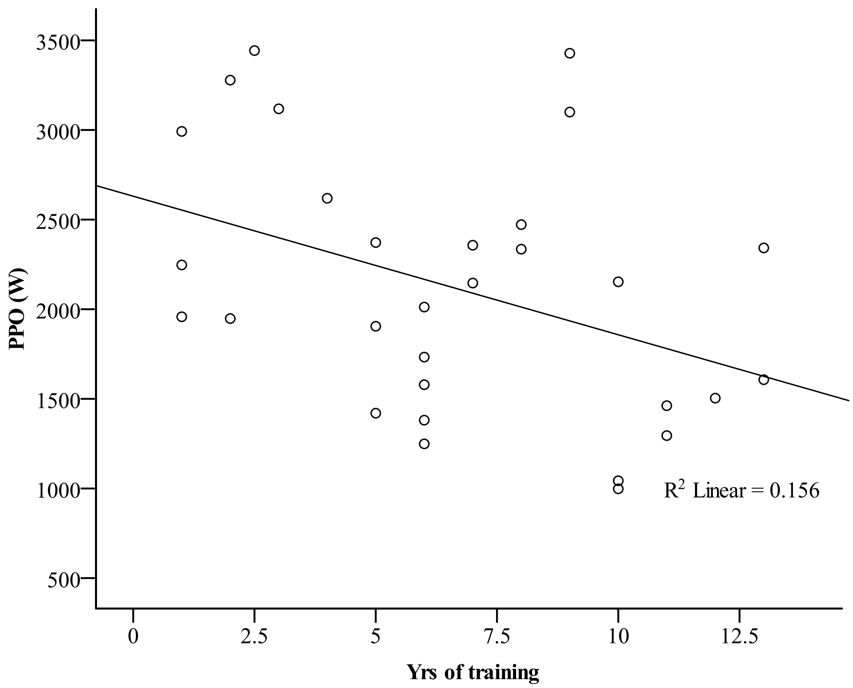

Figure 13. Relationship between PPO and Years of Training (r = -0.395, $p < .05$; ES = 0.156).

Two multiple regression analyses were completed to identify relationships between different variables and the two agility scores. The variables were entered in hierarchical order as follows: 1) BMI, 2) years of training, 3) PPO and 4) reaction time. To observe how performance measures (PPO and reaction time) contributed to body size and training indices, the performance measures were added last in the model. The resultant regression equations were:

Equation 1

505 Agility Test = 1.865 + 0.049 BMI - 0.015 years of training + 0.002 PPO + 0.001 reaction time, $R^2 = 0.48$

Equation 2

Agility T-Test = 10.078 + 0.185 BMI - 0.097 years of training - 0.002 PPO + 0.001 reaction time, $R^2 = 0.64$

Multiple regression analyses (Table 4 and Table 5) revealed that BMI, years of training, PPO and reaction time together predicted 48.2% and 64% of the 505 Agility Test scores and Agility T-Test scores, respectively. When predicting agility using equation 1 and equation 2, every 1 unit increase in BMI slows the Agility T-Test score by 0.185 s and the 505 Agility Test score by 0.049 s. Every 1 unit increase in years of training quickens the Agility T-Test score by 0.097 s and the 505 Agility Test score by 0.015 s. Every 1 unit increase in PPO quickens the Agility T-Test score by 0.002 s and slows the 505 Agility Test score by 0.002 s. Also every 1 unit increase in reaction time slows the Agility T-Test score by 0.001 s and the 505 Agility Test score by 0.001 s. Examination of the correlation matrix (Table 3) reveals that PPO alone accounts for 34% of the variance in Agility T-Test performance ($r = 0.58$, $r^2 = 0.34$), but only 8.7% of the variance in 505 Agility Test ($r = 0.30$, $r^2 = .09$). In contrast reaction time alone, accounts for only 0.1% of the variance in Agility T-Test performance ($r = 0.04$, $r^2 = 0.001$), and 2.3% of the variance in 505 Agility Test ($r = 0.15$, $r^2 = 0.02$). Multiple Regression analyses were performed to predict the strength of each variable in determining agility scores or agility performance. Multiple regression analyses showed that BMI, years of training, PPO and reaction time together predicted agility scores better than any variable alone.

Table 4

Regression Coefficients Predicting Agility T-Test

	b	*SE b*	*β*	R^2
				0.640
Constant	10.078			
BMI	0.185	0.047	0.516	
Years of training	-0.097	0.042	-0.300	
PPO	-0.002	0.000	-0.925	
Reaction time	0.001	0.002	0.043	

Table 5

Regression Coefficients Predicting 505 Agility Test

	b	*SE b*	*β*	R^2
				0.482
Constant	1.865			
BMI	0.049	0.013	0.617	
Years of training	-0.015	0.001	-0.205	
PPO	0.002	0.000	-0.671	
Reaction time	0.001	0.001	0.179	

Summary

This study examined the relationships between two measures of agility (Agility T-Test and 505 Agility Test) with BMI, years of tennis training, PPO and reaction time. Pearson correlations and scatter plots revealed a significant negative correlation between PPO and Agility T-Test (r = -0.583, $p < .05$) whereas the correlation between PPO and 505 Agility Test approached significance (r = -0.295, $p = .057$). Significant positive relationships were found between BMI and 505 Agility Test (r = 0.394, $p < .05$) and PPO and BMI (r = 0.416, $p < .05$). A significant negative relationship occurred between PPO and years of training (r = -0.395, $p < .05$). However, all other correlations were not statistically significant. When combined, BMI, years of training, PPO and reaction time explained more variability in agility scores than each variable alone. Reaction time did not contribute significantly to predicting agility scores, explaining only 0.1% of the variance in Agility T-Test scores and 2.3% of the variance in 505 Agility Test scores. Body mass index, years of training, power and reaction time together are the best predictors of Agility T-Test and 505 Agility Test.

Chapter 5

DISCUSSION

It is well established that agility scores are related individually to years of sport-specific training (Mujika et al., 2009), BMI (Mujika et al., 2009; Nimphius et al., 2009; Shultz et al., 2001), power (Djevalikian, 1993; Myer et al., 2005; Pauole et al., 2000; Shultz et al., 2001; Sporis et al., 2010; Young et al., 2002) and reaction time (Linford et al., 2006; Shaji & Saluja, 2009; Wojtys et al., 1996). These studies focused on the relationship between one factor or variable and agility, whereas the present study sought to identify the influence of several variables, collectively, on agility. This chapter includes discussion of the following: a) body size and agility, b) sport-specific training and agility, c) power and agility, d) reaction time and agility, e) body size, sport-specific training, power, reaction time and agility and f) summary.

Body Size and Agility

One might expect that body size and agility are highly related; however, the relationship between body size and agility is not clear. Webb and Lander (1983) measured body fat in rugby players and reported a weak correlation ($r = 0.21$, $p < .05$) between body fat and speed of change of direction. In contrast, Nimphius et al. (2010) measured body weight of female softball players and reported that body weight and 505 Agility Test score shared a moderate to strong correlation ($r = 0.71$, $p < .05$). The present study reported a moderate correlation between BMI and 505 Agility Test, this correlation was lower than the correlation reported by Nimphius et al. (2010) and was stronger than the correlation reported by Webb and Lander (1983). This discrepancy in correlations may be due to differences in the athletic populations and/or different measurements of body size. For example, the lack of significant correlation between body fat and agility in rugby players (Webb & Lander, 1983) may be attributed to the homogeneity of body fat that has been found across positions within the same level of rugby player (e.g. amateur versus professional players) (Gabbett, 2000). The strong correlation between body weight and time to complete the agility test in female softball players may be due to superior ability of smaller sized athletes to attain high speed, change directions quickly and possess high relative strength (Nimphius et al., 2010). In the present study of tennis players, a moderate correlation between BMI and time to complete the 505 Agility Test, may be due to higher body mass, similar to the findings of Nimphius et al. (2010), implying that smaller athletes take less time to complete the 505 Agility Test. However, the moderate correlation between BMI and time to complete the 505 Agility Test may also be due to differences in body composition that is, lean muscle mass and body fat. Without specific measurements of lean body mass and fat percentage, it is impossible to attribute the correlation to one specific variable.

The present study found that BMI was significantly correlated to 505 Agility Test alone and not to Agility T-Test. The correlation between BMI and 505 Agility Test may be because the 505 Agility Test could be more highly associated with the ability to attain high/fast speed compared to the Agility T-Test. Since a smaller body size is related to speed (Gabett, 2000; Nimphius et al., 2010), this may explain the stronger correlation of BMI and 505 Agility Test in the study.

Tennis Training and Agility

In a study of fitness determinants of success in men’s and women’s football, Mujika et al. (2009) suggested an association between sport-specific training and agility;

although they did not explicitly examine the correlation between sport-specific training and agility. However, in the present study, years of sport-specific training did not reveal a meaningful correlation between tennis training and agility. The difference between these two studies may be related to the calculation of 'years of training'. In the present study, years of tennis training was measured as years that the participants trained under a tennis coach or a professional tennis player. It was assumed that years of training under a coach would relate to years of experience performing agility-type activities that are part of tennis training. However not all participants may have undergone agility training as part of their tennis training. They may have only performed agility type motions as part of their tennis practice and not as part of additional drills or training. Thus, years of tennis training may not be an accurate indicator of actual agility training experience. This may better be understood by the following example: A participant with five years of training could have simultaneously trained for tennis and agility, while a person with five years of tennis training may have undergone agility training for only two years. So in the first case, sport training was five years, and agility training was five years; but, in the second case tennis training was five years, and agility training was two years. Thus sport-specific training alone may not have been a precise measure of agility training.

Years of sport-specific training was related to participant's age. However, as a player gets older, at some point the player is past their prime; physical performance decreases which explains the decline in performance past optimal age. In this study, the correlation between age and agility was not examined as the participant group was fairly homogenous in age (22 players were between the ages of 18 to 22) and young enough to be nearing their prime. So sport-specific training in reality consisted of tennis training, not age and experience.

Power and Agility

It is well known that power is correlated to agility (Djevalikian, 1993; Pauole et al., 2000; Young et al., 2002). Djevalikian (1993) examined the relationship between asymmetrical leg power and change of running direction, and reported a significant correlation between power and agility (r = 0.42, $p < .05$). Pauole et al. (2000) also reported moderate correlations (r = -0.49, $p < .05$ for males and r = -0.55, $p < .05$ for females) between power and agility. Further, Young et al. (2002) reported a similar correlation between power and agility time (r = -0.47, $p > .05$). Similar to this previous research, the present study reported a significant correlation between power and time on Agility T-Test, but not between power and time on 505 Agility Test (r = -0.30, $p = .057$). However, a larger sample size may have yielded a significant correlation between power and 505 Agility Test. Or, since each change in direction is comprised of acceleration and deceleration phases, and the ability to accelerate depends on power output (Halberg, 2001; Mayhew et al., 1989); the fewer changes of direction in the 505 Agility Test may be the cause for the lower correlation with power. In contrast, the Agility T-Test with more changes of direction, has more acceleration phases and thus possibly the reason for the higher correlation with power.

Interestingly, in addition to the negative correlation between time on agility test and power (in other words positive correlation between agility performance and power), power also shared a positive correlation with BMI. That is, as BMI increased, power output increased. However, the findings of the present study also suggest that as BMI increased, agility performance decreased, which seems counterintuitive. This finding (positive correlation between power and BMI) could be due to the influence of body mass or weight on power. In this study, an absolute value of power output was recorded; since power was measured from ground reaction force (GRF), which was influenced by body weight (BW), a higher absolute power output could be a result of greater BW. In future studies it may be prudent to investigate relationship between relative power output and agility and BMI.

As was done in the present study, several previous studies used a vertical jump test as a measure of power (Çankaya, 2012; Sporis et al., 2010; Shaji & Saluja, 2009; Young et al., 1996; Young et al., 2002), although, Sporis et al. (2010) included eight other measures of power in addition to vertical jump test. The vertical jump test in the aforementioned studies and the present study utilized a two legged take-off, which may not be the best predictor of agility because the vertical jump test is a bilateral task, whereas agility tests involve unilateral movements (changing direction where one foot follows another foot). No study to date has compared the results of single leg vertical jump power output versus the bilateral vertical jump power output and their relationships to agility. Agility scores may also be affected by initiating an agility task with the dominant side or the non-dominant side or the number of turns versus non-directional changes (where an individual can initiate with any side according to their own preference, irrespective of their dominant side) in the agility test (Green et al., 2011). For example, agility scores are different when a right-side dominant individual turns with the right foot versus the left foot.

In the present study, a strong correlation was found between Agility T-Test and 505 Agility Test. The Agility T-Test and 505 Agility Test were highly correlated since these were both designed to measure agility scores. However, the non perfect correlation between Agility T-Test and 505 Agility Test may be due to a difference in the number of changes in direction. The Agility T-Test requires four (90 degree) changes in direction whereas, the 505 Agility Test required one (180 degree) change in direction. The Agility T-Test also included sideways and backward movement while 505 Agility Test is entirely forward running.

Reaction Time and Agility

The reaction times reported in the present study were comparable to reaction times reported elsewhere for college-aged males and females (Brebner & Welford, 1980; Galton, 1899; Welford, 1980). No previous study has examined the relationship between reaction time and agility, although Wojtys et al. (1996) reported faster reaction time in an agility-training group, compared to other groups (isokinetic- strength trained, isotonic-strength trained and control groups- activities of daily living). The study conducted by Wojtys et al. (1996) is the only study to report an improvement in reaction time following agility training. However, in contrast, the present study did not report a significant correlation between reaction time and agility. The discrepancy between the two studies may be due to the fact that Wojtys et al. (1996) conducted a training study, whereas the present study was a correlational study. That is, Wojtys et al. (1996) studied the effects of training on reaction time, and the present study examined the correlation between reaction time and agility.

Age is another factor that may have influenced the correlation between reaction time and agility. Reaction time is widely affected by age (Luchies et al., 2002). Reaction time improves (shortens) from infancy until the late 20s, then gradually slows until the late 50s and 60s. Reaction time slows at a faster rate through the 70s and beyond (Der & Deary, 2006; Jevas &Yan, 2001; Luchies et al., 2002; Rose, Feldman, Jankowski, & Caro, 2002; Welford, 1977). It is unlikely that the range of participant ages would have a large effect on reaction time in this study given the homogeneity of the sample, but since the relationship between age and agility is not clearly understood, it is difficult to determine.

Body Size, Sport-Specific Training, Power, Reaction Time and Agility

No previous study has examined the combined effects of body size, sport-specific training, power, reaction time and agility; thus making this study unique. Each variable namely, body size, sport-specific training, power and reaction time contributed some amount in predicting agility in both Agility T-Test and 505 Agility Test. Reaction time accounted for the least amount of variance in predicting agility and BMI contributed the most in predicting agility for both the Agility T-Test and 505 Agility Test. It is likely that reaction time adds little to the predictive power of agility because the influence of reaction time in an agility test is very small compared to the duration of sprint involved in an agility test. Also the tests used to measure agility in this study were simple agility tests; the participants did not have to react to stimuli during the agility tests. However, Çankaya (2012) found that power (vertical jump) is strongly related to reaction time in wrestlers, and previous studies show that power is strongly correlated to reactive agility (Djevalikian, 1993; Halberg, 2001). Thus reaction time was expected to be correlated to agility. Moreover, researchers reported improvements in reaction time with agility-type training. Specifically, Linford et al. (2006) reported improvements in reaction time to strength, power and agility in physically active college-age subjects undergoing a six week neuromuscular training. Wojtys et al. (1996) reported a decrease in reaction time in an agility group compared to isokinetic, isotonic or control groups. These studies further support a link between reaction time and agility.

Despite the small positive relationship between BMI and 505 Agility Test score, BMI was positively related to power, and power was negatively related to agility score. Thus it was likely that as BMI increased, power output increased, which increased agility test time as shown by the prediction equations. However, BMI is not a perfect predictor of power; in fact many studies have shown a negative relationship between BMI and power (Nimphius et al., 2010). It is likely that BMI and power were positively related in this study because this study recorded an absolute value of power output and BMI was likely more directly related to body weight not body composition. Power was measured from ground reaction force (GRF) which was influenced by body weight (BW). A higher absolute power output could be a result of greater BW. In addition to BMI, other factors that are likely to be related to power output are muscular strength and neuromuscular training. Muscular strength is likely also related to agility (Djevalikian, 1993) but neuromuscular factors are unlikely to be related to BMI. Thus including power and BMI in the model accounts for a major part of the variance in predicting agility scores. Given other factors that are related to BMI and power, such as strength, lean body mass, and total mass, future studies could examine these additional factors that may affect agility.

Summary

It is well established that agility performance is related individually, to years of sport-specific training (Mujika et al., 2009), body size (Webb & Lander, 1983; Nimphius, McGuigan, & Newton, 2010), power (Djevalikian, 1993; Sporis et al., 2010) and reaction time (Linford et al., 2006; Wojtys et al., 1996). Previous research focused on the relationship of one factor or variable with agility, but the present study sought to examine the contribution of several combined factors to predict agility. Years of tennis training, BMI, power and reaction time collectively were expected to more accurately predict agility performance compared to a single variable. This study reported that reaction time and power when considered together along with years of sport-specific training and BMI are better predictors of agility compared to each variable alone.

Chapter 6

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the relationships between body size, training time and performance indices of agility to identify the best predictor(s) of agility. To that end, 30 college-aged tennis players (males=22, females=8) completed the Vertical Jump Test (power test), Reaction Time Test, Agility T-Test and 505 Agility Test. Power and reaction time were measured using AMTI force plates and Labview software and the agility scores were measured using a Smartspeed^{TM} Timing System.

Pearson correlation and multiple regression analyses were used to assess the relationships of all variables with the two agility scores (Agility T-Test and 505 Agility Test). Analyses showed a significant correlation between PPO and Agility T-Test; PPO and years of training; BMI and 505 Agility Test and PPO and BMI ($p < .05$). A negative correlation approached statistical significance between PPO and 505 Agility Test ($p = .057$). Multiple regression analyses were utilized to determine the contribution of the variables like: BMI, years of sport-specific training, PPO and reaction time in predicting agility scores, and also to determine the best predictor(s) of agility.

Conclusions

Based on the analyses, power, reaction time, BMI and years of sport-specific training predicted the Agility T-Test and 505 Agility Test scores better than each variable alone.

The results of this study yielded the following conclusions:

1. Years of sport-specific training and reaction time, individually, did not correlate significantly to agility scores.
2. Power and BMI, individually, correlated significantly to agility scores.
3. BMI, years of training, PPO and reaction time, collectively, were stronger predictors of Agility T-Test and 505 Agility Test, than these variables individually.

Recommendations

Body mass index (BMI) and power, collectively, may be useful predictors of agility of individuals when selecting a team. Future research should investigate this relationship using multiple power tests and reactive agility tests. In the future, this information may prove valuable to trainers and coaches who may be able to target specific predictor(s) to improve agility and sport performance. Thus, the following are recommended for further study:

1. Utilize multiple power tests to determine what type of power test best predicts agility.
2. Examine if body mass, height or muscle mass alter agility performance.
3. Determine the effectiveness of BMI, years of training, power and reaction time in predicting agility in sports other than tennis.
4. Determine the effectiveness of BMI, years of training, power and reaction time in predicting agility across genders.

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APPENDICES

APPENDIX A

Informed Consent Form

Physical and performance correlates of agility

1. Purpose of the Study: The purpose of this study is to evaluate the relationship of power, reaction time, anthropometric characteristics, years of sport-specific training and gender, to simple agility measured in tennis players.

2. Benefits: You will benefit from participating in the study because you will learn your agility score. If you choose to receive the results you may learn how to enhance your agility, which may help you to improve your performance. You will also get first hand experience on how scientific data are collected. Lastly, it is hoped that the data generated will benefit the scientific community.

3. Your Participation requires you to perform tests of agility and vertical jump on the testing day. All tests will be in the Biomechanics Laboratory in CHS 308 and the corridor at Ithaca College. Before the test, you will be given written instructions on how to come prepared for it. You will also be asked to complete a health history questionnaire. It is possible that you may be excluded from exercising if health risks are identified in this questionnaire such as previous or current injury. The physical tests are an Agility T-test, 505 Agility Test, Vertical Jump Test and Reaction Time Test. Each test is completed 2-3 times, interspersed by 1-2 minutes of rest period. Total time for the physical test is about 20 minutes. Physical tests will be preceded by a five minute warm-up which will consist of low intensity forward, backward and sideway run. Total participation time for each session is about 30 min.

4. Risks of Participation: Agility tests are usually part of training for tennis. The risks associated with this study are the same as the risks you endure everyday during practice which includes skeletal muscle injury or soreness. The risk of skeletal muscle injury and soreness are minimal. We are further minimizing these risks by having you warm-up before each session. If you feel poorly during the test, you may terminate it at any time. In the event that there is an injury, standard first aid procedures will be promptly administered by me (Himani Sood), who has a physical therapy license from India.

5. Compensation for Injury: If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost of such care is your responsibility. If you have insurance, you may bill your insurance company. Ithaca College and the investigator will not pay for any care, lost wages, or provide other compensation.

Initials:____________

6. If you would like more information about this study at anytime prior to, during, or following the data collection, you may contact Himani Sood at hsood1@ithaca.edu or 832.360.6396.

7. Withdrawal from the study: Participation in this study is voluntary and you may withdraw at any time if you so choose. You will not be penalized for withdrawing.

8. Confidentiality: Information gathered during this study will be maintained in complete confidence. Only the researcher will have access to this information, which will be stored in a locked cabinet or on password protected computer. You and your name will never be associated with this information in any future disclosures. To further ensure confidentiality, all files will be number coded and data collection instruments will be kept separately from Informed Consent Forms.

I have read and understood the above document. I agree to participate in this study and realize that I can withdraw at anytime. I also understand that I can and should address questions related to this study at any time to any of the researchers involved. I also verify that I am at least 18 years of age.

____

Your Name (please print)

____

Your Signature Date

Parent/Guardian Informed Consent Form

Physical and performance correlates of agility

1. Purpose of the Study: The purpose of this study is to evaluate the relationship of power, reaction time, anthropometric characteristics, years of sport-specific training and gender, to simple agility measured in tennis players.

2. Benefits: Your child will benefit from participating in the study because you will learn your agility score. If you choose to receive the results your child may learn how to enhance their agility, which may help with improving your child's performance. Your child will also get first hand experience on how scientific data are collected. Last, it is hoped that the data generated will benefit the scientific community.

3. Your Participation requires your child to be at least 15 (should be 18 as mentioned on page 60) Syears of age, and able to perform tests of agility and vertical jump on testing day. All tests will be in the Biomechanics Laboratory in CHS 308 and corridor at Ithaca College. Before the test, your child will be given written instructions on how to come prepared for it. Your child will also be asked to complete a health history questionnaire. It is possible that your child may be excluded from exercising if health risks are identified in this questionnaire such as previous or current injury. The physical tests are an Agility T-test, 505 Agility Test, Vertical Jump Test and Reaction Time Test. Each test is completed 2-3 times, interspersed by 1-2 minutes of rest period. Total time for the physical test is about 20 minutes. Physical tests will be preceded by a five minute warm-up which will consist of low intensity forward, backward and sideway run. Total participation time for each session is about 30 min.

4. Risks of Participation: Agility tests are usually part of training for tennis. The risks associated with this study are the same as the risks your child endures everyday during practice which includes skeletal muscle injury or soreness. The risk of skeletal muscle injury and soreness are minimal. We are further minimizing these risks by having your child warm-up before each session. If your child feels poorly during the test, he/she may terminate it at any time. In the event that there is an injury, standard first aid procedures will be promptly administered by me (Himani Sood), who has a physical therapy license from India.

5. Compensation for Injury: If your child suffers an injury that requires any treatment or hospitalization as a direct result of this study, the cost of such care is your responsibility. If your child has insurance, you may bill your insurance company. Ithaca College and the investigator will not pay for any care, lost wages, or provide other compensation.

Initials:______

6. If you would like more information about this study at anytime prior to, during, or following the data collection, you or your child may contact Himani Sood at hsood1@ithaca.edu or 832.360.6396.

7. Withdrawal from the study: Participation in this study is voluntary and your child may withdraw at any time if you so choose. Your child will not be penalized for withdrawing.

8. Confidentiality: Information gathered during this study will be maintained in complete confidence. Only the researcher will have access to this information, which will be stored in a locked cabinet or on password protected computer. Your child and your child's name will never be associated with this information in any future disclosures. To further insure confidentiality, all files will be number coded and data collection instruments will be kept separately from Informed Consent Forms.

I have read and understood the above document. I give consent for my child to participate in the study. I also understand that I can and should address questions related to this study at any time to any of the researchers involved.

____

Your Name (please print)

____

Your Signature Date

Minor's Form

Physical and performance correlates of agility

1. Purpose of the Study: The purpose of this study is to evaluate the relationship of power, reaction time, anthropometric characteristics, years of sport-specific training and gender, to simple agility measured in tennis players.

2. Benefits: You will benefit from participating in the study because you will learn your agility score. If you choose to receive the results you may learn how to enhance their agility, which may help with improving your child's performance. You will also get first hand experience on how scientific data are collected. Lastly, it is hoped that the data generated will benefit the scientific community.

3. Your Participation requires you to be at least 15 years of age, and able to perform tests of agility and vertical jump on testing day. All tests will be in the Biomechanics Laboratory in CHS 308 and corridor at Ithaca College. Before the test, you will be given written instructions on how to come prepared for it. You will also be asked to complete a health history questionnaire. It is possible that you may be excluded from exercising if health risks are identified in this questionnaire such as previous or current injury. The physical tests are an Agility T-test, 505, Agility Test, Vertical Jump Test and Reaction Time Test. Each test is completed 2-3 times, interspersed by 1-2 minutes of rest period. Total time for the physical test is about 20 minutes. Physical tests will be preceded by a five minute warm-up which will consist of low intensity forward, backward and sideway run. Total participation time for each session is about 30 min.

4. Risks of Participation: Agility tests are usually part of training for tennis. The risks associated with this study are the same as the risks you endure everyday during practice which includes skeletal muscle injury or soreness. The risk of skeletal muscle injury and soreness are minimal. We are further minimizing these risks by having you warm-up before each session. If you feel poorly during the test, you may terminate it at any time. In the event that there is an injury, standard first aid procedures will be promptly administered by me (Himani Sood), who has a physical therapy license from India.

5. Compensation for Injury: If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost of such care is your responsibility. If you have insurance, you may bill your insurance company. Ithaca College and the investigator will not pay for any care, lost wages, or provide other compensation.

Initials:______

6. If you would like more information about this study at anytime prior to, during, or following the data collection, you may contact Himani Sood at hsood1@ithaca.edu or 832.360.6396.

7. Withdrawal from the study: Participation in this study is voluntary and you may withdraw at any time if you so choose. You will not be penalized for withdrawing.

8. Confidentiality: Information gathered during this study will be maintained in complete confidence. Only the researcher will have access to this information, which will be stored in a locked cabinet or on password protected computer. You and your name will never be associated with this information in any future disclosures. To further insure confidentiality, all files will be number coded and data collection instruments will be kept separately from Informed Consent Forms.

I have read and understood the above document and I agree to participate in this study and realize that I can withdraw at anytime. I also understand that I can and should address questions related to this study at any time to any of the researchers involved.

____
Your Name (please print)

____
Your Signature Date

APPENDIX B

24-Hour Health History Questionnaire

Name: ________________________________ Date: ____________________

Current Health Status (please check all that apply)

[ ] Nausea	[ ] Sore Throat	[ ] Headache
[ ] Body Ache	[ ] Chills	[ ] Lethargy
[ ] Nasal Drip	[ ] Cramping	[ ] Muscle Aches
[ ] Chest Pain	[ ] Shortness of Breath	[ ] Dizziness

If female, date of last period ____

Diet

Have you consumed alcohol in the last 12 hours? [ ] Yes [ ] No

Have you used caffeine or nicotine in the last three hours? [ ] Yes [ ] No

Did you eat any food in the last three hours? [ ] Yes [ ] No

If so, please list:

Exercise

Have you exercised in the last 24 hours? [ ] Yes [ ] No

If so, please describe:

Over-the-Counter and/or Prescription Drug Use

Have you taken any over the counter drugs (e.g., cold meds) in the last 24 hours?
[ ] Yes [ ] No

Has there been any change in your use of prescription drugs? [ ] Yes [ ] No

If so, please explain:

Injury

Have you experienced any physical pain in the last 24 hours? [ ] Yes [ ] No

If so, please explain:

Is there any physical injury we should know about before you perform the test?
[ ] Yes [ ] No

If so, please explain:

Sleep Pattern:

Do you feel drowsy, tired, or run down at this time? [ ] Yes [ ] No

If so, please describe:

Other questions/comments/concerns please state below.

APPENDIX C

Agility Data Collection

Name: ______________________________

Age: __________

Gender: __________

Mass: __________

Height: __________

BMI: __________

Years of tennis training: __________

Checklist		Trial 1	Trial 2
Informed consent	________		
24-Hour Health History	________		
Agility T-Test		_________	_________
505 Agility Test		_________	_________
Vertical Jump Test		_________	________
Reaction Time Test		_________	_________

APPENDIX D

Raw Data

Age	Gender	BMI	Wt (Kg)	Ht (m)	Yrs of training	T-test (sec)	505 (sec)	PPO (W)	Reaction time (ms)
22	M	20.45	68.40	1.83	5	9.992	2.198	2372	122
21	M	24.29	80.10	1.82	10	10.44	2.619	2153	105
19	F	21.12	63.00	1.73	6	10.728	2.71	1579	266
19	M	27.76	79.20	1.69	6	11.647	2.67	1733	144
18	M	20.19	57.60	1.69	4	9.15	2.288	2619	165
18	M	19.63	60.30	1.75	2	10.558	2.57	1948	306
18	F	23.53	61.20	1.61	5	12.455	2.769	1420	165
18	F	18.25	51.30	1.68	6	11.492	2.74	1381	251
22	F	19.64	62.10	1.78	11	11.63	2.589	1295	110
18	M	21.02	74.25	1.88	1	9.307	2.118	1958	174
18	M	26.54	90.00	1.84	2.5	10.327	2.573	3443	284
19	M	21.98	67.50	1.75	7	8.479	2.152	2357	203
20	M	22.70	89.10	1.98	9	8.802	2.228	3428	287
27	M	28.71	88.20	1.75	13	9.878	2.449	2342	165
24	M	25.62	81.00	1.78	6	10.836	2.596	2012	208
19	M	24.21	83.25	1.85	8	10.811	2.732	2335	224
20	M	24.22	81.00	1.83	9	9.266	2.41	3100	196
20	M	23.23	69.30	1.73	7	10.105	2.463	2146	165
19	F	21.39	65.70	1.75	10	12.872	3.03	1043	223
22	M	31.94	98.10	1.75	1	11.76	3.106	2992	305
21	F	20.80	56.70	1.65	8	10.34	2.353	2472	190
20	M	28.78	93.60	1.80	3	10.552	2.795	3118	182
21	M	21.12	63.00	1.73	6	11.249	2.367	1249	194
30	M	26.33	83.25	1.78	13	10.756	2.42	1607	320
39	M	25.64	78.75	1.75	5	12.54	2.864	1905	114
33	M	20.06	65.25	1.80	11	10.293	2.459	1462	131
35	F	24.60	63.00	1.60	10	12.253	2.822	998	173
22	F	19.96	49.50	1.57	12	10.455	2.546	1504	237
23	M	24.20	76.50	1.78	2	9.255	2.133	3278	195
35	M	25.64	74.25	1.70	1	12.56	2.898	2247	238

APPENDIX E

ANOVA Tables

ANOVA[e]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.359	1	1.359	.983	.330[a]
	Residual	38.700	28	1.382		
	Total	40.059	29			
2	Regression	1.361	2	.680	.475	.627[b]
	Residual	38.699	27	1.433		
	Total	40.059	29			
3	Regression	25.569	3	8.523	15.293	.000[c]
	Residual	14.490	26	.557		
	Total	40.059	29			
4	Regression	25.638	4	6.410	11.111	.000[d]
	Residual	14.421	25	.577		
	Total	40.059	29			

a. Predictors: (Constant), BMI

b. Predictors: (Constant), BMI, Yrs of training

c. Predictors: (Constant), BMI, Yrs of training, PPO (W)

d. Predictors: (Constant), BMI, Yrs of training, PPO (W), Reaction time (ms)

e. Dependent Variable: T-test (sec)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.614	1	13.614	14.415	.001[a]
	Residual	26.445	28	.944		
	Total	40.059	29			

a. Predictors: (Constant), PPO (W)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.614	1	13.614	14.415	.001[a]
	Residual	26.445	28	.944		
	Total	40.059	29			

a. Predictors: (Constant), PPO (W)

b. Dependent Variable: T-test (sec)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.055	1	.055	.038	.846[a]
	Residual	40.005	28	1.429		
	Total	40.059	29			

a. Predictors: (Constant), Reaction time (ms)

b. Dependent Variable: T-test (sec)

ANOVA[e]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.311	1	.311	5.133	.031[a]
	Residual	1.698	28	.061		
	Total	2.009	29			
2	Regression	.311	2	.156	2.476	.103[b]
	Residual	1.698	27	.063		
	Total	2.009	29			
3	Regression	.908	3	.303	7.142	.001[c]
	Residual	1.101	26	.042		
	Total	2.009	29			
4	Regression	.968	4	.242	5.812	.002[d]
	Residual	1.041	25	.042		
	Total	2.009	29			

a. Predictors: (Constant), BMI

b. Predictors: (Constant), BMI, Yrs of training

c. Predictors: (Constant), BMI, Yrs of training, PPO (W)

d. Predictors: (Constant), BMI, Yrs of training, PPO (W), Reaction time (ms)

e. Dependent Variable: 505(sec)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.175	1	.175	2.674	.113[a]
	Residual	1.834	28	.065		
	Total	2.009	29			

a. Predictors: (Constant), PPO (W)

b. Dependent Variable: 505(sec)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.045	1	.045	.645	.429[a]
	Residual	1.964	28	.070		
	Total	2.009	29			

a. Predictors: (Constant), Reaction time (ms)

b. Dependent Variable: 505(sec)

ANOVA[d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.311	1	.311	5.133	.031[a]
	Residual	1.698	28	.061		
	Total	2.009	29			
2	Regression	.311	2	.156	2.476	.103[b]
	Residual	1.698	27	.063		
	Total	2.009	29			
3	Regression	.908	3	.303	7.142	.001[c]
	Residual	1.101	26	.042		
	Total	2.009	29			

a. Predictors: (Constant), BMI

b. Predictors: (Constant), BMI, Yrs of training

c. Predictors: (Constant), BMI, Yrs of training, PPO (W)

d. Dependent Variable: 505(sec)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.311	1	.311	5.133	.031[a]
	Residual	1.698	28	.061		
	Total	2.009	29			

a. Predictors: (Constant), BMI

b. Dependent Variable: 505(sec)