# Movement and skill adaptability: A novel approach to talent identification and development in tennis

Aaron William Potter

Bachelor of Applied Science (Human Movement) (Honours)

Institute of Sport, Exercise and Active Living

College of Sport and Exercise Science, Victoria University

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# Abstract

Tennis at the elite level is a sport that is intermittent in nature and requires proficiency across a number of key performance attributes; physical, technical, tactical and psychological (Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009; Hornery, Farrow, Mujika, & Young, 2007a; Kovacs, 2006, 2007; Unierzyski, 2002). The diverse skill set required for success in tennis poses a problem for practitioners attempting to identify and develop talent at an early age. The current methods of talent identification in tennis are largely based on ranking and tournament results despite reported low success rates (Brouwers, De Bosscher, & Sotiriadou, 2012). These methods represent an evaluation of current performance, often overlooking the capacity for further development, which is essential in any talent identification/development program (Martindale, Collins, & Daubney, 2005). Movement and skill adaptability (used interchangeably with the term adaptability herein) is an individual's ability to acutely adjust their performance based on the changing constraints within the performance environment (Martin, Nejad, Colmar, & Liem, 2012; Newell, 1986). This definition has merit for use in tennis as optimal performance requires a player must be able to acutely modify their game in relation to the changing stimuli. Adaptability is relevant for talent identification purposes as it is representative of the dynamic, unpredictable nature of the sporting environment. To progress from a theoretical concept, development of adaptability metrics is required combined with evidence of its impact as a training mechanism.

Therefore, two novel measures of adaptability; the throwing and rebound task (TRT) and the continuous rebounding task (CRT) were created. Construct and

face validity of both tasks was established, as was reliability via a test-retest method. Adaptability explained a higher percentage of tennis performance (assessed via a volley test), when compared to anthropometric, maturation, physical performance and general motor skill variables. This demonstrates the importance of adaptability in junior tennis performance. In contrast to the volley test, coaches' subjective stroke evaluation reported no significant relationships. Adaptability was compared to a conventional tennis training program, with both groups reporting significant improvement on a number of variables (best TRT, average TRT, sum CRT, KörperKoordinations Test Für Kinder [KTK] and forehand stroke evaluation). Importantly, only the adaptability group improved on a timed, tennis-specific accuracy task and reported higher levels of enjoyment than the conventional tennis training group. These findings provide evidence for potential inclusion of the TRT and CRT into tennis talent identification programs. Additionally, the importance of adaptability as a theoretical construct which can develop junior players has been established. More broadly, the theoretical concepts underpinning adaptability as a testing mechanism (TRT and CRT) and training method could be applied to other sports where time constrained perception-action is required.

# Student Declaration

I, Aaron William Potter, declare that the PhD thesis entitled "Movement and skill adaptability: A novel approach to talent identification and development in tennis" is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: [redacted] Date: August 31st, 2017

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# List of Publications

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## Conference Presentations

Potter, A., Berry, J., & Zois, J. (2015, June). *Development of a novel skill adaptability test for talent identification in tennis*. 20$^{th}$ Annual Congress of the European College of Sport Science, Malmö, Sweden.

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| | |
|---|---|
| TRT | Throwing and rebound task |
| CRT | Continuous rebounding task |
| TI | Talent identification |
| AFL | Australian Rules Football |
| ATP | Association of Tennis Professionals |
| WTA | Women's Tennis Association\ |
| TD | Talent development |
| KTK | KörperKoordinations Test Für Kinder |
| FTEM | Foundations, Talent, Elite, Mastery model |
| DMSP | Development Model of Sports Participation |
| CGS | Centimetres, grams and seconds sports |
| ITF | International Tennis Federation |
| LTAD | Long Term Athlete Development model |
| CI | Contextual interference |
| PHV | Peak height velocity |
| HRE | Human research ethics |
| PACES | Physical Activity Enjoyment Scale |

# Chapter 1. Introduction

Talent identification (TI) in tennis is currently confined to tennis (e.g. rankings, match results) and physical performance measures (e.g. 20m sprint) (Brouwers et al., 2012; Miley & Nesbitt, 1995; Phillips, Davids, Renshaw, & Portus, 2010b; Reid, Crespo, & Santilli, 2009; Reid, Crespo, Santilli, Miley, & Dimmock, 2007; Reid & Morris, 2013; Vergauwen, Spaepen, Lefevre, & Hespel, 1998). In Australia, there are detailed criteria specifying the ranking, tournament result or participation level that you must achieve to be eligible for a support scholarship ("Athlete development scholarship criteria," 2015). The governing bodies of tennis in the U.S.A and UK operate similar policies selecting children less than 12 years of age for advanced training programs based on their competitive tennis playing ability (Pankhurst & Collins, 2013). The efficacy of this approach can now be questioned with research suggesting junior rankings and results only accounting for ~4-13% of professional ranking variance (Brouwers et al., 2012; Reid et al., 2009; Reid, Crespo, Santilli, et al., 2007).

The majority of research has been conducted with populations with a maximum age of 18 years. Athletes approaching 18 years of age would be preparing for the transition to senior competition and therefore, due to the closer time proximity, it would be expected that these results are reporting the maximum influence of rankings. Extending this theory to a younger cohort, a decrease in the effectiveness of rankings (<4-13%) would be the expected outcome due to the larger time difference. Currently, there is a dislocation between research and practice where by TI processes in the field are conducted with younger cohorts (<12 years old) despite the research base being performed with older junior athletes (17-18 years of age) (Bastieans, 2006; Pankhurst, 2013). An underlying assumption of current TI processes, (which lacks support in the literature) is attributes required for senior and junior success are the same (Morris, 2000). In tennis, this assumption is unsupported as the factors discriminating athletes at junior level (experience and maturation) and senior level are very different (service and return outcomes) (Ma, Liu, Tan, & Ma, 2013; Unierzyski, 2002). Therefore, the aim of this thesis was to provide an alternative method of talent identification in tennis for a junior population (<12 years of age) that is not underpinned by current tennis performance.

The most influential variables on junior tennis performance are not well understood. Current research is conflicting, advocating the importance of a number of variables (e.g. tennis-specific, physical, and perceptual). A systematic review reported perceptual abilities and co-ordination skills discriminated between elite and non-elite populations whereas physical attributes returned conflicting findings, preventing any conclusion on their influence (Faber, Bustin, Oosterveld, Elferink-Gemser, & Nijhuis-Van der Sanden, 2016). Serve velocity and medicine ball throw yielded the strongest correlations when attempting to discriminate between competitive tennis level and a number of physical and tennis variables (e.g. anthropometric, 20m sprint and serve velocity) (Ulbricht, Fernandez-Fernandez, Mendez-Villanueva, & Ferrauti, 2016). Serve velocity and medicine ball throw in association with the hit and turn tennis test, discriminated between national and regional level players (Ulbricht et al., 2016).

The hexagon text, a test measuring agility and speed was correlated to sectional rankings, whilst stroke ratings and physical tests (1.5 mile run, vertical jump, grip strength, push ups, sit and reach) yielded no significant correlations (Roetert, Garrett, Brown, & Camaione, 1992). Agility was the most influential variable explaining 8% of the sectional ranking despite not being relevant for national rankings, whilst the forehand tennis stroke rating explained 47% of the variance in national rankings between the 8-12 year olds (Roetert et al., 1992). A test battery containing speed, agility, strength and flexibility measures correctly classified 91.5% of junior tennis players into their respective level (national, development camp, area training centre) (Roetert, Brown, Piorkowski, & Woods, 1996).

It is evident that due to the varied and conflicting results, no strong conclusions can be drawn from this research on the influential variables for junior tennis performance. Additionally, the athletes in these studies had already been talent identified, as a result they have experienced greater training loads, been exposed to better coaching, and strength and conditioning programs. Therefore, are the reported differences a consequence of the talent identified participants' environment or an attribute that is crucial for junior tennis performance? Further research is required to clarify pertinent variables for junior tennis performance.

The development of sport expertise is a contentious issue with the two most reported development pathways, early sport specialisation and sport sampling advocating largely opposing viewpoints. Early sport specialisation encourages individuals to focus on one sport from a young age, therefore accumulating a greater number of sport-specific practice hours (Ericsson, Krampe, & Tesch-Romer, 1993; Mostafavifar, Best, & Myer, 2013). Detractors of this approach cite the increased risk of injury, burnout, early de-selection and decreased lifelong physical activity (Brenner, 2016; Mostafavifar et al., 2013).

In contrast, sport sampling promotes a period of multi-sport involvement providing a broad range of motor control experiences. A functional outcome of sport sampling is the potential reduction in sport-specific practice hours required for the development of expertise (Baker, Côté, & Abernethy, 2003). Beginner tennis players too often experience an early specialisation approach that is deficient in the multi-dimensional attributes (physical, technical, tactical, psychological) that are required for senior success (Gonzalez & Ochoa, 2003). Specialisation is not recommended before the age of 10 with a general (sport sampling) approach adopted prior (Balyi & Hamilton, 2003). It is evident that it is not only the accrual of practice hours that is necessary for the development of expertise but of equal importance is the type of practice undertaken (Baker et al., 2003; Williams & Ericsson, 2005). Future research should focus on how to optimise the development environment and the potential for an intermediary pathway that maximises the advantages of early sport specialisation (accrual of practice hours) and sport sampling (wide range of motor control experiences) whilst minimising the risks (e.g. burnout and less sport-specific practice, respectively).

Movement and skill adaptability is an individual's ability to acutely adjust their performance based on the changing constraints within the performance environment (Martin et al., 2012; Newell, 1986) and is hypothesised as a potentially beneficial addition to talent identification and development processes in tennis. This definition is applicable to tennis as to perform optimally a player must be constantly adjusting their skilled performance in relation to changing stimuli. Simultaneously, this definition is relevant for talent identification, as it represents the dynamic, unpredictable nature of sport. In contrast, many current TI processes decompose movements and skills (e.g. using closed isolated skills to identify or detect talent) (Lidor, Côté, & Hackfort, 2009; Vaeyens, Lenoir, Williams, & Philippaerts, 2008), therefore not providing the required level of perception-action coupling that is representative of the dynamic nature of sport (Davids, Araujo, Vilar, Renshaw, & Pinder, 2013; Lidor et al., 2009; Mann, Abernethy, & Farrow, 2010; Vaeyens et al., 2008).

The potential as a development tool is derived from the manipulation of constraints, either individual, task or environmental (Newell, 1986). In tennis, the manipulation of constraints (e.g. using an overweighted racquet, modified base of support or ball toss as a non-exhaustive list of examples) has reported positive results (Genevois, Frican, Creveaux, Hautier, & Rogowski, 2013; Hernandez-Davo, Urban, Sarabia, Juan-Recio, & Javier Moreno, 2014). These results are reinforced by the developmental histories of elite Australian Rules Football (AFL), cricket and soccer players who report unstructured, non-coached, varied forms of their sports as juniors (Araujo et al., 2010; Berry, Abernethy, & Côté, 2008; Phillips, Davids, Renshaw, & Portus, 2010a; Weissensteiner, Abernethy, & Farrow, 2009). These participants may have appeared to specialise early, however, the extreme variability in constraints they experienced allowed them to maximise the benefits of both early specialisation (accumulation of practice hours) and sport sampling (variety of motor control experiences). This thesis will investigate the potential for movement and skill adaptability to:

- better incorporate skill acquisition theories (constraints approach, play and practice) into TI where there are previously unsubstantiated
- serve as a valid and reliable testing mechanism for TI in tennis
- act as a developmental coaching tool for beginning tennis players
- contribute to a holistic model of learning and performance for junior tennis

# Chapter 2. Literature review

## 2.1 Overview of tennis performance

Tennis at the elite level is a sport that is intermittent in nature and requires proficiency integrated across a number of key performance attributes including, physical, technical, tactical, motor skill and psychological. This multifaceted nature of elite tennis is well established and is coupled with an extended duration of performance, potentially reaching >5 hours (Fernandez-Fernandez et al., 2009; Hornery et al., 2007a; Kovacs, 2006, 2007; Unierzyski, 2002). In the last 20 years tennis has evolved significantly due to increases in power, speed and strength of the players (Kovacs, 2007). Additionally, the uncertainty from week to week of competition calendars (e.g. unpredictable playing times and number of matches) provide a unique, ever changing set of variables that force athletes to be flexible.

### *2.1.1 Physical demands*

The physical demands of junior and senior tennis are significantly impacted by athletes repeatedly accelerating, decelerating, changing direction, maintaining balance and generating coordinated stroke play (Barber-Westin, Hermeto, & Noyes, 2010; Fernandez-Fernandez et al., 2009). The range of attributes required is reflected in large test batteries, as evidenced by Tennis Australia, who, when assessing players 10-16 years of age, include anthropometry, flexibility, speed, agility, leg power, upper body strength, aerobic endurance and anaerobic endurance testing (*National Academy Strength and Conditioning Test Protocols*, 2009). Professional tennis players have a $VO_{2max}$ of between 55-65 ml/min/kg (Banzer, Thiel, Rosenhagen, & Vogt, 2008; Smekal et al., 2001) with the average intensity of a tennis match ranging between 60-70% of $VO_{2max}$ (Konig et al., 2001). This relatively high level of aerobic fitness is required to maximize recovery periods (e.g. between rallies, games and sets) and allow for high-intensity, repeated anaerobic efforts (Fernandez-Fernandez et al., 2009; Kovacs, 2006, 2007; Smekal et al., 2001).

Multidirectional movement via varied forms of locomotion (e.g. side stepping, striding and shuffle steps) is required in tennis (Hughes & Meyers, 2005; Kovacs, 2006). Therefore, improving agility, balance and coordination (which underlies multidirectional movement) will increase the change of direction speed whilst maintaining control for the next shot (Parsons & Jones, 1998). These findings remain consistent when applied to a junior population, with agility discriminating between playing level across 2 separate studies (Elliot, Ackland, Blanksby, & Bloomfield, 1990; Roetert et al., 1992).

For both junior and senior populations, a number of additional factors including, court surface (grass vs. clay), playing style (attacking vs. baseline) and environmental conditions may impact the physical cost of a match (Fernandez-Fernandez, Mendez-Villanueva, Fernandez-Garcia, & Terrados, 2007; Fernandez-Fernandez et al., 2009; Kovacs, 2006, 2007; Smekal et al., 2001). As the physical cost of a match increases there is a resultant decrease in physical and technical skill performance, with this relationship being repeatedly demonstrated in the literature (Girard, Lattier, Micallef, & Millet, 2006; Hornery et al., 2007a; Hornery, Farrow, Mujika, & Young, 2007b; Kovacs, 2007). Whilst the importance of a professional tennis player's physical condition is well established, further examination is outside the scope of this thesis. A number of comprehensive reviews concentrating solely on the physical demands of tennis match play can be found elsewhere (Fernandez-Fernandez et al., 2009; Fernandez, Mendez-Villanueva, & Pluim, 2006; Kovacs, 2007).

### *2.1.2 Technical skills*

The development of technical skill in tennis has received less attention than the physical demands, largely being driven by accepted practice and anecdotal evidence (Reid, Crespo, Lay, & Berry, 2007). This lack of research focus is surprising as good technique/tennis skill has previously separated elite and high performing senior athletes (Landlinger, Lindinger, Stoggl, Wagner, & Muller, 2010) and is considered an influential attribute for talent identification (MacCurdy, 2006; Strecker, Foster, & Pascoe, 2011). For example, 47% of the variance in the national rankings of junior male tennis players was explained by their forehand tennis stroke rating (Roetert et al., 1992). Specifically, groundstroke velocity and not accuracy separated elite and high performing players (Landlinger, Stöggl, Lindinger, Wagner, & Müller, 2012). The timing of pelvis and trunk rotation were found to be critical factors in developing higher shoulder and racquet velocities (Landlinger et al., 2010). An increase in racquet head speed, the underlying mechanism for increased velocity of tennis strokes, is a constant technique based goal that players and coaches strive for. The development of correct technique in young players is crucial, with new research guiding a productive method to achieve this.

The use of modified equipment, such as low compression tennis balls, scaled courts and modified racquets are becoming more commonplace. This has a positive impact on technique development for junior tennis players, including elements that are essential for improving stroke velocity (Buszard, Farrow, Reid, & Masters, 2014; Hammond & Smith, 2006; Larson & Guggenheimer, 2013; Timmerman et al., 2015). Participants' (8 ± 0.4 years of age) who played on an adult sized court and used a standard tennis ball had significantly less hitting opportunities and a poorer success rate relative to the scaled court groups (Farrow & Reid, 2010). The increased success rate allowed junior players to not only further develop their technical skills but also their tactical skills.

### *2.1.3 Tactical abilities (including perceptual cognitive)*

Tactical abilities such as anticipation and decision making are critical to success at the elite level of tennis, with differences between experts and novices well established (Del Villar, Gonzalez, Iglesias, Moreno, & Cervello, 2007; Mann, Williams, Ward, & Janelle, 2007; Scott, Scott, & Howe, 1998; Shim, Carlton, Chow, & Chae, 2005; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996; Singer et al., 1994; Ward, Williams, & Bennett, 2002). Anticipation of a future occurrence, derived from information in the visual display, is commonly regarded as a critically important perceptual attribute that underlies skilled performance (Williams, Ward, Knowles, & Smeeton, 2002). Minimising information overload whilst optimising the speed and accuracy of information processing directly influences task success (Williams, Anshel, & Quek, 1997). Anticipation is more pertinent in separating highly skilled and beginner tennis players than either reaction or movement time (Singer et al., 1996). Skilled tennis players make a decision 140ms before less skilled players and use cues from earlier occurring events (Williams et al., 2002). This is a significant advantage as limb position can be continuously updated with a delay of as little as 160ms (Saunders & Knill, 2003). Skilled players focus more on the proximal cues of the head, shoulder and trunk of opponents whereas less skilled players focus more on the later occurring movements of the arm and racquet (Williams, Huys, Canal-Bruland, & Hagemann, 2009). Applying this result to the temporal demands of tennis, where reaction time can be less than 500ms, the benefit exhibited by skilled players is substantial (Rowe & McKenna, 2001). Understanding which information in the visual display is task relevant or irrelevant is part of the advantage experienced by experts (Ericsson & Charness, 1994; Mann et al., 2007).

Decision making research reports the same expert advantage that is present with anticipation (Mann et al., 2007; Voss, Kramer, Basak, Prakash, & Roberts, 2010). Two separate meta-analyses reported sport type influencing cognitive abilities (e.g. response time, processing speed, attention) with interceptive sports (e.g. tennis) outperforming strategic (e.g. soccer) and other sports (e.g. golf) (Mann et al., 2007; Voss et al., 2010). The superiority of in-game decision making is of equal significance when compared to the execution of motor skills (Del Villar et al., 2007). Del Villar et al. (2007) reported that tennis experts put their opponents under more pressure by choosing responses that best compromised the ability of the opponent to play a return shot (e.g. forcing movement or playing to the opponent's poorest side). The equal level of importance for cognitive and motor expertise is a view that is supported in the literature (McPherson, 1999; Nielsen & McPherson, 2001).

There is an individual element to perception and action, with all athlete's possessing their own unique perceptual preferences for receiving and attending to information in the environment (Fuelscher, Ball, & Macmahon, 2012; Williams et al., 1997). Therefore, when assessing tennis performance it is paramount that cognitive abilities are evaluated in conjunction with motor performance. Focusing on only motor execution will limit the significance of results, as decision making is a critical element in competition (Nielsen & McPherson, 2001).

### *2.1.4 Fundamental motor skills*

Fundamental motor skills can be classified as either locomotive (running, jumping, and hopping) or object control skills (throwing, catching, kicking and striking) (Logan, Robinson, Wilson, & Lucas, 2012). The development of skills such as running, jumping, striking and throwing are required to play tennis. A program designed to enhance coordination abilities, movement adaptability and object manipulation reported improvement in participant's (5 years of age) motor abilities and their readiness for tennis specific learning (Quezada, Riquelme, Rodriguez, & Godoy, 2000). Children aged 7-10 years of age should focus on the development of reaction speed, perception and coordination under pressure (Bourquin, 2003).

Unfortunately, the mastery of fundamental motor skills is an area of concern with one study reporting <44% of boys and girls demonstrated mastery on 7 out of 8 tests of fundamental motor skills (Hardy, King, Farrell, Macniven, & Howlett, 2010). The development of 6 fundamental motor skills in students year 1 to year 3 (the actual skills varied depending on the age) stated that, across all age groups, a maximum of 35% had mastered a required skill (Okely & Booth, 2004). The downward trend in motor skill competence is a consistent theme across a number of Western countries (Bardid, Rudd, Lenoir, Polman, & Barnett, 2015; Okely & Booth, 2004; Vandorpe, Vandendriessche, Lefevre, et al., 2011). The motor skill proficiency of children (aged 6-8 years) in Australia and Belgium was significantly worse than norm scores from ~40 years earlier (Australian $p<0.001$, Belgian $p=0.003$) (Bardid et al., 2015). The development of these skills is not a natural occurring process, they must be practiced and learned (Logan et al., 2012). An intervention conducted in the childcare setting with children 3-5 years of age reported significant improvement ($p=0.028$) in fundamental motor skills when they were practiced via a physical activity intervention (Adamo et al., 2016). Additionally, the control group in this study did not improve ($p=.357$) over the 6 month time frame of the intervention, reinforcing the need for these skills to be practiced and developed (Adamo et al., 2016).

The level of coordination required for tennis is unlike most other sports; a tennis ball will never be struck in exactly the same manner, speed, height, spin or displacement will be different (Bourquin, 2003). This necessitates the development of a broad base of abilities to counteract the inherent uncertainty in tennis. Participation in tennis alone cannot sufficiently develop the underlying skills required (Bourquin, 2003). An insufficient level of expertise in coordination activities; elements related to the cooperation of muscles resulting in optimal contact of racquet and ball, are extremely difficult to compensate for in tennis (Stojan, 2006).

### *2.1.5 Psychological*

When assessing current sport performance and identifying talent, psychological factors have been speculated to be more important than the physical components of sport (Abbott & Collins, 2002; Abbott & Collins, 2004). The importance of achievement motivation and self-determination was reported for junior soccer players, with those that scored poorly not selected onto the national team (Zuber, Zibung, & Conzelmann, 2015). Specific to tennis, psychological characteristics such as achievement motivation, positive self-talk and self-regulation are established as essential components for success at the elite level (Lacourse & Young, 1995; Lubbers, 2006; Unierzyski, 2003). Broadly speaking, enjoyment is a critical factor when examining junior populations with one study finding enjoyment was the only consistent predictor of physical activity (DiLorenzo, Stucky-Ropp, Vander Wal, & Gotham, 1998). Whilst a lack of enjoyment and fun has been described as the main cause of children ceasing to play sport (Hecimovich, 2004). This has theoretical implications for talent identification and development programs which should strive to maximise enjoyment, in turn helping maximise program adherence and minimise dropout.

## 2.2 The concept of adaptability

Adaptability is an “individual’s capacity to constructively regulate psycho-behavioural functions in response to new, changing and/or uncertain circumstances, conditions and situations” (Martin et al., 2012) where an individual cannot change their immediate goals or path (e.g. a player must attempt their next tennis stroke in an attempt to win the point). This definition has merit for use in tennis as unlike some sports that possess relatively closed skills (e.g. running, rowing), tennis requires the performance of open skills, which require constant adjustment in relation to changing stimuli. The importance of adaptability is long-recognised, Megginson (1963) at page 4 interpreting Darwin’s *Origin of Species* stated, “it is not the most intellectual of the species that survives; it is not the strongest that survives; but the species that survives is the one that is able best to adapt and adjust to the changing environment in which it finds itself”. This evolutionary interpretation of adaptability provides a pertinent example of the challenges an individual faces in the sporting environment; to constantly adjust their performance based on the immediate and ever changing stimulus of competition.

Three distinct phases must occur for successful adaptability in a given situation (Mckeown, 2012). First, the need for adaptability must be recognised (Mckeown, 2012). This phase is underpinned by the desire to improve, as without this, an individual will be content to maintain their current level of performance. In tennis, if a player continually makes a similar error they should acknowledge the error and recognise that in the next similar situation they must alter their performance. Second, an individual must understand the adaptation that is needed (Mckeown, 2012). Adaptability is rendered useless if the individual is not cognisant of the appropriate response. Continuing the tennis example, once the player acknowledges the need to alter their performance they must correctly identify the change required (for example, stroke mechanics or movement). However in complex movements, such as a tennis stroke, with multiple muscles and body segments operating, there may ambiguity in deciding what caused the error and needs rectifying (Wolpert, Diedrichsen, & Flanagan, 2011). Finally, an individual must do what is necessary to adapt. It is possible that the need is recognised; the solution is known but is not executed (Mckeown, 2012). Completing the tennis illustration, a player may perceive the need for change (continually making errors); possess the knowledge of the required correction (altered stroke mechanics) but fail in the motor execution of the task (make another error). Therefore the underpinning factors of adaptability and skilled performance lie within how individuals perceive their environment and how they act upon this perception.

### *2.2.1 Theoretical framework of adaptability*

#### *2.2.1.1 Perception and action*

Perception is the process of detecting information from the environment which is interpreted to determine the appropriate motor response (action) (Williams, Davids, & Williams, 1999). Initial theories of perception and action suggest that motor control (action) was a distinct and subsequent process compared to perception (Creem-Regehr & Kunz, 2010). The separation of perception and action allowed for greater ease in studying verbal responses, or simple movements relative to perception. However, separating perception and action did not allow experts to fully demonstrate their abilities, as coupling perception and action has been reported to increase perceptual accuracy (Mann et al., 2010). Subsequent to these initial theories, our understanding of perception and action was furthered by Gibson (1966), who purported that an interactionist view should be adopted; where the information available in the environment is the emphasis (Creem-Regehr & Kunz, 2010; Greeno, 1994). This approach ensures individuals become accustomed to operating via a perception-action method where relevant information is first extracted from the environment and used to guide action (Passos, Araujo, Davids, & Shuttleworth, 2008; Renshaw, Chow, Davids, & Hammond, 2010).

Within this individual-environment interaction there are abilities and affordances (Creem-Regehr & Kunz, 2010; Greeno, 1994). Abilities refer to anything the individual contributes to the interaction, whilst affordances are the environment's contribution to the interaction (Creem-Regehr & Kunz, 2010; Greeno, 1994). Abilities and affordances are considered conditions in which the constraints of successful performance lie (Greeno, 1994). For example, when performing a tennis stroke, an individual must move their body to achieve the outcome of returning the ball. Abilities include the perceptual ability to see the ball, coordinating movement towards the ball and striking it. Affordances include a court with a suitable surface for tennis play and a ball that will bounce appropriately to be struck. An integrated approach to understanding perception and action is now considered best practice for future research (Creem-Regehr & Kunz, 2010).

#### *2.2.1.2 Dynamical systems theory*

Tennis can be thought of as a complex dynamical system that is composed of a number of different interacting components. Building on work from Newell (1986), Williams et al. (1999) articulated the central elements of a nonlinear dynamical neurobiological system include a number of interacting parts that possess high levels of integration and self-organisation with the ability to adapt to changes in the system. This is evidenced by stable outcomes emerging from different patterns of organisation in the system and variable (unstable) outcomes occurring as a result of different components of the system influencing each other. For example, a player may have a number of techniques to hit a cross court forehand (different patterns of organisation producing a stable outcome) but this will be impacted upon by everything in the system (opponent, environment) which may result in a different outcome (down the line forehand). Therefore the action that emerges from this dynamical system are subject to the context dependent constraints that exist in the differing components of the system (e.g. the opponent) (Passos et al., 2008).

Constraints, generally speaking are aspects or limits that impact the entity in question (Newell, 1986). For example, if a player is moved wide in the forehand court, the decision of where and what type of shot to hit are constrained by a number of factors; the opponent’s position, opponent’s speed, court size (singles/doubles) and a player’s own ability. Simultaneously, these same factors are influencing the upcoming actions of the opponent. The interaction of these components is exclusive to that particular shot only. A similar shot will not possess the exact same characteristics (e.g. ball speed, bounce, angle) implying that despite their similarity, the outcome may not be the same. Consequentially, outcomes are neither completely predictable nor are they random (Passos et al., 2008), to maximise success an individual must produce stable but adaptive behaviour (Crespo, 2009; Warren, 2006).

*2.2.1.3 Newell’s theory of constraints*

Adaptive behaviour arises from the amalgamation of individual task constraints (Davids et al., 2013; Warren, 2006) with expertise defined as the ability to functionally exploit constraints for successful task performance (Davids et al., 2013). There are three types of constraints that impact on a person’s ability to optimally perform motor activities, individual, task and environmental (Newell, 1986). Individual constraints refer to the physiological, technical, tactical and psychological characteristics of an individual (e.g. body composition, fitness/fatigue levels, decision making skills, feedback variations). Individual constraints are the resources that a person has at their disposal to help develop a unique solution to a particular problem (Renshaw et al., 2010). As such, uniformity across a population or even between two individuals should not be expected; variability is much more likely and functionally appropriate.

Task constraints are factors that influence successful task performance (e.g. rule changes, types of equipment used, and number of players), these are generally what is manipulated by a coach. Effective manipulation of task constraints is crucial, as the coach must be changing them for the purpose of creating a desired functional outcome (Renshaw et al., 2010).

Environmental constraints can be physical (e.g. weather, playing surface) or social (e.g. social expectations, presence of an audience) (Passos et al., 2008). Using a constraints led approach when teaching physical education empowers students to become active learners (Renshaw et al., 2010). Additionally, teachers should encourage movement variability rather than an “optimal movement pattern” (Renshaw et al., 2010). Learners operating under this theoretical framework will create specific movement and skill solutions to fulfil the distinct set of constraints they are faced with (Renshaw et al., 2010). Using a constraints based approach with a junior population is valid and appropriate, assuming the underlying fundamental motor skills are sufficiently developed (Pill, 2013).

*2.2.1.4 Adaptability training/methods*

In tennis, knowing the correct shot to play and executing the required stroke are very different concepts. Error based learning is a potential means that the motor system will use to adapt a movement (Wolpert et al., 2011). The predicted outcome (a forehand that went in) will be compared to the actual outcome (a forehand that was out) and adjustments can be made on a trial by trial basis. The disparity between predicted outcome and actual outcome can provide valuable insight into the best method to adapt to a situation (Mckeown, 2012). Trial by trial adjustments in motor systems help individuals adapt to unique circumstances and contrast the view that a pre-determined motor pattern is a pre-requisite for increased expertise. In their review, Davids, Glazier, Araujo, and Bartlett (2003) detail a number of studies which promote the benefit of movement variability and denounce the ideology of a single motor pattern.

Use-dependent learning refers to changes in the motor system that occur through repetition of movement without outcome information (Wolpert et al., 2011). This biases the system towards performing one specific movement pattern in comparison to the movement patterns learned during error based learning (Wolpert et al., 2011). The repetitive, outcome irrelevant principles of use-dependent learning are aligned with current tennis development processes that focus on repetitive task performance. This reductionist approach oversimplifies learning and development in sport by not providing adequate stimulus for athletes (Davids et al., 2013). An applied example is provided by examining the ball toss in tennis (Reid, Whiteside, & Elliott, 2010). In an attempt to create a repeatable, consistent ball toss participants practiced this component in isolation, a common method used by coaches in the field. The ball toss was no more consistent when practiced in isolation with no significant differences between the standard deviation of ball position at the ball zenith (flat serve 5.1±1.8cm, ball toss only 9.0±3.4cm). If anything, the ball toss only condition trended towards being less consistent when compared to performing the serve as normal (Reid et al., 2010). The efficacy of this approach therefore has to be questioned, as not only does it create athletes who are less fluid and adaptive to the current situation it also does not appear to fulfil its theoretical purpose in creating consistency. The adaptability that is required for repeated trials is however different to the immediate perception and action required to adapt to changing constraints.

The viability and validity of adopting a constraints led approach was examined in two different fields, rugby union and physical education (Passos et al., 2008; Renshaw et al., 2010). Both studies suggest the need for increasing variability in training practices. Variability allows for an adaptive response by the individual as during skilled performance the consistency of performance is what is critical not the consistency of underlying movement patterns (Passos et al., 2008; Renshaw et al., 2010). An assumption is generally held that to achieve consistent performance the underlying movement pattern must be consistent and this assumption has driven training practices (Ranganathan & Newell, 2013). Specifically relating to tennis, biomechanical variability in the tennis serve was found to be functional, with the authors recommending coaches include deliberate perturbations of the serve into training to help develop movement coordination and perception action coupling (Whiteside, Elliott, Lay, & Reid, 2015). The underlying theory behind this recommendation is that if a player is faced with a broad range of movement and skill contexts they will become more proficient at adapting their performance to successfully negotiate the variability that has been shown to exist in tennis (Whiteside et al., 2015).

Differential learning promotes variability in training by constantly changing the movement pattern, avoiding repetitions and incorporates principles of discovery learning (Schőllhorn et al., 2006). Soccer passing and shooting was used to compare differential learning and traditional learning (minimal inter-trial variability, focus on 'ideal' movement pattern) (Schőllhorn et al., 2006). After 12 training sessions (~20-40 minutes), there was a significant improvement in the passing score of the differential training group ($p=0.009$) but not the traditional group ($p=0.49$). All participants in the differential training group improved their score whilst only 50% of the traditional group improved their score from pre to post-test (Schőllhorn et al., 2006). The significant improvement from pre to post-test in the differential learning group was maintained when investigating shooting at goal (differential group $p=0.02$, traditional $p=0.41$) (Schőllhorn et al., 2006). The benefits of differential learning extend to speed skating with a significant difference between the differential learning and control groups (Savelsbergh, Kamper, Rabius, De Koning, & Schőllhorn, 2010). There was no difference between the traditional and differential learning group, however the differential learning group operated with a number of techniques that would have been considered 'incorrect' via the traditional approach. Therefore the result can be construed in a positive context as there was no performance decrement despite learning 'incorrectly' (Savelsbergh et al., 2010). The introduction of increased variability in training can account for the problems associated with creating a 'one size fits all' optimal movement pattern. The focus is shifted to athlete-environment interaction and allows the athlete to identify their own unique movement solution via exploration (Davids et al., 2013; Savelsbergh et al., 2010; Schőllhorn et al., 2006).

An additional method to promote variability and adaptability, is the use of a training environment that has high contextual interference (CI) (Brady, 2008). This can be achieved by using a varied order of practice and increasing the cognitive demands placed on the individual (Memmert, Hagemann, Althoetmar, Geppert, & Seiler, 2009). Practicing a task under high contextual interference has been demonstrated across a range of sporting and skill environments (e.g. tennis, golf, basketball) and can improve learning and produce performers who are more adaptable to a transfer task (Babo, Azevedo Neto, & Teixeira, 2008; Brady, 2008; Broadbent, Causer, Ford, & Williams, 2015; Porter & Magill, 2010; Van Merrienboer, Kester, & Paas, 2006). The anticipation of tennis shots was assessed via a random and blocked practice schedule (Broadbent et al., 2015). Transfer of learning was also assessed with a field based test as training was conducted in a simulated laboratory setting. The random practice group significantly outperformed the blocked group with response accuracy on the laboratory retention test ($p<0.05$, 71.7 ± 5.3% and 63.3 ± 6.0%, respectively). The decision time on the transfer test was significantly faster for the random practice group compared to the blocked group ($p<0.05$, 98 ± 89ms and 238 ± 118ms, respectively), demonstrating the benefits that an environment of high CI can provide (Broadbent et al., 2015).

Adaptability can be summarised in terms of how an individual optimises their perceptual motor performance. The practical value of adaptability, or any novel training stimuli, lies within its ability to generalise and provide a transfer effect. That is, how the knowledge, skills and abilities gained can be used in different, novel circumstances and how adaptability training impacts on competitive tennis performance (Issurin, 2013; Wolpert et al., 2011). Although the limitations around exercise specificity are acknowledged, discovering a novel training stimuli such as adaptability, is beneficial as varied and innovative exercises are a sought after method of improving training stimulation (Issurin, 2013).

#### *2.2.1.5 Skill transfer*

Skill transfer can be separated into three separate categories, positive, negative and zero transfer (Mitchell & Oslin, 1999). Positive transfer is when learning one skill supports the learning of another skill. Negative transfer is when learning one skill inhibits the learning of another skill, whilst zero transfer is when learning one skill does not impact on the learning of another (Mitchell & Oslin, 1999). Skill transfer is thought to occur in general cognitive and physiological abilities rather than sport-specific skill execution (Baker et al., 2003). Baker et al. (2003) recorded the practice history of expert field hockey, netball and basketball players reporting that the most common other activities participated in were football (Australian Rules Football and rugby) and basketball. These sports share attributes with the athletes chosen sport in that they require rapid, continual decision making, advanced spatial awareness (including the field of play, team mates and opponents), and physical fitness (Baker et al., 2003). Additional benefits, namely, improved hand-eye coordination may have been derived from other sports which the athletes had participated in at an earlier age, such as, cricket and softball (Baker et al., 2003). Berry et al. (2008) reinforced the beneficial impact of engaging in activities with shared attributes, in their case, invasion type activities. From an elite cohort of Australian Rules Football players they found that those who were classified as expert decision makers had accumulated more hours in invasion type activities than their less skilled counterparts (Berry et al., 2008).

Transfer related benefits extend to tactical situations in sport as well (Mitchell & Oslin, 1999). In net sports such as tennis and badminton, the underlying tactics are similar, in that the goal is to strike an object over the net in a manner that creates the most difficulty for the opponent to return the object. Mitchell and Oslin (1999) found that there is a basis for tactical transfer with the learning of one game being beneficial for the performance of another. The recall of patterns of play has been shown to be a transferable skill (Abernethy, Baker, & Côté, 2005). Experts from netball, basketball and field hockey were compared with non-experts and required to watch a video (of structured offensive or defensive play) then recall the position of offensive and defensive players. Experts from other sports (for example, basketball and field hockey participants watching a netball video) outperformed non-experts when recalling defensive player positions, providing evidence of tactical transfer (Effect sizes, hockey = 1.03, netball = 0.59 and basketball = 0.29) (Abernethy et al., 2005). Due to the benefits demonstrated with positive transfer strict specificity has been questioned (Mulavara, Cohen, & Bloomberg, 2009).

The effect of two types of training (treadmill walking and wobble board training) whilst wearing either multiple different distortion lenses, a single pair of distortion lenses or sham lenses was compared on a novel walking obstacle avoidance task . The obstacle avoidance task was conducted on10cm thick foam and used to provide a novel test environment compared to what had been trained in the participants, therefore assessing their adaptability and transfer. The multiple lens group outperformed the single and sham lens group ($p<0.04$ and $p<0.006$ respectively) when comparing the percentage change in time to complete the obstacle avoidance task (from pre to post-test). This finding was for the treadmill training group suggesting that performance and training conditions do not need to be the same. However, the training task must include the crucial elements involved in the performance task (in this study, walking rather than wobble board training) (Mulavara et al., 2009). Relating the finding from this study to tennis, competition conditions will almost always be different from practice conditions, therefore training in an innovative, original setting will best prepare the athlete for this.

Training should be a combination of stability of action, to ensure there is transfer to the main task and variability, preparing the athlete to cope with the unique constraints of the situation (Passos et al., 2008). A study comparing a non-sport specific and sport specific (handball, soccer and field hockey) development pathway showed that the non-sport specific group improved their general creativity and the sport specific improved their creativity in their sport (Memmert & Roth, 2007). However, the most important outcome was that there were positive transfer effects across the other sports, with the soccer specific group improving their handball and field hockey creativity ($p=0.001$ in both sports) and the field hockey group improving their creativity in handball ($p=0.024$) (Memmert & Roth, 2007). From a general development of sport expertise perspective, 57% of a group of 673 athletes reached an advanced level of competition in a sport which was not their main sport (Gulbin, Oldenziel, Weissensteiner, & Gagne, 2010).

Providing a large base of movement and skill experiences should enhance the ability of an individual to transfer their skills. As the individual is exposed to a greater number of experiences, they possess a broader range of behaviours to draw on when attempting to adapt their performance to satisfy unique task constraints. However, the method used to acquire these skills (explicit vs. implicit learned) will impact on their adaptability.

#### *2.2.1.6 Explicit and implicit learning*

Explicit learning is characterised by a conscious, purposeful effort in the learning process whilst implicit learning is considered to be an automatic, unconscious and unintentional learning process (Kaufman et al., 2010). A pragmatic view of these opposed learning methods is that they are end points on a continuum of learning modalities (Magill, 1998), as operating in a solely explicit or implicit environment is extremely difficult to achieve. An example of an implicitly learned skill is demonstrated with the basic fundamental motor skills of catching a ball (Reed, McLeod, & Dienes, 2010). Participants were unable to correctly verbalise the mechanisms from which they decide to move forwards or backwards when catching a ball. Furthermore, participants weren't able to correctly identify how their angle of gaze changed when catching a ball despite receiving familiarisation with the concept (Reed et al., 2010). The benefits of implicit learning when compared to explicit learning is well supported in the literature (Buszard, Reid, Farrow, & Masters, 2013; Liao & Masters, 2001; Masters, 1992; Reid, Crespo, Lay, et al., 2007). Skills learned implicitly are less susceptible to breakdown during periods of stress (psychological, physical, performance of simultaneous tasks).

Implicit learning possesses significant benefit for tennis, with an implicit learning group significantly ($p<0.05$) improving their anticipation skills despite there being no change post intervention in the explicit learning, placebo and control group (Farrow & Abernethy, 2002). The implicit and explicit learning groups viewed temporally occluded video-based footage of the tennis serve, with only the explicit group receiving instructions on how to anticipate the serve location. The benefits of implicit learning have also been demonstrated with junior tennis players (Smeeton, Hodges, Williams, & Ward, 2005). A control group was compared to an explicit group, a guided discovery group and a discovery group (Smeeton et al., 2005). Discovery learning mirrors the same principles as implicit learning with guided discovery a mix of explicit and implicit modalities (Figure 1). All intervention groups improved in decision time and response accuracy when compared to the control group. However, only the explicit group experienced a decline in performance under anxiety induced conditions (Smeeton et al., 2005). With a junior population (9-11 years of age), scaled tennis equipment (for example, modified racquets and low compression balls) promotes implicit learning processes in comparison to full sized equipment (Buszard et al., 2014). There was a significant decrement in performance under dual task conditions when using full sized equipment in comparison to single task conditions ($p=0.01$) and no difference when using scaled equipment. This implies implicit learning processes as there was a reduced conscious effort with the scaled group. Therefore, to maximise the benefits of an implicit learning intervention the use of scaled equipment in junior tennis is recommended.

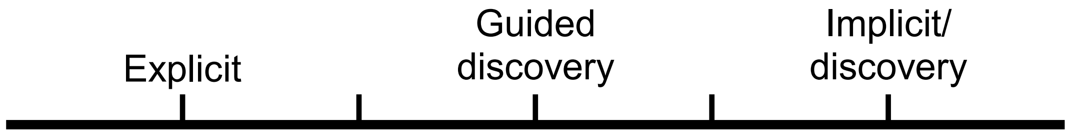


**Figure 1**. Continuum of learning modalities.

Functional variability in performance underlies implicit learning as it promotes an approach where the individual discovers their own solution to the task (Hernandez-Davo et al., 2014; Renshaw et al., 2010). There are individual differences in implicit learning (Kaufman et al., 2010) and therefore this aligns with unique outcome oriented solutions defined by adaptability.

## 2.3 Talent identification in tennis

### *2.3.1 Background to talent identification*

Talent identification is the process of recognizing current participants with the potential to excel in a particular sport, and although acknowledged as a separate process, talent detection, which recognizes those not currently participating in the sport, will be used interchangeably with TI (Lidor et al., 2009; Mohamed et al., 2009; Vaeyens et al., 2008; Williams & Reilly, 2000). The key element in this definition is identifying the characteristics that demonstrates an individual has the potential to develop and gain senior success (Abbott & Collins, 2002). The distinction between current performance level and the capacity to further develop is an essential but often overlooked element (Martindale et al., 2005). As such, the importance of evidence based effective sports policy, encompassing TI, is increasing, with successful identification of future elite athletes providing the sporting organisation with a competitive advantage (Morris, 2000; Vaeyens et al., 2008). Conversely, substandard policies are considered at least partly responsible for a lack of achievement in sport (De Bosscher, De Knop, & Heyndels, 2003).

A specific example is provided in Australia where the number of elite (top 100) tennis players has been declining for a number of decades. Year-end ranking data, as available from official tennis websites (ATP and WTA) demonstrates this point (Figure 2). Given that substandard TI policies are partly responsible for a lack of achievement in sport, the figures below warrant investigation in an attempt to understand best practice moving forward.

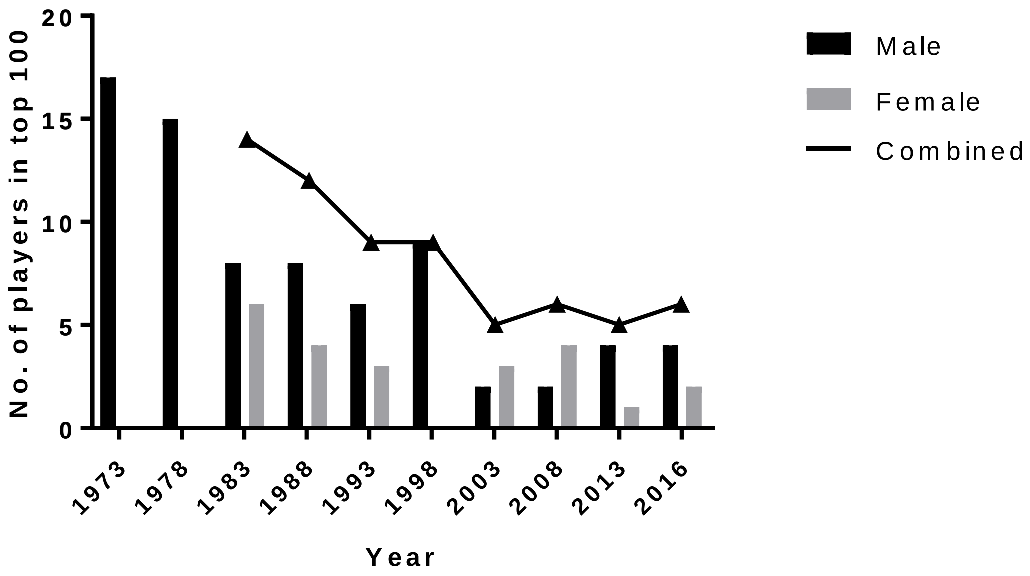


**Figure 2**. Number of Australian men and women ranked inside the top 100.

The complexity of TI is heightened in sports of open skill performance (e.g. tennis, team sports) compared to those that possess discrete, objective performance measures (e.g. swimming, rowing and cycling) (Reilly, Williams, Nevill, & Franks, 2000). An open skill sport requires players to react to the changing and unpredictable environment. As a result, TI that is static or one dimensional, rather than dynamic and multi-dimensional, is likely to result in early de-selection of potentially talented individuals (Abbott & Collins, 2002; MacNamara & Collins, 2014). The support for a multi-dimensional approach to TI is well supported in the literature (Abbott & Collins, 2004; Burgess & Naughton, 2010; Elferink-Gemser, Visscher, Lemmink, & Mulder, 2004; Mohamed et al., 2009; Nieuwenhuis, Spamer, & van Rossum, 2002; Phillips et al., 2010b; Simonton, 1999; Vaeyens et al., 2008; Williams & Reilly, 2000). Although there appears to be a consensus on some methods to improve TI (e.g. multi-dimensional, dynamic), the creation of a TI protocol which is representative of the open skill environment, but maintains scientific credibility (strong validity and reliability), is a challenging proposition and seldom attempted in the literature (Breitbach, Tug, & Simon, 2014).

*2.3.2 Talent identification models*

The difficulty in obtaining a meaningful and discriminatory method of talent identification is demonstrated by a study conducted over three seasons assessing technical, physical and perceptual actions in rugby league (Waldron, Worsfold, Twist, & Lamb, 2014). A methodological feature of this study was that the majority of players completed the season with the same club, therefore undertaking the same development program. Theoretically, minimising the influence of training on results whilst maximising the opportunity to identify a significant variable. However, no differences were found between the selected and unselected groups at the under 15 and under 17 level. Whilst, there was some differences at the under 16 level, once corrected for playing time these results matched the other age groups. This highlights the need to continue to search for variables that appropriately discriminate between groups. Examining unique but practically relevant variables will provide a novel approach to talent identification.

A multidisciplinary approach assessing anthropometric, physiological, psychological and soccer-specific skills was used to discriminate between elite and sub-elite 15-16 year old soccer players (Reilly et al., 2000). The most important factors predicting talent were agility, speed, motivational orientation and anticipation skill. The underlying key concept from this study and others, such as, Coelho et al. (2010) and Nieuwenhuis et al. (2002) is sports which possess a multifactorial skill set, should have this reflected in their TI policy. The combined integrated performance of this skill set is what underpins ‘talent’ (Simonton, 1999). If all attributes from the required skill set are not included, the TI policy is flawed as coaches or selectors may make a misguided choice by analysing only one portion of performance (Nieuwenhuis et al., 2002).

A TI model put forward by Simonton (1999) supports this notion by being multiplicative in nature rather than the traditional additive approach. In this model there is scope for numerous developmental pathways with the final measure of talent reached by multiplying each required attribute together. This allows for outstanding performance of one skill to compensate for the poor performance of another. Only the complete absence of an attribute instead of a deficiency cannot be offset. This will result in the finding of no potential for the individual, despite the possibility of superiority in one or even a number of other attributes required for success. This is a view that has received some support in tennis with the theory of inborn limits (Stojan, 2006). It is suggested that negative predictions should be the focus; identifying those who can’t develop into elite level talent rather than identifying those who could develop into elite level talent (for example, a player will never reach the elite level because of their lack of physical, technical, tactical or psychological attributes).

In an attempt to elucidate the specific attributes required for TI, a study investigated if at a 2 year follow up, 11-12 and 13-14 year old soccer players had dropped out, maintained or progressed their level (Figueiredo, Goncalves, Coelho, & Malina, 2009). Growth, maturation, physical and sport-specific attributes were important factors for determining which group athletes were currently in, with the 13-14 year old age group reporting stronger results. Implications from these results are twofold; there should be a focus on overall general development up to this age (11-12) and/or a different set of variables needs to be defined to more meaningfully assess this age group. Additionally, a number of variables contribute to performance at the junior level of sport, therefore focusing on only one attribute (e.g. physical performance) can provide misleading results.

The common use of closed skill and physical performance measures (in isolation) is fraught with danger, as the correlation to game-specific demands is low (Phillips et al., 2010b). English Premier League Academy players' (under 9 and under 10 squads) in-game running performance was analysed via a global positioning system and results were interpreted based on whether a player was retained by the academy or released (Goto, Morris, & Nevill, 2015). Retained players cover a greater total distance ($p<0.05$) and at low speeds ($p<0.05$) than released players. The interpretation of these results was that this information should be used to influence training, talent identification and development practices despite acknowledging no difference in high intensity running which is the pertinent variable in senior soccer (Goto et al., 2015). This simplistic explanation does not account for biological maturity, represent game-specific demands and changing physical attributes over the development period, highlighting the limitations of using physical measures in isolation (Carling & Collins, 2015).

Physical measures are considered poor predictors of tennis performance as they only represent one element of the multifaceted skill set required (Vergauwen et al., 1998). The use of an open skill test incorporating technical and cognitive demands of the sport would significantly add to the TI literature (Falk, Lidor, Lander, & Lang, 2004). The critical element then becomes the ability of TI policies to correctly identify the variables that separate potential elite tennis players in comparison to the general tennis playing population (Elliot et al., 1990).

### *2.3.3 Motor skill tests used for talent identification*

The use of a generic motor skill test for talent identification purposes has gained momentum as the effect that sport-specific training has on results is limited (Faber, Oosterveld, & Nijhuis-Van der Sanden, 2014; Pion et al., 2015; Vaeyens et al., 2008).

For example, a proficient tennis serve which is developed through high levels of sport-specific training is likely to influence traditional performance measures (ranking/results) of TI but not a generic motor skill test (e.g. jumping). Furthermore, the stability that is exhibited in motor abilities beyond the age of 6 provides evidence as to why they may carry some predictive power (Vandorpe, Vandendriessche, Vaeyens, Pion, Matthys, et al., 2012). General motor skill tests that possess the ability to predict performance in tennis are currently lacking (Lees, 2003) however some seminal work has been conducted in the field of table tennis (Faber et al., 2014). In this study participants (aged 7-12 years) were required to throw a ball against a wall with one hand and catch with the opposite hand as many times as possible in 30 seconds. The task was designed to be similar to table tennis but not an activity that would have been practiced in training. Identifying talent through a perceptual-motor task, which has not been influenced by training, is more effective than a sport-specific skill assessment (Faber et al., 2014; Vaeyens et al., 2008; Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). This test was able to discriminate between local, regional and national players. The optimal distance from the wall was assessed to be 1 metre as this emphasised the need for fast reactions in comparison to 2 metres. A central element of this test was that the highest performers were able to rapidly adapt their technique (overhand vs. underhand) as required, therefore allowing freedom to choose their own method to achieve task success. (Faber et al., 2014).

The KörperKoordinations Test Für Kinder is a widely used and reliable test that measures and monitors development of gross motor coordination in children (Cools, De Martelaer, Samaey, & Andries, 2008; Vandorpe, Vandendriessche, Lefevre, et al., 2011). Using the KTK for talent identification has been explored previously in gymnastics (Vandorpe, Vandendriessche, Vaeyens, et al., 2011; Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). The KTK was able to discriminate between 6-8 year old elite and sub-elite gymnasts (Vandorpe, Vandendriessche, Vaeyens, et al., 2011) and during a two year longitudinal study it accounted for more than 40% of the variation in competition results (Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). Furthermore, the KTK was superior in predicting performance when compared to coaches' judgment, anthropometric and physical characteristics (Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). Currently the KTK has not been used in tennis from a talent identification perspective, however a descriptive study was completed with junior tennis players (aged 6-14 years) (Söğüt, 2016). Compared to norm scores, none of the participants recorded scores below normal with 40.6% scoring above normal level, suggesting a positive effect for sport on developing motor skills.

A potential limitation of motor skills assessment is that physiological characteristics such as strength, speed, endurance and flexibility can influence results (Vandorpe, Vandendriessche, Lefevre, et al., 2011). However, a wide ranging assessment of skill sets may be beneficial for talent identification, specifically in sports where a multifaceted skill set is required (Vandorpe, Vandendriessche, Vaeyens, et al., 2011). The assessment of fundamental motor skills, which are appropriate for the developmental stage of the athlete, should be considered more frequently in test batteries. Especially as sport-specific skills, such as serving in tennis, are potentially too difficult for young athletes and therefore lack validity (Lidor et al., 2009).

#### *2.3.4 Current talent identification processes in tennis*

The incumbent methods of talent identification in tennis are largely based around ranking and tournament results (Brouwers et al., 2012). In Australia, there are detailed criteria specifying the ranking, tournament result or participation level that you must achieve to be eligible for a support scholarship (e.g. top 4 Australian ranking, competing in Nationals or State championships) ("Athlete development scholarship criteria," 2015). Despite acknowledging individual pathways of development in the document, the continued reliance on competitive, performance related benchmarks does not reflect this viewpoint.

The literature surrounding talent identification in tennis is scarce and conflicting, focusing on the legitimacy of junior tournaments and rankings as a predictor of future success (Brouwers et al., 2012; Kolman, Huijgen, Kramer, Elferink-Gemser, & Visscher, 2017; Miley & Nesbitt, 1995; Reid et al., 2009; Reid, Crespo, Santilli, et al., 2007; Reid & Morris, 2013). The predictive value of under 14 year old youth tennis tournaments and the rankings of junior (under 18) tennis players revealed they both have low success rates at predicting later achievement (Brouwers et al., 2012). Participation in the youth tournaments resulted in 6.2% of the males achieving a top 200 ranking and 9.2% for females. A top 20 junior ranking resulted in 65.8% of players achieving a top 200 ranking for males and 64.6% for females. No significant relationship was found for players who achieved a top 20 ranking at a younger age (males $p=0.102$, females $p=0.069$). Whilst it is acknowledged that good results at younger ages can increase the chances of senior success, it is not a pre-condition for senior success. Therefore, the use of current performance as best practice to predict success must be questioned.

Achieving a top 10 ITF junior ranking has been reported to equate to a 50% chance of achieving a top 100 men’s or women’s ranking (Miley & Nesbitt, 1995). Applying a contrasting top-down approach found that of the top 100 ranked senior men, 91% had achieved a junior ranking, although no stipulation was placed on this ranking (for example, top 100) (Reid & Morris, 2013). When examining this result more closely, the average peak in their junior ranking was $94.1 \pm 148.9$. This demonstrates the marked variability that can occur when using only performance based measures and brings into doubt the importance of a high junior ranking. A study investigating the importance of a junior ITF top 20 ranking for girls reported that 99% achieved a professional ranking, however this reduced to 58% when a top 100 ranking was the determinant of success. A similar study for boys reported 91% ranked in the ITF junior top 20 achieved a professional men’s ranking. However the junior ranking only accounted for approximately 4.5% of variation in the professional rank (Reid, Crespo, Santilli, et al., 2007).

The varying markers of ‘success’ in these studies limit comparison and lack practical reasoning. Two practical examples are provided as a more appropriate definition of success. Firstly, for direct entrance into a ‘grand slam’ a player has to be ranked in the top 104 players. Secondly, it has been estimated that a player has to be ranked inside the top 130 to earn enough prize money to cover their costs of competing on the tour (Bane, Reid, & Morgan, 2014). These appear to be more relevant measures than achieving a singles ranking alone. The insight these studies provides is significant. However, only Brouwers et al. (2012) investigated under 14 age group tournament results with the main focus being the under 18 age group. This presents an opportunity for research with younger children, as talent identification processes are occurring in the field with this population despite the lack of research (Bastieans, 2006; Pankhurst, 2013).

In an attempt to identify the most pertinent variables for TI in tennis, current research findings have been unclear. A systematic review attempting to identify the most relevant variables for TI in racquet sports (tennis, table tennis, badminton and squash) provided valuable insights (Faber et al., 2016). Perceptual abilities and coordinative skills discriminated between elite and non-elite populations but their predictive ability was not able to be established. Physical attributes returned conflicting findings, preventing a clear conclusion (Faber et al., 2016).

An investigation into the relationship between competitive tennis level and a number of physical attributes (anthropometric, maturity status, grip strength, vertical jump, 20m sprint, tennis specific sprint test, serve velocity, medicine ball throws and the hit and turn tennis test) discovered that serve velocity (females $r=0.43-0.64$, males $r=0.33-0.49$) and medicine ball throw (females $r=0.26-0.49$, males $r=0.20-0.49$) yielded the strongest correlations (Ulbricht et al., 2016). These variables combined with the hit and turn tennis test discriminated between national and regional level players (Ulbricht et al., 2016). A physical performance test battery (assessing strength, agility, speed and endurance) did not predict the competitive level of junior (8-12 years of age) tennis players (Roetert et al., 1992). The hexagon text, a test measuring agility and speed, was correlated (r=0.23) to sectional rankings explaining 8% of the variance, whilst stroke ratings and physical tests yielded no significant correlations (Roetert et al., 1992). For national rankings, 47% of the variance was explained by forehand tennis stroke ratings (Roetert et al., 1992). Expanding on their previous work, Roetert et al. (1996) discovered that a test battery containing speed, agility, strength and flexibility measures correctly classified 91.5% participants from 3 different junior tennis levels. However, these athletes were previously talent identified, experiencing greater training loads, exposure to better coaching, and strength and conditioning programs, therefore potentially biasing the results.

*2.3.5 Summary and limitations of current processes in tennis*

Skilled tennis performance, especially at the junior level, is not wholly related to performance outcomes, e.g. games, matches won or lost (Nielsen & McPherson, 2001). A more pertinent question to ask is what constitutes expertise and how is this best developed? Winning in any sport is contextually based and the result alone does not reveal a significant amount on an individual's key performance attributes (physical, technical, tactical and psychological) or development path (Rink, French, & Tjeerdsma, 1996). As a result, the use of performance measures for TI exposes athletes to a system that possesses severe bias (Pankhurst & Collins, 2013).

The "winning now" culture that is promoted by rankings and results based current TI processes is complicit in the prevalence of overtraining in young players. Despite strength, aerobic and anaerobic power being trainable characteristics in children, they cannot be subject to the same pressures as adults, with regards to training loads and competition schedules without potentially subjecting themselves to the detrimental effects of overtraining (Matos & Winsley, 2007; Pearson, Naughton, & Torode, 2006).

An additional bias is that early maturing players can be perceived to possess more talent and potential than is actually present. An extensive number of changes occur during maturation and if unaccounted for, can impact on sport performance and talent identification (Pearson et al., 2006; Torres-Unda et al., 2016). If performance measures are the focus, coaches will select athletes to maximise their current competitive success rather than focusing on long term development (Coelho et al., 2010).

Competitions in tennis are commonly divided by chronological age groups. This results in children 12-14 years of age opposing each other with potentially significant differences in maturation levels and physiological capabilities (Hoare & Warr, 2000). The outcome can be selection bias; better coaching and selection awarded to more physically developed players (Edgar & O'Donoghue, 2005; Malina, Ribeiro, Aroso, & Cumming, 2007). This disadvantages potentially talented players who may withdraw from the sport after missing selection/development opportunities. Additionally, selected players may withdraw after the advantage of their early maturation fades (Edgar & O'Donoghue, 2005; Malina et al., 2007). A novel finding was reported with Australian Rules Football draftees with a bias towards athletes born earlier in the selection year (Coutts, Kempton, & Vaeyens, 2014). The draftees were split into two groups, adolescent (< 20 years of age) and mature (≥20 years of age). The relative age effect was confirmed for the adolescent draftees but a reverse effect was found with the mature draftees. More mature draftees were born in the 4$^{th}$ quartile (37.1%, $p=0.047$) and second half of the year (62.9%, $p=0.028$). The later born mature draftees may have initially been disadvantaged during their adolescent years however, those that persisted with the sport were rewarded at a later date. This highlights the importance of maturation, the relative age effect and how these must be considered during talent identification processes.

Non-invasive measures of biological maturity exist such as Mirwald, Baxter-Jones, Bailey, and Beunen (2002) and in sports where athletes do not generally participate in elite competition until the age of 20, their addition to a talent identification/development process is essential (Pearson et al., 2006). Physical and performance measures are often used in TI despite the obvious impact that maturation may have on these variables (Abbott & Collins, 2002). TI test batteries should be appropriate for the age and stage of development that the specific research has been conducted on, as the relationship between the test, growth, maturation and development will change over time (Abbott & Collins, 2004; Pienaar & Spamer, 1998; Reilly et al., 2000). A number of studies and review papers have reported the influence of maturation in talent identification, favouring early and average maturing athletes (Burgess & Naughton, 2010; Coelho et al., 2010; Lidor et al., 2009; Malina et al., 2007; Mohamed et al., 2009; Pearson et al., 2006; Pienaar & Spamer, 1998; Torres-Unda et al., 2016; Unierzyski, 2002; Vaeyens et al., 2008). Despite hypothesising in agreement with the aforementioned studies, one study in tennis provided a contrasting view; an advantage for late maturing individuals (Hoare & Warr, 2000). However there were some methodological flaws in this study, with a small sample size, especially in the early maturing group (n=4) acknowledged by the authors and a small difference between the year of most growth (early = 11.37, average 12.18, late, 12.70). The combination of these factors and robust evidence base that exists surrounding the influence of maturation mitigates the influence of this study.

Specific to tennis, Unierzyski (2002) and Unierzyski and Osinski (2007) both present that the major factors responsible for success in junior tennis (12-13 years of age) are related to increased experience (playing age, no. of matches played, no. of hours practising per week etc.) and advanced biological maturation (height, weight and power). This is a view that is supported from a general talent identification perspective (Abbott & Collins, 2002). At 12-13 years of age, the development of skills that are essential for senior success (technical, tactical) should be the focus rather than 'winning now'. This is extremely important as the factors discriminating athletes at junior level (experience and maturation) and senior level are very different (service and return outcomes) (Ma et al., 2013; Unierzyski, 2002). Furthermore, experience, measured as years as a professional, did not affect senior match outcomes and stature, had only a mitigated impact with no additional benefit for a male athlete to be over 186cm (Ma et al., 2013).

The ambiguous results surrounding the use of ranking and performance measures coupled with the underlying reasons for junior success (experience, maturity) suggest that at best, current systems need improvement and at worst may be wasting resources. From a practical viewpoint, current TI performance based measures don't assess potential, they identify those who have matured early, specialised early, or have tournament experience. Player investment should be geared towards individuals with the greatest likelihood of future success; this may not necessarily include those ranked in the top echelon of current junior tennis.

An alternative method of talent identification, which is not underpinned by playing experience and maturation, but instead identifies juniors that display heightened levels of pertinent attributes, is warranted. This should include the combination of a number of relevant attributes such as, physical, mental, tactical and take into account players' development levels (Brouwers et al., 2012). An effective TI model is a necessary predecessor to talent development (TD) as it directs support and resources to individuals that have the greatest potential to succeed (Abbott & Collins, 2002). This presents a significant gap in the literature, requiring the development of a skill-based test for talent identification purposes (rather than immediate skill assessment) incorporating a range of pertinent variables. This will add substantially to the current body of knowledge and provide practitioners with an enhanced means of identifying talent.

## 2.4 Developing talent in tennis

Talent development is the process of providing the most appropriate learning environment to realize identified potential (Lidor et al., 2009; Vaeyens et al., 2008; Williams & Reilly, 2000). The capacity of an individual to develop and progress from one stage of development to the next is arguably the most important factor in the development of sport expertise (Abbott & Collins, 2004). Consequentially, optimising the talent development pathway is critical as it is a long term investment and the 'reward' may not appear for a number of years (Martindale et al., 2010).

The focus of talent development pathways should be on the interacting constraints impacting on the performance potential of athletes, rather than evaluating current physical performance and referencing to group norms (Phillips et al., 2010b). Traditional methods of TD, which reward age group success, will de-select a number of athletes and therefore not allow optimal development of individuals (Abbott & Collins, 2002). If new approaches that lead to improved athlete performance can be identified they have the potential to change current coaching practices and potentially the talent development system (Hammond & Smith, 2006).

### *2.4.1. Development of expertise*

The learning environment of an athlete is a major factor impacting on their capacity to develop (Abbott & Collins, 2004). To achieve elite performance, an environment containing deliberate practice which begins at a very young age and is maintained at high levels for at least a decade is suggested (Ericsson et al., 1993). Deliberate practice has the explicit purpose of improving the current level of performance and is defined as an activity that requires significant effort, is not considered enjoyable or motivating (as compared to 'play') and does not lead to immediate rewards (as compared to paid employment) (Ericsson et al., 1993). This type of practice is critical as experience alone is a weak predictor of current level of performance, with Ericsson (2013) noting that simply accruing practice hours will not result in the development of expertise. From an applied perspective, this makes sense as a number of people have accumulated a large number of hours playing sport without significantly improving their level (Pankhurst & Collins, 2013). The narrow definition of deliberate practice has encountered some opposition in the domain of sport, with speculation that the definition should include a wider range of activities. However, a broader definition for sport only (and not other domains) undermines the relevance of deliberate practice as a general theory of expertise development (Helsen, 1998).

The acquisition of deliberate practice is the major limiting factor in achieving expert performance (Ericsson & Charness, 1994), with the level of performance being closely related to the amount of deliberate practice completed (Ericsson et al., 1993). The interpretation of this development theory is that 'talent', plays at best, a very limited role in the development of expertise (Ericsson et al., 1993; Helsen, 1998). The common belief that people must possess 'talent' is more widespread in fields where there are a number of active individuals but only a few at the highest level of performance (e.g. sports) (Ericsson & Charness, 1994).

This development theory is generally considered to be a linear ascent towards expertise. However, evidence to the contrary suggests that this occurs in the vast minority (16.4%) (Gulbin, Weissensteiner, et al., 2013). This could be explained by the reduced role that deliberate practice is now believed to play in the development of expertise (Hambrick et al., 2014). Therefore, in conjunction with deliberate practice a number of other variables (e.g. starting age, genetics) also contribute to the development of expertise increase the complexity in its understanding. The number of development pathways is related directly to the complexity of the domain; the more complex the domain, the more pathways that are possible, and conversely the less required components for a domain, the less pathways that are possible (Simonton, 1999). Figure 3 demonstrates the considerable variety that exists in the developmental ascent of athletes with the majority of athletes experiencing one return to a lower level of competition before ascending again (Gulbin, Weissensteiner, et al., 2013). This is in contrast to the proposed linear ascent of deliberate practice. The vast diversity in development pathways is thought to be due to the individuality that occurs in each athlete's development pathway (Simonton, 1999).

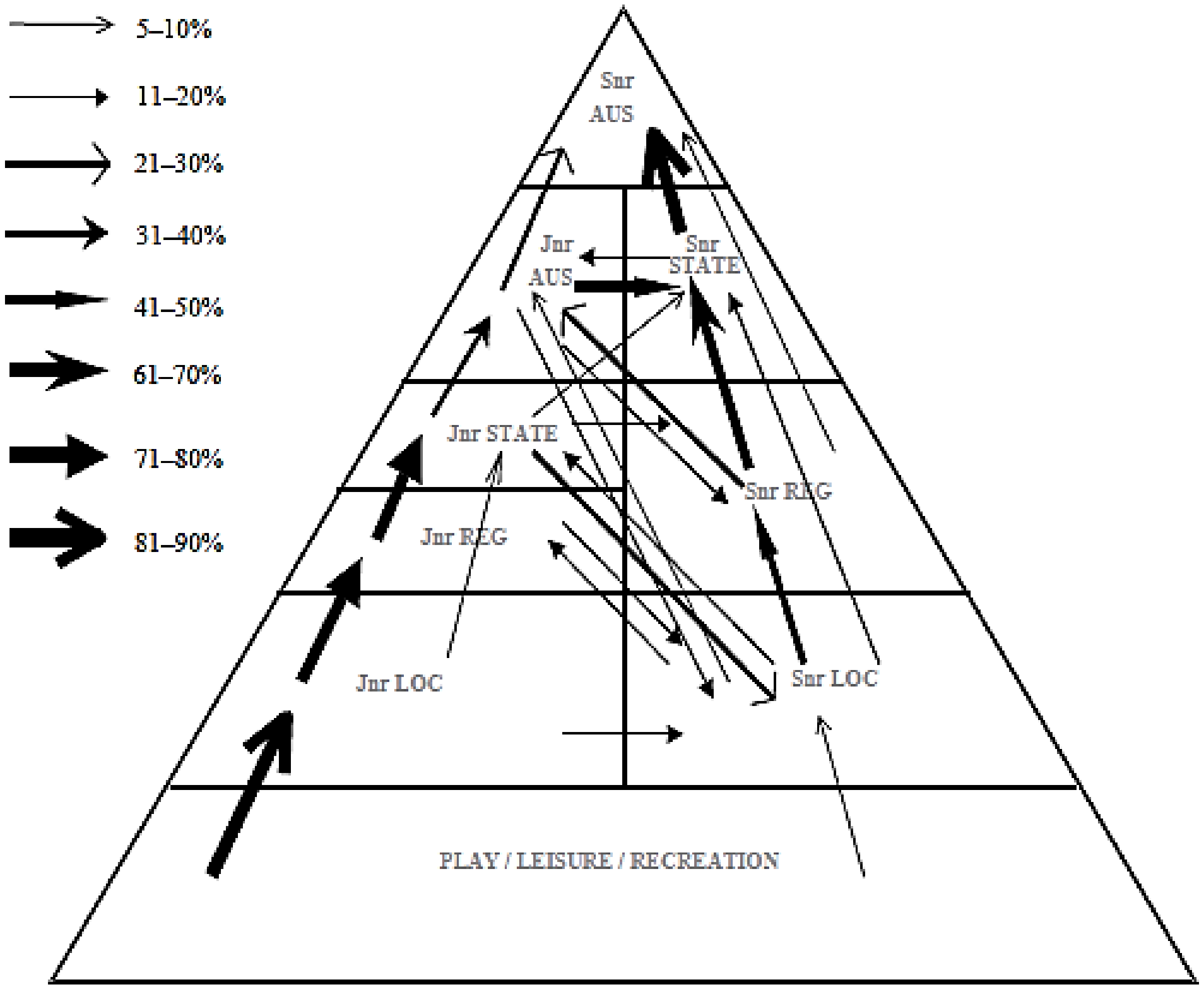


**Figure 3**. Representation of prevalence, magnitude and direction of transitions between competition levels. Transitions occurring in less than 5% of cases were not depicted and there were no transitions between 51-60%. Jnr - Junior competition, Snr – Senior competition, LOC – local club competition, REG – Regional competition, STATE – State competition, AUS – National competition. Taken from Gulbin, Weissensteiner, et al. (2013).

There is partial support for the theory of deliberate practice, with the relationship between training and expertise acknowledged. However, other elements such as the need for early specialisation, the exact amount of practice and lack of enjoyment in training not only lack sufficient evidence in sport but face stern opposition (Baker, Côté, & Deakin, 2005; Hambrick et al., 2014; Helsen, 1998; Oldenziel, Gagne, & Gulbin, 2004). There is a highly variable range in the number of sport-specific practice hours undertaken by expert athletes (Hambrick et al., 2014; Oldenziel et al., 2004). The development pathways of 681 athletes reported that 69% of novice athletes progressed to senior representation in <10 years, with the average being 7.5+4.1 years. Athletes who developed in <4 years were more prominent in individual sports, commenced their sport later and had greater variety in their sporting background prior to beginning their main sport (Oldenziel et al., 2004). An explanation for these results is related practice in other sports or activities lessened the amount of deliberate practice required (Baker et al., 2003). The theory of deliberate practice appears to simplify the development of expertise with evidence stating that there are a variety of elements both related to and separate from practice which are crucial to the development process. Gulbin et al. (2010) detail a number of important factors such as:

- A diverse sporting background prior to specialisation
- Commitment to practice
- Coaching and parental support
- A passion for the sport
- An ability to overcome obstacles.

Côté (1999) examined the development pathways of 4 families (3 rowing, 1 tennis) by conducting interviews with family members. Three distinct phases in the athlete's development pathway were identified, the sampling years, the specialising years and the investment years. The sampling years (age 6-13) were characterised as the initial involvement in sport where the focus was fun, excitement and experimentation rather than specific goal achievement. The specialising years (age 13-15) denotes a shift from fun and excitement towards sport-specific skill development and a limiting of sports participation to one or two sports. The investment years (age 15>) dictates athletes committing to achieving expert performance by narrowing their focus to their primary sport and increasing volume and intensity of practice. This study provided the foundations for the development model of sports participation (DMSP,

Figure 4) (Côté & Fraser-Thomas, 2007). Seven postulates that are central to the DMSP were identified, (Côté, Lidor, & Hackfort, 2009) they are:

- Early diversification does not hinder elite sport participation in sports where peak performance is reached after maturation
- Early diversification is linked to a longer sport career and has positive implications for long-term sport involvement
- Early diversification allows participation in a range of contexts that most favourably affects positive youth development
- A high amount of deliberate play during the sampling years establishes a range of motor and cognitive experiences that children can ultimately bring to their principal sport of interest
- High amounts of deliberate play during the sampling years builds a solid foundation of intrinsic motivation through involvement in activities that are enjoyable and promote intrinsic regulation
- Around the end of primary school (about age 13), children should have the opportunity to either choose to specialise in their favourite sport, or to continue in sport at a recreational level
- By late adolescence (around age 16), youth have developed the physical, cognitive, social, emotional, and motor skills needed to invest their efforts into highly specialised training in one sport

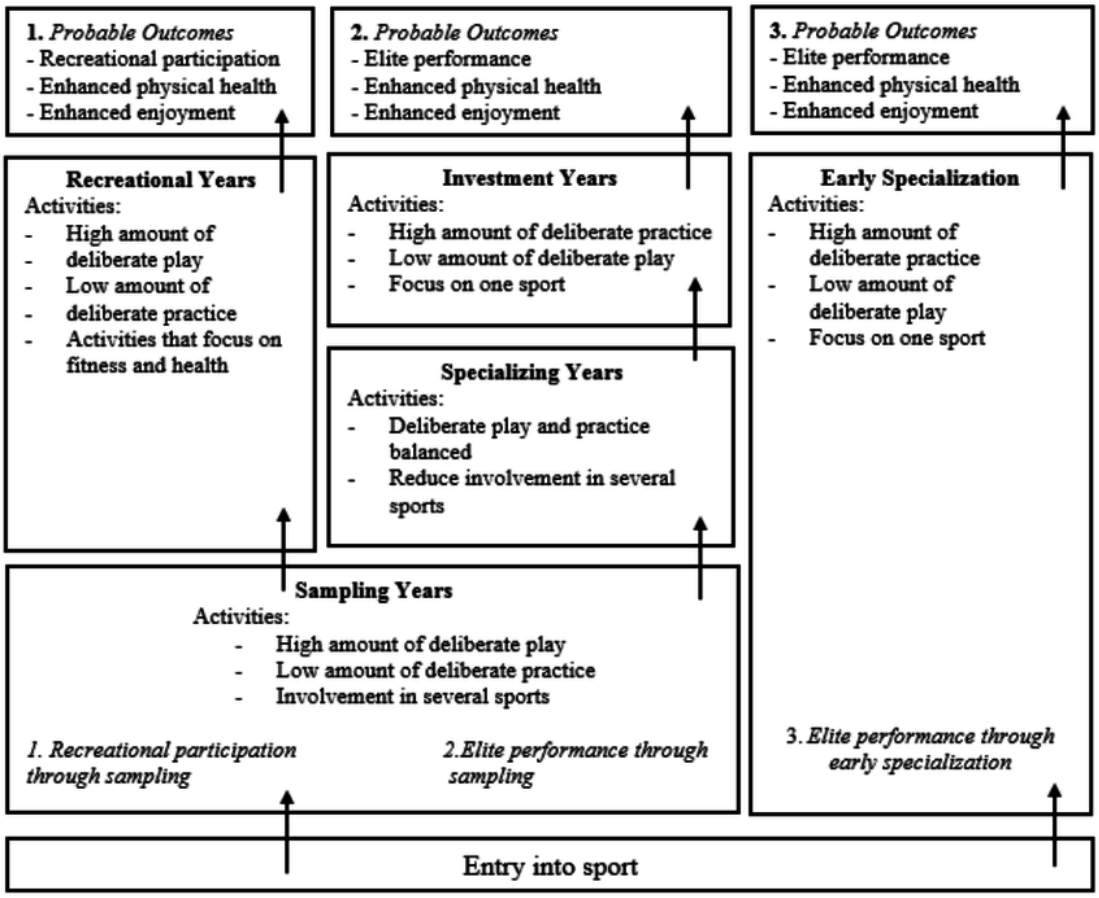


**Figure 4**. Developmental Model of Sport Participation. Adapted from Côté and Fraser-Thomas (2007).

The strength of evidence supporting these principles was assessed and confirmed, therefore validating the DMSP and its postulates (Côté & Vierimaa, 2014). This emphasises the importance of sampling (early diversification) and deliberate play in creating improved athlete performance, participation and personal development.

Despite having different names (the sampling years of the DMSP, the foundation component of the Foundations, Talent, Elite, Mastery (FTEM) model [Figure 5], or the determinants of potential (transferable variables) (Figure 6), the focus of these development models is on developing the underlying skills required for elite sport performance (not current performance) through play and sampling a wide range of sports (Abbott & Collins, 2004; Gulbin, Croser, et al., 2013). This is in comparison to when athletes begin to specialise, in which case the focus should move towards the investment years in the DMSP, elite and mastery components of the FTEM, or determinants of performance (sport specific). Understanding the optimal time to move from sampling a range of sports to specialising in one, or even specialising from as early as possible is an often discussed point in the literature

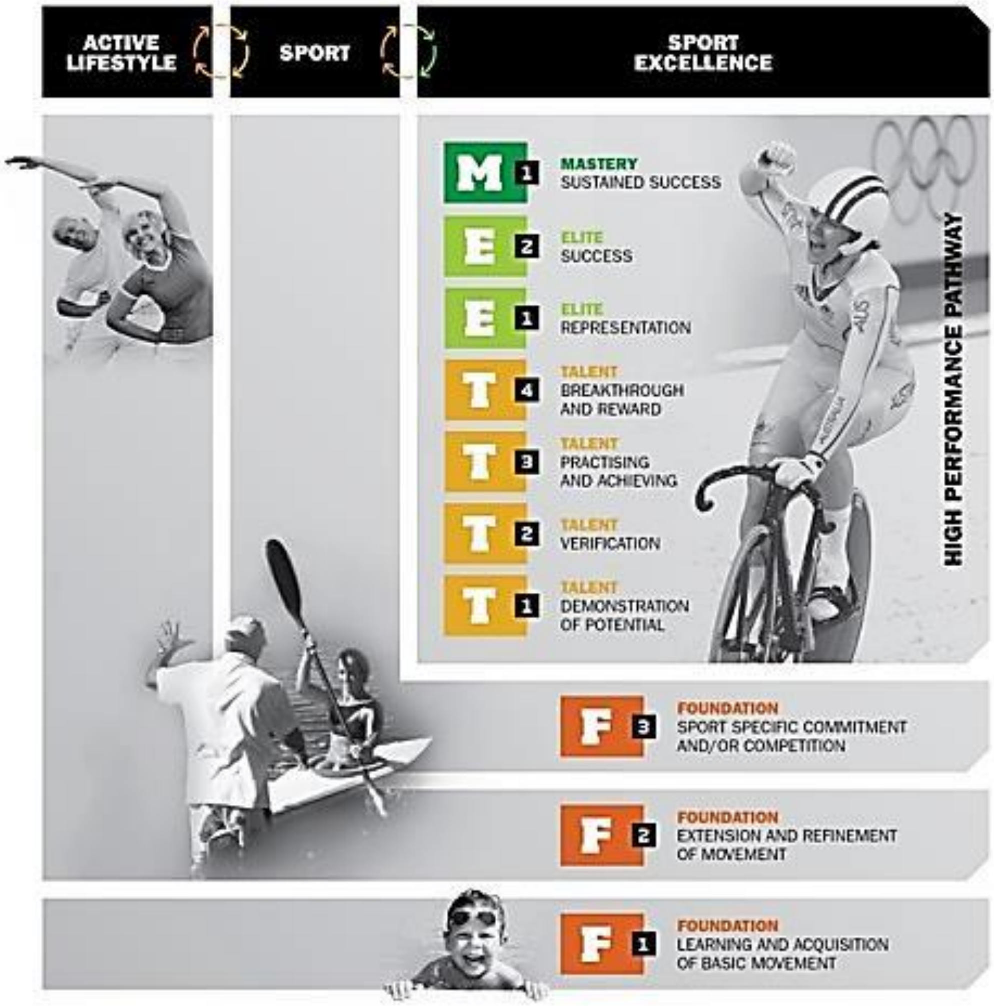


**Figure 5**. The integrated FTEM (Foundations, Talent, Elite, Mastery) framework for the optimisation of sport and athlete development, taken from Gulbin, Croser, et al. (2013).

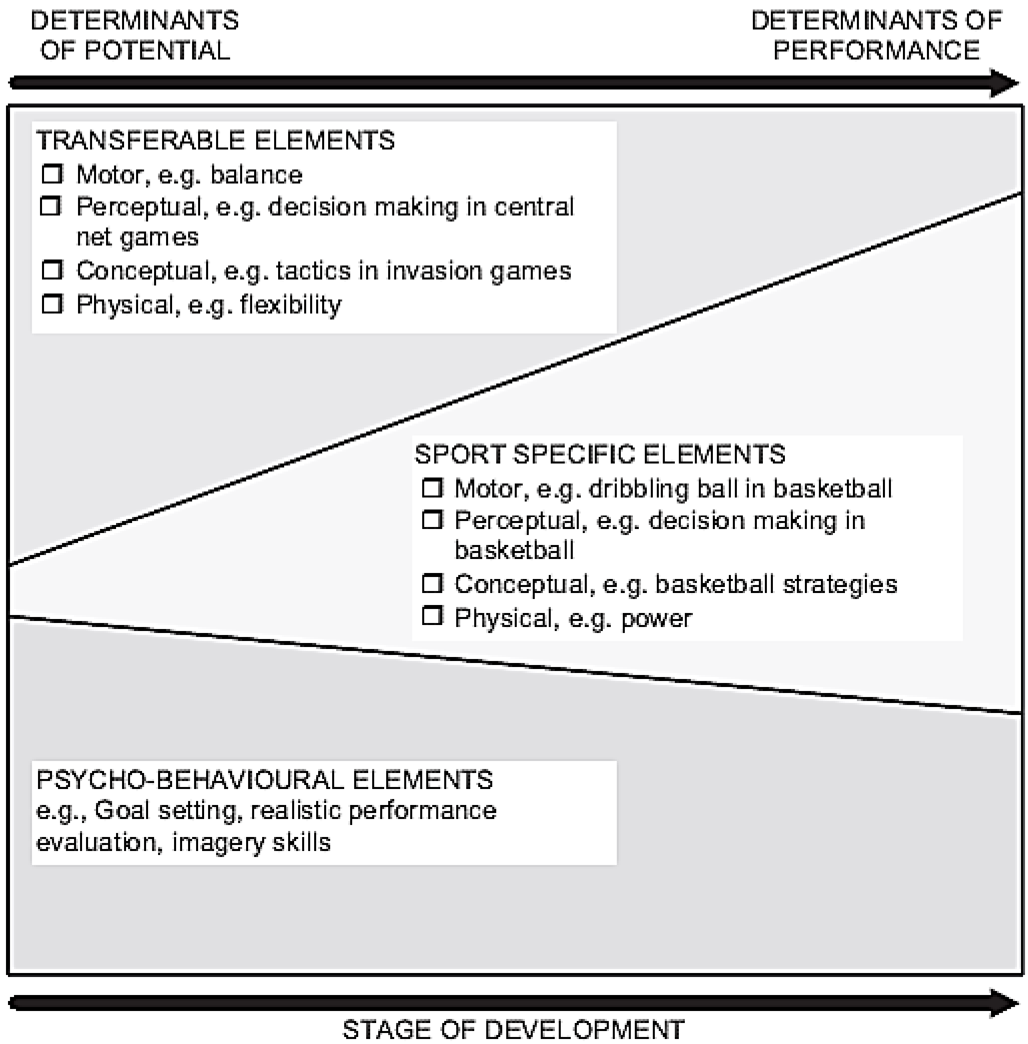


**Figure 6**. Contribution of motor, perceptual, conceptual, physical and psychological elements to athlete development. Taken from Abbott and Collins (2004).

*2.4.2 Sampling vs early specialisation*

Experts who participate in a broad range of sports experiences during their development years may derive a functional benefit, in that, the amount of sport-specific practice required is lessened (Baker et al., 2003). This is articulated succinctly in Abernethy et al. (2005) who state “the greater the number of activities the athletes experienced and practised in their developing years (0-12 years) the less deliberate, domain-specific practice that was necessary to acquire expertise within their sport of specialization”. The importance of this developmental period, titled the sampling years (6-12 years old) by Côté (1999), is the underlying fundamental motor skills required for sports participation such as running, jumping and throwing are developed and refined.

It is proposed that these fundamental motor skills are transferable across a number of different sports that share similar general abilities (Baker et al., 2003). Additional benefits from sampling a range of sports include a positive impact on the length of sports career, general long term involvement in sport and improved perceptual and decision making skills within their sport (Berry et al., 2008; Côté et al., 2009).

A number of studies have demonstrated benefit from undertaking a sampling path of development and that early sport specialisation is not a requirement for the development of expertise (Baker et al., 2003; Baker et al., 2005; Berry et al., 2008; Fransen et al., 2012; Gullich, 2016). Sampling possesses the ability to discriminate between a population of athletes already classified as elite (Gullich, 2016). The practice histories of 83 international medallists were compared to non-medallists across a variety of sports (an example sport is provided per category with a greater range completed in the study), such as:

- Centimetres, grams and seconds (CGS) sports – Athletics
- Game sports – Basketball
- Combat sports – Boxing
- Artistic composition sports – Artistic gymnastics
- Others – Equestrian

Medallists begun practicing their main sport at a significantly later date than non-medallists (11.8 ± 4.5 years of age compared to 10.3 ± 4.0 years of age, $p<0.01$) and specialised later (14.8 years ± 6.0 years of age compared to 11.9 ± 5.5 years of age, $p<0.01$). Medallists also completed a greater number of practice hours in other sports up until the age of 18 compared to non-medallists ($p<0.01$). Non-medallists performed more practice in their main sport until 10 years of age ($p<0.01$), between 11-14 years of age ($p<0.05$) and between 15-18 years of age ($p<0.01$). The variety of sports considered and homogeneity of the population (elite athletes) serve to strengthen the findings of this study and its support for a sampling path of development (Gullich, 2016).

From a junior perspective, a study comparing the developmental profiles (sampling vs. specialisation) of boys aged 6-12 years found a positive effect in sampling a variety of sports for variables such a strength, speed, endurance and gross motor coordination although the need for longitudinal research was acknowledged (Fransen et al., 2012). Sampling provides a positive effect for the developing athlete as they are exposed to a variety of different environments (physical, cognitive, psycho-social) which require the development of a solution for those unique circumstances (Côté et al., 2009; Vaeyens, Gullich, Warr, & Philippaerts, 2009). The wider the learning base of an individual the more possible outcomes that can be considered in finding the best solution (Mckeown, 2012). Additionally, it increases the probability that an athlete will uncover the most appropriate sport for their own individual talent, reduces the risk of staleness and emotional fatigue and importantly increase the total talent pool from which athletes can be later developed (Vaeyens et al., 2009).

Early sports specialisation has been defined as year round sport-specific training and participation on a number of teams within a sport. The prevalence of early specialisation in pre-adolescent youth is on the rise (Bergeron et al., 2015; Brenner, 2016; Hecimovich, 2004; Mostafavifar et al., 2013). Despite the low probability of achieving a college scholarship or a professional career the lure they present results in children and parents believing that early sport specialisation is not only necessary, but undertaking any other course of action would be unwise (Brenner, 2016; Hecimovich, 2004; Wiersma, 2000). Advocates of this approach state that it is practically impossible for other athletes to catch up with elite performers that have maintained high levels of deliberate practice (Ericsson & Charness, 1994).

Opponents of the early sport specialisation approach, such as the American Academy of Pediatrics, caution that not only are children missing out on benefits associated with sampling a range of sports, but face increased physical, physiological and psychological demands (Brenner, 2016). This arises from the level of commitment required by specialisation which tends to supersede a number of other important developmental aspects in the junior athlete's life (Wiersma, 2000). The potential negative impact of early sport specialisation is a decrease in general motor skill development, increased risk of injury, burnout (as a result of stress, missed social and educational opportunities) and consequentially a potential decrease in lifelong physical activity (Figure 7) (Bergeron et al., 2015; Brenner, 2016; Côté et al., 2009; Hecimovich, 2004; Mostafavifar et al., 2013; Wiersma, 2000). In light of these potential negative consequences it is unlikely that a child would choose to participate in an early sports specialisation program. Parents place a much greater value on the perceived outcomes of a specialised program in comparison to children (Wiersma, 2000).

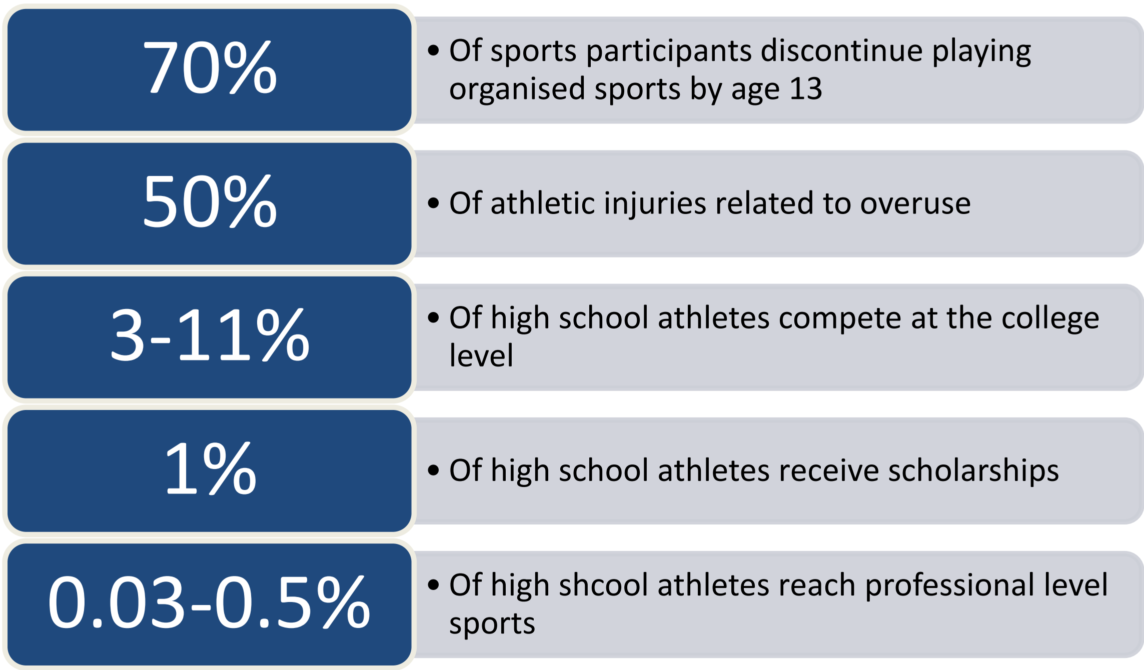


**Figure 7**. Impact of sport specialisation. Adapted from Brenner (2016)

A study specifically on tennis development compared elite senior players to control participants who were matched based on their junior ranking (Carlson, 1988). The controls had greater interest and pressure for success from their parents. Early sport specialisation was found not to be conducive to the development of expertise with the elite group engaging in other sports for longer. Additionally the elite group began sport specialisation at 14 years of age compared to 11 for the controls who did experience greater junior success. This data advocates a sport sampling approach and reinforces that greater success at junior level does not translate to senior success. Tennis players who experienced burnout reported less input into their training, playing in older age divisions and higher perceived parental expectations and criticism (Gould, Udry, Tuffey, & Loehr, 1996). Due to the comparative lack of complexity, it could be argued that early specialisation would be more effective in sports which focus more on physical effort (CGS sports) rather than skill and tactical expertise. However, this was found not to be the case within a group of CGS sports (Canoeing/kayak, cycling, orienteering, rowing, sailing, skiing, swimming, track and field, triathlon and weightlifting) (Moesch, Elbe, Hauge, & Wikman, 2011). Elite athletes were characterised as specialising later when compared to their non-elite counterparts, with the non-elites completing significantly more practice at ages 9, 12 and 15 (moderate effect sizes 0.45-0.50, $p<0.05$) (Moesch et al., 2011).

It is not only the individual that prioritises early specialisation as policy makers often unconsciously reinforce early specialisation (Martindale et al., 2005). Governing bodies of tennis in the U.S.A and UK endorse the value of ‘fun’, along with participation in other sports and general development until the age of 12 but select players for advanced training programs before this age because of their competitive tennis playing ability (Pankhurst & Collins, 2013). Talent development processes are undermined via the provision of opportunities (coaching, equipment) and funding to athletes that excel in their age group (Martindale et al., 2005). The discrepancy between stakeholders (coaches, parents and governing bodies) and the literature is further illustrated by interviews with these stakeholders regarding their opinion on researched ‘principles’ surrounding talent identification and development (Pankhurst, Collins, & Macnamara, 2013). None of the stakeholders strongly agreed with any of the 5 key constructs examined (sport specialisation and selection, practice, athlete development, junior and adult success, the role of the stakeholders) demonstrating a preference for incumbent practices due, at least in part, to a lack of support/knowledge of the researched principles. Providing an alternative but practical development pathway may help alleviate some of the disagreement. The optimal talent development process should allow junior athletes to develop an appropriate and wide ranging number of skills that include physical, psychological, social and educational (Wiersma, 2000). However, there is a lack of research investigating effective development environments and how they can be optimised (nature, type, frequency) whilst remaining relevant to a specific domain (for example, sport) (Martindale et al., 2005; Williams & Reilly, 2000).

Sport sampling is at best, very beneficial, and at worst, does not hinder the development of sport-specific expertise where peak performance occurs after maturation (which applies to tennis as peak performance is ~24 years of age (Allen & Hopkins, 2015)) (Côté et al., 2009). This is in comparison to early sports specialisation which at best, is also beneficial but at worst, may hinder the development and long term sports participation of an individual, through early de-selection, injury and dropout (Bergeron et al., 2015; Brenner, 2016; Côté et al., 2009; Hecimovich, 2004; Mostafavifar et al., 2013; Wiersma, 2000). Amidst the conjecture of the optimal method to develop athletes, at a minimum this research shows that early specialisation may not be the essential prerequisite for expert performance that it was once thought to be (Baker et al., 2003; Vaeyens et al., 2009).

### *2.4.3 Summary and limitations of current processes in tennis*

The introduction into tennis for beginners is too often characterised by an early specialisation approach, deficient in the multi-dimensional attributes required (physical, technical, tactical, psychological)(Gonzalez & Ochoa, 2003). The International Tennis Federation (ITF) endorsed the Long Term Athlete Development Model (LTAD) which contains 6 distinct stages (FUNdamental stage, learning to train, training to train, training to compete, training to win, retirement/retainment) (Balyi & Hamilton, 2004; Balyi & Hamilton, 2003). In this model success occurs after a substantial period of development and the hastening of competition will always result in deficiencies in a vital area of the game (physical, technical, tactical psychological) (Balyi & Hamilton, 2003). It is advised that competition and training schedules should reflect the developmental requirements of the athlete (Balyi & Hamilton, 2003). For tennis, it is noted that specialisation should not occur before the age of 10 and a general (sport sampling) approach be adopted focusing on the development and subsequent mastery of critical underlying fundamental motor skills (Balyi & Hamilton, 2003). It is postulated that this will aid in the "better trainability for long-term sport specific development". The development of suitable training programs for the unique demands of tennis is an ongoing task (Lees, 2003).

Increased variability coupled with the emergence of intrinsic feedback will provide a greater benefit to the developing athlete than the more commonly accepted occurrence of overly prescriptive coaching (Reid, Crespo, Lay, et al., 2007). Young athlete's following the same path of development as senior athletes is not supported by the literature as these athletes are in very different stages of development (for example, sampling years vs. investment years in the DMSP) (Côté & Fraser-Thomas, 2007). The senior athlete is specialised and looking to maintain their elite level of performance, whilst the young athlete is in a sampling and development phase.

Despite the plethora of research detailing the significant differences between junior and senior athlete's and how they must be treated differently, the status quo of coach led, highly repetitive tennis based training has dominated the applied setting (Hewitt, Edwards, Ashworth, & Pill, 2016; Reid, Crespo, Lay, et al., 2007). This may be in part, due to the lack of thoroughly researched tennis-specific alternatives. The difficulty of performing longitudinal studies of alternative development theories is a problem acknowledged in the talent development literature (Morris, 2000). The practical application of research in the field appears to be where the breakdown is occurring. The reality of separating the will to compete and the will to improve performance is acknowledged as players who strive to improve will naturally want to test their improvements via competition (Goncalves, Rama, & Figueiredo, 2012).

However, this needs to be tempered during early development and not encouraged by the governing bodies. The International Olympic Committee's consensus statement on youth athletic development succinctly articulates the purpose of development programs, "the goal is clear: develop healthy, capable and resilient young athletes, while attaining widespread, inclusive, sustainable and enjoyable participation and success for all levels of individual athletic achievement" (Bergeron et al., 2015).

**2.5 Relevance of adaptability to talent identification and development**

Adaptability has been investigated previously in different fields (e.g. business, leadership) with the findings providing transferable elements to talent identification and development in sport. An individual can maintain their current level or adapt and attempt to transcend the constraints of the situation (Mckeown, 2012). This statement highlights the need for adaptability as a common principle of talent development in elite sport. The primary focus of talent development pathways should be to progress individuals to the next stage of development rather than focusing on current performance (Abbott & Collins, 2004; Phillips et al., 2010b). Regardless of the field, the adaptability literature is discussed in the context of aspiring towards the development of expertise, separating the individual, group or business from their competition. Adaptability is discussed as having the potential to provide an entity with a competitive advantage (Mckeown, 2012). In these terms, it is clear to see how adaptability can be relevant to sport, specifically, talent identification and development.

A study investigating creativity in junior European handball (7, 10 and 13 years of age) recommended that talent identification programs would profit from an improved understanding of the development of unique tactical solutions and tests that accurately assess this construct (Memmert, 2011). This is especially pertinent as childhood is considered the best period to examine creativity and unique thinking, with a plateau effect in creative thinking emerging between the ages of 10 and 13 (Memmert, 2011). However, due to the declining levels of deliberate play, the opportunity for children to embrace and explore their creativity and adaptability is limited (Weissensteiner et al., 2009). To better develop expertise, there is a need to understand the type of practice and development that stimulates higher order processing during competition (McPherson, 1999). Experts in their field are able to adapt quickly and overcome new circumstances by correctly understanding the response required, rather than providing an automated response that has roots in a highly repetitive development pathway (Ericsson, 1998).

Non-linear development is a player centred process that is focused on the interaction of the individual and their environment (Phillips et al., 2010b). Movements and decisions are a direct result of the assessment of individual, task and environmental constraints. Therefore, the focus of the athlete becomes how to best exploit these constraints to produce a specific performance outcome (Davids et al., 2013). An applied example is provided in cricket where eleven international fast bowlers were interviewed regarding their development pathway (Phillips et al., 2010a). A number of constraints influenced the development pathway; family support, birthplace, timing of specialisation, talent development program support and maturation. As individuals uniquely interact with these constraints, their development pathway also becomes unique, therefore resulting in an individualised, non-linear development pathway. The benefit of unstructured play was reported with all participants recalling that they engaged in 'backyard cricket' and that this was an important part of their development (Phillips et al., 2010a). Engaging in 'backyard cricket' provided experts an early opportunity to adapt to the constraints of the activity (for example, different number of fielders, different balls) and create unique performance outcomes (Phillips et al., 2010a). Additional evidence is found in Brazil where "pelada" a cultural term to describe soccer with modified norms and rules is regularly played (Araujo et al., 2010). A number of world class players recalled their involvement in these unstructured, non-coached games, noting the variable environment; changes such as, substitutes for the ball (avocado seed, rubber ball, sock balls), playing on uneven surfaces and different environments (orchard, against a wall) (Araujo et al., 2010). The number and magnitude of constraints impacted can be seen in Table 1. The subjects may have appeared to specialise early but the extreme variability in constraints they experienced allowed them to benefit from important aspects of both early specialisation (accumulation of practice hours) and sampling (variety of motor control experiences). Non-linear development promotes implicit learning as individuals search for their own solution to the task, whilst maintaining a developmentally appropriate focus as the constraints are dictated by the coach and individual (Renshaw et al., 2010).

**Table 1**. Environmental and task constraints that characterise Brazilian "pelada". Taken from Araujo et al. (2010)

| | |
|---|---|
| **Locale of practice** | Street, beach, court, dirt-fields, formal fields, backyards or any available space. Different surfaces and conditions can generate different variations of football games. |
| **Field dimension** | Tacit, undefined and variable. The pitch can be constantly adjusted through implicit agreement amongst players, based on player's suggestions or to adjust to the particularities of the task, or of the local (e.g., before the building). |
| **Facilities** | Stones, shoes or bags are used as posts, and goal sizes can be modified according to the game. Game can be played with any kind of ball or something able to be kicked. Uniform can be t-shirts versus shirtless. Players also often are playing barefoot. |
| **Team conditions** | Adaptive and versatile. The number of players is adjusted to keep ongoing challenge, fun and well-balanced levels of competition. It can happen with different age-groups and gender playing together, with numerical disparity and different levels of ability. |
| **Intervention** | No coach or instructors intervention. Learning happens among players, who usually try to replicate skills performed by elite players or skillful friends. |
| **Functions and tactical positions** | There are no fixed positions or tactical arrangements. A player can change position or function many times during the game and the actual game might help players arrange themselves in defensive and attack movements and positions. |
| **Targets** | Replicate the same technical movement or skill performed by a famous player. Try to execute something new or in a new way. Have fun with friends. Maintaining high levels of competition and challenges as criteria for the continuity of the game, besides winning. |
| **Training sessions** | The game happens until a number of goals have been scored, reach a set time or even players get tired or lose fun and enjoyment. During a whole day, the game might be stopped many times and restarted in an old or new configuration. |

In response to some of the main criticisms of talent identification and development programs, a pathway that provides children with a wide ranging, varied training experience can help alleviate a number of these problems (Côté et al., 2009; Hecimovich, 2004; Mostafavifar et al., 2013). Children should be thought of as all round players and not sport specific specialists. This premise aligns with the corresponding period of development that they are currently in (Côté & Fraser-Thomas, 2007; Gulbin, Croser, et al., 2013). When considering athlete developmental models for the most appropriate developmental period for adaptability training, a logical conclusion would be that stable behaviour would best develop under conditions of high specialisation (later in the developmental period). However, aside from the theory of deliberate practice, developmental models generally prescribe participation in a wide range of activities and different sports up until the age of 12 (Balyi & Hamilton, 2003; Côté, 1999; Côté & Fraser-Thomas, 2007; Gulbin, Croser, et al., 2013), this focus on variation and sampling presents itself as an opportune time to develop adaptability.

To maximise the benefits of developing athletes via this method (e.g. improved retention of athletes and therefore increased talent pool), coaches who believe in and practice this non-sport specific view must be employed (Gulbin et al., 2010). A survey of 673 elite athletes reported that the required qualities of coaches changed throughout the development pathway (Gulbin et al., 2010). As performance level increased, the required attributes of coaches changed from the ability to motivate/encourage/teach to detailed knowledge of the sport and insistence on perfection (Gulbin et al., 2010). Ensuring coaches are matched to the development period they are best suited will provide the best outcome for the athlete, potentially minimising dropout and injury risk due to early specialisation and overtraining (Brenner, 2016; Memmert & Roth, 2007).

Despite the potential of adaptability to be trained through all of the aforementioned methods, there is still some literature that takes a narrower view on adaptability (Ugrinowitsch, Dos Santos-Naves, Carbinatto, Benda, & Tani, 2011). A coincidence timing task was conducted with university students who obtained one of three learning levels prior to assessment, pre-stabilisation (too few trials to achieve performance stabilisation), stabilisation (performance stabilisation) and super-stabilisation (an increased level of performance stabilisation). The test was deliberately perturbed in the assessment phase to ensure participants had to adapt their movements to a new perceptual stimulus. At the end of the stabilisation phase, analysis of the coefficient of variation for absolute error found that the stabilisation and super-stabilisation group were more variable than the pre-stabilisation group ($p<0.0002$), whilst after the perturbation the super-stabilisation group was more accurate than the pre-stabilisation group ($p=0.001$). These results were interpreted as variability in early learning being due to inconsistency in performance, where in later learning it is due to higher amounts of practice (Ugrinowitsch et al., 2011). The perturbation was uniform across the groups and as adaptability was tested after participants reached a certain stabilisation level the perturbation was not specific for that population group. Therefore the manipulation to the test was not developmentally appropriate for each group. Additionally, at no point was an intervention with the purpose of improving adaptability (broad range of experiences, contextual interference, skill transfer, specific task related adaptability training) included. As a result, it would appear appropriate that this narrow view of adaptability should only be applied in a suitably narrow context.

## 2.6 Relevance of adaptability to tennis

Tennis places a high level of demands on the player; the sub-maximal output of the lower body, the precise inter-muscular coordination of the upper body, all under the backdrop of significant cognitive demands (Ferrauti, Pluim, & Weber, 2001). Providing complex situations that occur quickly, lack uniformity and are unpredictable, will best expose the disparity between experts and non-experts as these situations require the retrieval and attending to of perceptual information, combined with using this information to perform a skilled task (Mann et al., 2007). Tennis is a sport that is centred around unpredictability. Point length, shot type, tactics, duration, environment (weather, surface, spectators) and the opponent all provide an element of uncertainty in a tennis match and significantly influence the outcome of a match (Kovacs, 2006). Regardless of the detailed planning and preparation undertaken by an individual athlete, they can never be certain about what their opponent will do at any given stage of the match. Successful players understand that they are operating in an unstable, changeable environment and adapt their skills to best suit the environment (Passos et al., 2008). The ability to be creative in sports is underpinned by perceiving the relevant stimuli and making a unique or unexpected decision that is beneficial for performance (Memmert, Baker, & Bertsch, 2010). This has been identified by coaches as a desirable quality, although the method to develop this is less clear with a broad range of experiences being the most prolific argument behind its development (Memmert et al., 2010).

Specific examples have been found in tennis, even where intuitively it would appear least likely, with the closed skill of the serve (Whiteside, Elliott, Lay, & Reid, 2013). No single mechanical element was responsible for service faults and therefore trying to perfect a repeatable service action was denounced in favour of a highly adaptable movement system (Whiteside et al., 2013). An adaptable movement system can account for variability that naturally exists in components of the serve such as the ball toss. The functional benefit of a variable and adaptable movement system was reinforced when it was reported that the location of the ball toss was more variable at impact than ball zenith ($p<0.001$). The variability impacted elbow mechanics but not the temporal organisation of joint mechanics, suggesting the ball toss dictated the service motion (Whiteside et al., 2015). Therefore, it is more important for players to learn how to perceive and act appropriately to the variable ball toss rather than focusing on a perfect toss location (Whiteside et al., 2015). Serve accuracy and velocity was investigated with two groups of young tennis players (13 ± 1.52 years of age), one undertaking consistent practice and one variable practice (Hernandez-Davo et al., 2014). The variable practice group experienced a number of different manipulations, such as:

- Modified base of support – on the floor, on 5cm and 10cm thick mats, standing on one leg (dominant and non-dominant leg) and changing the width of the base of support
- Modified position of player – 1m behind and in front of the baseline; in centre court; at a 2.5m and 5m distance from the centre service mark.
- Modified ball toss – in front of, over and behind the player; to the right, over and to the left of the player; very high, at a normal height and very low
- Modified spatial orientation – facing the net, in a 45° and 90° angle to the baseline
- Modified length of movement – starting from a pause, preparing to hit the ball forward and preparing to hit the ball exaggeratedly behind

Both groups experienced significant increases in velocity ($p=0.001$, variable group 7.68%, consistent group 4.8%) whist the accuracy was significantly improved in only the variable practice group ($p=0.035$, radial error decreased from $2.67 \pm 1.52$m to $2.21 \pm 1.19$m). The variability in practice allowed for the development of an intrinsic understanding of the task by the individual. As a result the variable group adapted to the post-test better, the specificity associated with the consistency group did not yield the same result.

Research has begun to use these principles to incorporate variability into a number of studies. Tasks such as medicine ball throws and using an overweighted racquet have been reported to increase the velocity of a tennis stroke by 11 and 5% respectively. More importantly, the accuracy of the overweighted racquet group was not significantly different when compared to the regular tennis training group whereas the medicine ball throw group experienced decreases in accuracy when compared to the overweight racquet group (p=0.043) and regular tennis group (p=0.027) (Genevois et al., 2013). This demonstrates the potential benefits from purely a performance perspective that may be unearthed by using different training protocols. This does not encompass the underlying cognitive benefits that are occurring as well. The varied tasks force the motor action plan to be under constant cognitive reconstruction which is considered crucial for retention (Memmert et al., 2009).

Additional training stimuli which are used regularly in the field are the practice of over-arm throwing and serving from the knees as methods to improve the serve (Reid, Giblin, & Whiteside, 2015). Over-arm throwing received some support from a mechanical (trunk kinematics) and ball speed perspective (Reid et al., 2015) but this was tempered by the fact that the throwing movement did not reflect the serve across arm joint segments, therefore limiting the efficacy of this approach. Serving from the knees received similar cautious support with some favourable adaptations to the constraints (increased racquet angle) but also the lack of some hypothesised benefits (increased elbow extension) (Reid, Whiteside, Gilbin, & Elliott, 2013).

**2.7 Summary and conclusions**

Every tennis match is different, every set, game and individual point are different. Athletes must draw on their wide ranging skill set (physical, technical, tactical and psychological) to continually adapt their performance to the unique set of circumstances they are faced with. The combination of a dynamic environment and the necessity to be proficient in a number of different areas (physical, technical, tactical and psychological) poses a significant challenge when trying to identify talent in tennis. The reliance on current performance based measures to identify talent has a number of shortcomings (biasing previous tennis experience, advanced maturation, not an assessment of potential). An alternative method of talent identification that still reflects the dynamic environment of tennis but addresses the shortcomings of performance measures is warranted. Fundamental motor skill tests begin to address these shortcomings and require further investigation. The proposed link between the legitimacy of these tests (such as the KTK) for talent identification purposes in sports that require a wide-ranging skill set has some support but requires a more complete evidence base (Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012).

Understanding the optimal development pathway that is required for expert performance in sport is an incredibly difficult task. A complete understanding of the role of sport-specific practice and other complimentary sports and activities is required (Baker et al., 2003). This is in conjunction with fully understanding the environmental factors that impact on the athlete (Ericsson et al., 1993). Despite some opposition, the general consensus of the literature is that a sampling path of development should be promoted until at least the teenage years where specialisation may occur. However, it is not only the accrual of hours that is necessary for the development of expertise but of at least equal importance is the type of practice which is undertaken (Williams & Ericsson, 2005). The creation of a novel development method that combines a wide range of activities that a sampling theory of development dictates, but is performed in a context that maintains a link to sport specialisation, will be a valuable tool in the field. The discovery of novel training methods that have the potential to generalise will significantly add to the literature (Ericsson & Charness, 1994).

The benefit of an adaptability talent identification and development program is that it will provide wide ranging movement and skill challenge for individuals. The greater exposure to unique situations will provide a level of comfort with change and unexpected events that will allow athletes to prosper rather than succumb during these situations. The ability of an athlete to adapt and produce desired outcomes impacts on their ability to learn and develop (Phillips et al., 2010a) with the fastest learners being those with the ability to adapt to a number of simple and complex situations (Bourquin, 2003).

## 2.8 Purpose and research questions

The aims of this research are to:

- Develop two novel tests for the purpose of talent identification in tennis, targeted for children 8-11 years of age. These tests will incorporate the novel concept of movement and skill adaptability and be scientifically valid and reliable.
- Investigate the relationship between the novel adaptability tests and established tests in areas pertinent to tennis, talent identification and talent development (anthropometric, maturation, physical, general motor skill and tennis skill) with a beginner, junior (8-11 years of age) population. It is hypothesised that the novel adaptability tests will correlate strongest to tennis skill.
- Compare the effectiveness of an adaptability based training intervention to a regular tennis training intervention with a beginner, junior (8-11 years of age) population. The adaptability program will produce greater benefits in tennis performance compared to the regular tennis training intervention.
- Examine the predictive ability of the novel adaptability tests in reference to pre and post intervention values of tennis performance with a beginner, junior (8-11 years of age) population. Adaptability will predict future tennis performance.

# Chapter 3. Study 1: Development of two novel movement and skill adaptability tests for talent identification in tennis

## 3.1 Introduction

Tennis requires expertise in a number of key performance areas (physical, technical, tactical and psychological) (Fernandez-Fernandez et al., 2009; Hornery et al., 2007a; Kovacs, 2006, 2007; Unierzyski, 2002). The talent identification protocols should reflect the diverse, dynamic nature of the sport, otherwise potentially talented individuals may be wrongly de-selected from the talent development pathway (Abbott & Collins, 2002; MacNamara & Collins, 2014; Reilly et al., 2000). There are recommendations from the literature on how to improve TI protocols (e.g. embracing variability) (Davids et al., 2013) however, creating a viable alternative is a challenging proposition and rarely attempted (Breitbach et al., 2014). Creating a TI protocol which is representative of the sport's dynamic environment but maintains scientific credibility with strong validity and reliability is a difficult task. Movement and skill adaptability is defined as an individual's ability to manipulate their performance in response to changing constraints (Martin et al., 2012; Newell, 1986) and has the potential to address these issues. Adaptability and tennis require the performance of open skills, which are constantly being adjusted in response to changing stimuli.

The incumbent methods of talent identification in tennis and the researched evidence base focus on junior rankings and tournament results ("Athlete development scholarship criteria," 2015; Brouwers et al., 2012; Miley & Nesbitt, 1995; Reid et al., 2009; Reid, Crespo, Santilli, et al., 2007; Reid & Morris, 2013). Using a rankings/results approach represents an evaluation of current performance and often overlooks the capacity to further develop (Martindale et al., 2005). Adaptability better reflects the diverse, dynamic nature of tennis and therefore was used as the underlying principle in the design of two novel tests, the Throwing and Rebound Task (TRT) and the Continuous Rebounding Task (CRT).

The rankings/results approach currently predominantly employed in tennis is not underpinned by clear research findings (Brouwers et al., 2012; Reid et al., 2009; Reid, Crespo, Santilli, et al., 2007; Reid & Morris, 2013). The predictive value, relative to a senior career, of under 14 youth tennis tournaments and junior rankings (under 18) was found to be poor (Brouwers et al., 2012). Under 14 youth tournaments only yielded $R^2$ values of 0.043 for males and 0.088 for females when correlated to senior professional rankings.

The developmental history of the top 100 ranked senior men revealed 91% achieved a junior ranking (Reid & Morris, 2013). However, examining this result more closely shows the junior ranking did not have a cut-off (e.g. it could have been in the 1-2000's). The average peak in top 100 junior rankings' was 94.1±148.9, demonstrating the marked variability that can occur with performance based measures of development. Two studies examined the relationship between junior ITF top 20 rankings and professional rankings (Reid et al., 2009; Reid, Crespo, Santilli, et al., 2007). A regression equation using the girls' junior ranking and age at junior ranking predicted 13% of the variance in their professional ranking. Whilst for boys, the junior ranking only accounted for approximately 4.5% of variation in the professional ranks (Reid et al., 2009; Reid, Crespo, Santilli, et al., 2007). A limitation of this research is that although participants were considered "juniors", ranked athletes are generally 17-18 years of age and therefore TI protocols are less relevant. Athletes are focusing on optimising their performance for elite senior success rather than being talent identified and developed. Furthermore, there are varying definitions of 'success' in these studies (achieving a ranking, top 100, top 200) which limits comparison between results. Only Brouwers et al. (2012) investigated the under 14 age group with the majority of studies focusing on the under 18 age group.

This provides an opportunity for research on younger children (<14 years old), as talent identification processes are occurring in the field with younger children despite there being limited research in this area (Bastieans, 2006; Pankhurst, 2013).

Importantly, a ranking and results approach only accounted for ~4-13% in professional ranking variance. Therefore, the legitimacy of this approach can be questioned and future research should focus on the search for more pertinent variables.

Research conducted with younger tennis players has generally focused on assessing the impact of physical attributes. For example, high performance junior tennis players, competitive junior tennis players and a control population were compared at three different ages (11, 13 and 15 years of age) and reported agility as the most potent discriminator of playing level across all age groups (Elliot et al., 1990). Agility was further highlighted as the only physical attribute related to level of tennis ranking in a study of 8-12 year olds (Roetert et al., 1992). A test battery containing speed, agility, strength and flexibility measures correctly classified 91.5% participants across 3 different levels of junior tennis players (Roetert et al., 1996). Sprint speed, leg power and maximal strength in the dominant limbs were also shown to correlate ($r=0.69$-$0.74$, $r=0.66$-$0.80$ and $r=0.67$-$0.73$ respectively) to current performance for junior (13.6±1.4 years) male tennis players (Girard & Millet, 2009). However, if these athletes already have clear, defined differences in their ability (e.g. control population compared to a nationally ranked population) the discriminating variable cannot automatically be assumed to be predictive in nature, it should be considered descriptive. One population has previously been talent identified and therefore likely experienced greater training loads, exposure to better coaching and strength and conditioning programs which potentially biases the results. A cohort of 12-13 year old children illustrates this, with the major factors responsible for success in tennis being increased experience (playing age, number of matches played, number of hours practising per week, exposure to coaching etc.) and advanced biological maturation (height, weight and power) (Unierzyski, 2002; Unierzyski & Osinski, 2007).

The ambiguous findings regarding the use of ranking and performance measures coupled with the descriptive data on influential variables and impact of tennis playing experience and maturation suggest that current TI protocols need improvement and may be wasting resources. From a practical viewpoint, current TI performance based measures don't assess potential, they identify those who have matured early, specialised early or have tournament experience (Unierzyski, 2002; Unierzyski & Osinski, 2007). An alternative method of talent identification, which is not underpinned by playing experience and maturation, but instead identifies juniors that display heightened levels of pertinent attributes, such as developed fundamental movement skills and movement and skill adaptability, is warranted.

Fundamental motor skills can be classified as either locomotive (running, jumping, and hopping) or object control skills (throwing, catching, kicking and striking) (Logan et al., 2012). The use of a generic skill based test for assessing talent potential in children has gained momentum as the effect that sport-specific training has on results is limited (Faber et al., 2014; Vaeyens et al., 2008). Furthermore, the stability that is exhibited in motor abilities beyond the age of 6, provides a reason as to why it may carry some predictive power (Vandorpe, Vandendriessche, Vaeyens, Pion, Matthys, et al., 2012).

The KTK is a widely used and reliable test that measures and monitors development of gross motor coordination in children (Cools et al., 2008; Vandorpe, Vandendriessche, Lefevre, et al., 2011). Using the KTK for talent identification purposes has been explored previously in gymnastics (Vandorpe, Vandendriessche, Vaeyens, et al., 2011; Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). The KTK accounted for more than 40% of the variation in competition results during a two year longitudinal study and was superior when compared to the coaches' judgment, anthropometric and physical characteristics in terms of predicting performance (Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). Currently the KTK has not been used in tennis from a talent identification perspective however the significant benefit that a general motor skill test with the ability to predict performance would provide has been noted in the literature (Lees, 2003).

The most comparable research has been conducted in the field of table tennis (Faber et al., 2014). Participants (aged 7-12 years) were required to throw a ball against a wall with one hand and catch with the opposite hand as many times as possible in 30 seconds. The task was designed to be similar to table tennis but not an activity that would have been practiced in training. Identifying talent through a perceptual-motor task, which has not been influenced by training, is more effective than a sport-specific skill assessment (Faber et al., 2014; Vaeyens et al., 2008; Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). This test successfully discriminated between local, regional and national players ($p<0.001$). Optimal performance of this task required participants to rapidly adapt their technique (overhand vs. underhand) as needed and therefore allowed them the freedom to choose their own method to satisfy the task constraints. (Faber et al., 2014).

There are three types of constraints that require a person to adapt their motor activities to perform optimally, individual (e.g. body composition), task (e.g. modified equipment) and environmental (e.g. weather) (Newell, 1986). For every movement and skill performance the amalgamation of these constraints results in a unique movement and/or skill challenge. As such, an individual must create a unique solution, specific to the constraints imposed on them (Renshaw et al., 2010). Therefore, uniformity across a population or even between two individuals should not be expected; variability is much more likely and functionally appropriate.

Support for movement and skill adaptability originates from the benefits discovered with variability in the talent development pathway. Variability was found to have a positive impact across a number of different sports (soccer, cricket, speed skating) including tennis (Araujo et al., 2010; Hernandez-Davo et al., 2014; Phillips et al., 2010a; Savelsbergh et al., 2010). Although these studies are more related to talent development than talent identification, movement and skill adaptability will fill this void and provide the appropriate construct to evaluate talent incorporating variability through manipulated constraints and a higher reliance on fundamental motor skills by lessening the sport specificity.

To ensure that it is best practice, a TI protocol must reflect the dynamic, unpredictable environment that is tennis, and allow athletes to implicitly showcase their movement and skill adaptability. Therefore, the objective of this study was to create two novel tests which possessed these qualities and establish their validity and reliability.

## 3.2 Methods

### *3.2.1 Participants*

Fifty healthy participants, (as determined via a health screening questionnaire [Appendix A]) 37 male and 13 female, volunteered to participate in the construct validity component of this study. The skilled junior athlete group was formed from twenty-four of these participants and had expertise in different sports (tennis [n=12], Australian Rules Football [n=9] and basketball [n=3]). For this group, the mean ± SD for age, height, body mass and estimated age of peak height velocity (PHV) was 13.56 ± 0.61 years, 164.9 ± 9.9 cm, 54.4 ± 9.8 kg and 13.34 ± 0.99 years respectively (Mirwald et al., 2002). The skilled junior athletes were previously talent identified and held scholarships at a local sports academy in Melbourne, Australia. This group was matched to a recreational tennis group (n=26). The recreational group recorded a mean ± SD age of 13.44 ± 0.94 years, height of 161.78 ± 9.75 cm, body mass of 52.92 ± 14.99 kg and estimated age of PHV of 13.45 ± 0.81 years and were involved in local level tennis competition.

Three sport scientists and three tennis coaches volunteered to complete the face validity component of this study. The sports scientists were PhD qualified and had published in high ranking (Q1) journals in the fields of expertise development, talent identification, skill acquisition and tennis. The tennis coaches were, at a minimum, a club professional coach (Tennis Australia qualification) with extensive experience in coaching and developing athletes within the target age range for the novel tests.

Reliability was assessed by a total of forty participants, this comprised the skilled junior athlete group mentioned previously and a group that was within the target age range for the novel tests (8-11 years old, n=16, 13 male and 3 female). The 8-11 year old group had a mean ± SD age of 9.24 ± 1.40 years, height of 138.06 ± 8.74 cm, body mass of 34.52 ± 10.30 kg and an estimated age of PHV of 12.55 ± 0.55 years.

Prior to the commencement of their involvement, each participant provided assent and written, informed consent via parent/guardian for their voluntary participation in the study. The study was approved by the Victoria University Human Research Ethics Committee (HRE 14-069) and the Department of Education and Early Childhood Development ethics committee (2014_002479).

### *3.2.2 Study Design*

Two novel movement and skill adaptability tests were created for the purpose of identifying talent in junior tennis (8-11 years of age); the Throwing and Rebound task and the Continuous Rebounding Task. To evaluate their scientific merit two validity measures were used (construct and face validity) in conjunction with a reliability assessment. This study used a cross-sectional, quasi-experimental design to compare a population of skilled junior athletes and a recreational group. This approach was used to demonstrate construct validity of the TRT and CRT. To strengthen the validity of the tests, face validity was used to provide evidence that the tests represented the properties of movement and skill adaptability and were appropriate for the target age range. Reliability was assessed via a test-retest method on three separate occasions. Each test was separated by seven days and a schematic of the study design is below (Figure 19).

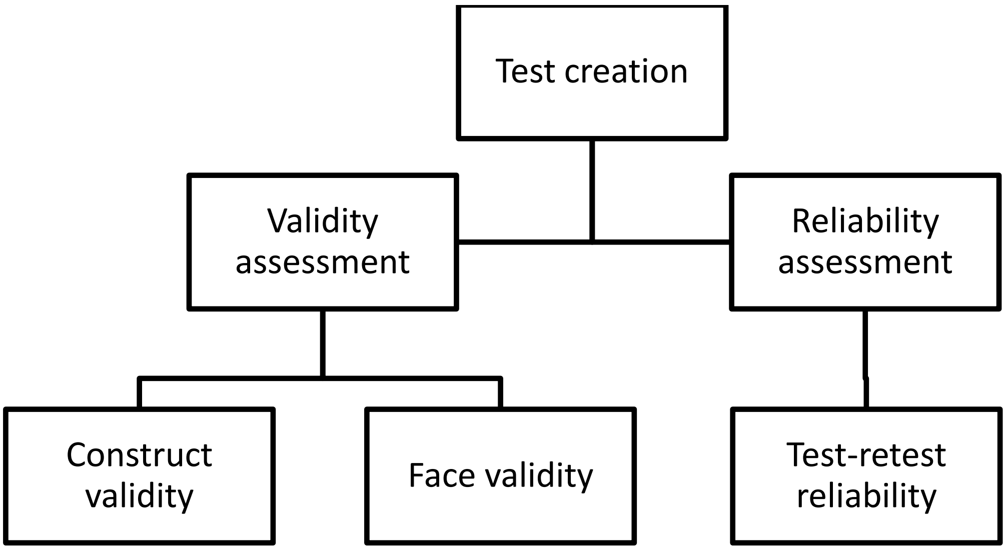


**Figure 8**. Study design

*3.2.3 Preliminary Testing*

Prior to performing the adaptability tasks for the first time, all participants height, sitting height (0.1cm, Seca, Chino, U.S.A) and weight (0.1kg, Tanita Australia, Kewdale, Australia) was measured (Beunen et al., 2011) with an estimate of biological maturity calculated (Mirwald et al., 2002). This information was used to provide a description of their biological maturation (e.g. early, average or late), an estimation of years to and age of PHV and a predicted adult height (Sherar, Mirwald, Baxter-Jones, & Thomis, 2005).

*3.2.4 Movement and skill adaptability testing*

Participants that were part of the construct validity group only completed one testing session of the TRT and CRT. Participants involved in assessing reliability completed three sessions, performing only the TRT and CRT in their second and third session.

*3.2.4.1 Throwing and rebound task*

The purpose of this task was to throw a ball towards five targets as quickly as possible. Participants began with a red (25% compression) tennis ball (Wilson, Chicago, U.S.A.) in their dominant hand and threw towards a self-selected target. They were required to retrieve the rebounding ball after each throw, alternating throwing arms until all targets were hit. If the pattern of alternating arms was broken a successful throw would not count and that specific target would have to be hit again in the correct manner. The time taken to complete the task was recorded on a stopwatch (0.01s, Apple, Cupertino, U.S.A) for analysis and two trials were completed to gain maximal performance per session. To minimise potential learning effects, no demonstration was provided and participants were not allowed to watch each other complete the task.

The minimum throwing distance was 3m and the participants' started 1m wider than the closest target. This created an angle for the first throw which encouraged movement and the use of alternate throwing arms. Five square, 50cm diameter targets (Sioux Archery, Tiaro, Australia) were used and the targets differing positions were designed to encourage movement and changes in throwing patterns (e.g. overarm, underarm). A diagram detailing the throwing and rebound task set up and target positions is shown in Figure 9. Pilot testing was completed with varied balls, target sizes, varied distances from the wall and varied spatial arrangement of the targets. Elements that were considered when adjusting these variables were the amount of movement by pilot participants, changes in throwing technique, difficulty and therefore time to complete the task.

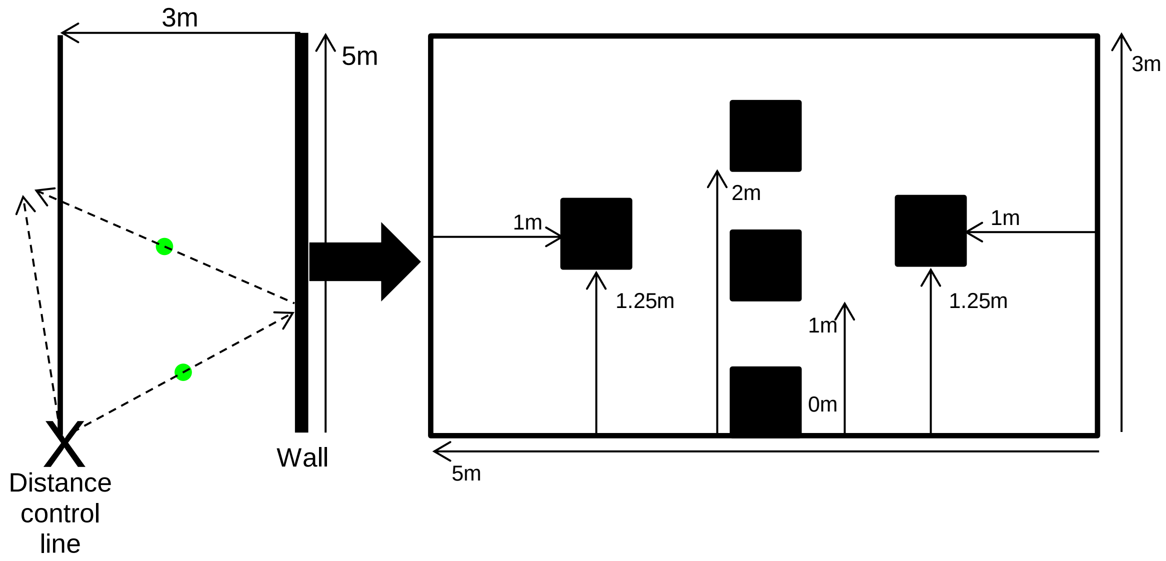


**Figure 9**. Throwing and rebound task set up (left; birds eye view) and target positions (right; front on view as participants would have seen). X shows starting position for right handed participant with expected throwing and movement pattern, ● represents a tennis ball, ■ represents the targets

*3.2.4.2 Continuous rebounding task*

Participants struck a ball with alternating hands against a wall as many times as possible in a 30 second period. Similar to the throwing and rebound task, if a strike was performed in the incorrect sequence (e.g. with the incorrect hand) then it was not counted, with the count only being restarted when the participant returned to the correct sequence. The ball was required to reach the wall without bouncing and was allowed one bounce before being struck again. If this pattern was not maintained (e.g. ball is struck but rolls along the ground) inside the 30s period, participants were encouraged to regain the ball and continue the test. This did not incur a direct penalty to a participant’s score however indirectly their performance would be impacted due to the extra time taken to recover the ball and restart the striking pattern. The starting position was 3m away from a wall however this was for the first strike with the dominant hand only. After this initial strike, the participants could move forward to a distance of 1.5m from the wall. This provided some autonomy for participants in regards to how the task was completed. A diagram showing the task set up and an anticipated movement pattern is shown below (Figure 10).

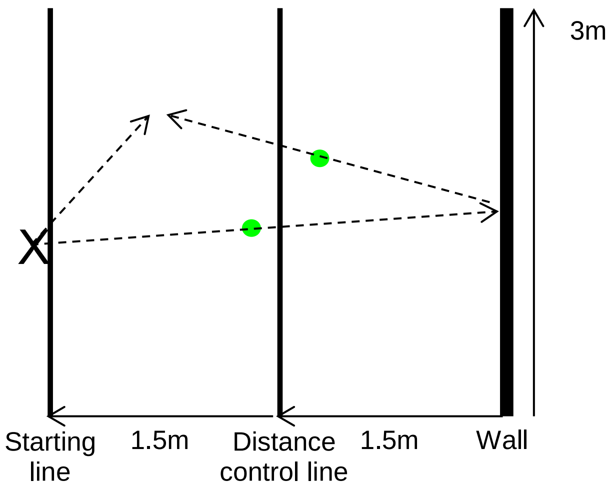


**Figure 10**. Continuous rebounding task set up and expected strike and movement pattern. X represents participant and expected movement pattern, ● represents a ball

This task was performed three times per session with three balls of different compression levels and sizes used for each individual trial (Spalding high bounce ball [Spalding, Scoresby, Australia], red [25% compression] tennis ball [Wilson, Chicago, U.S.A] and a Hart foam ball [Hart Sport, Aspley, Australia). The properties of these balls were not disclosed to the participant. The aim of utilising balls of different size, feel and bounce was to encourage participants to adapt their overall technique (movement and strike pattern) in order to maximise success, this theory is consistent with the ball toss dictating the tennis serve (Whiteside et al., 2015). The number of successful strikes in 30 seconds was recorded, with the variable analysed being the sum of the three different balls used in each individual trial. Pilot testing examined different types of balls, distances from the wall and the length of time for each trial with reference to the influence on outcomes similar to the TRT (movement of participants, changes in striking technique, difficulty and time to complete task).

*3.2.5 Validity and reliability measures*

*3.2.5.1 Construct validity*

This study used a cross-sectional, quasi-experimental design to compare a population of skilled junior athletes and a recreational group. Using this ‘known groups’ method allowed for an assessment of the TRT and CRT’s ability to discriminate between different levels of athletes. This approach was used to demonstrate construct validity of the TRT and CRT. Participants completed anthropometric testing as detailed in section 3.2.3 Preliminary testing prior to performing the TRT and CRT.

*3.2.5.2 Face validity*

Three expert sports scientists and three expert tennis coaches received a four page document (Appendix B) and a short video (~4 mins, “Adaptability task explanation, https://youtu.be/G0zRlEVsq7E) related to the novel tests. A scientific and practical definition of movement and skill adaptability was provided with examples from a number of sports. The procedures of the TRT and CRT were detailed and the accompanying video provided a visual representation of the tests and showed potential means of adaptability (e.g. a participant changing from an overarm throw to an underarm throw in the TRT or a participant changing from a forehand strike to a backhand strike in the CRT). After reading and viewing all information scientists and coaches were asked to rate the TRT and CRT based on how they reflect movement and skill adaptability. This was completed with a 5-point Likert scale (1=strongly disagree, 2=disagree, 3= neither agree nor disagree, 4=agree, 5=strongly agree).

*3.2.5.3 Test-retest reliability*

Test-retest reliability was used to assess the reliability of the TRT and CRT. Participants completed the tasks on three separate occasions; each testing session separated by a week. To reduce any order effect and ensure consistency participants performed the throwing and rebound task first, and completed the continuous rebounding task second. In the first session only participants completed anthropometric testing as detailed in section 3.2.3 Preliminary testing.

*3.2.6 Statistical analysis*

Prior to analysis, raw data was assessed for normality (Shapiro-Wilk test). Due to the lack of normality data pertaining to reliability and construct validity was log-transformed for analysis. All data are reported as mean ± SD unless otherwise stated.

*3.2.6.1 Construct validity*

Construct validity data (including descriptive characteristics) was analysed with the IBM Statistical Package for the Social Sciences (IBM SPSS Statistics 21.0.0, SPSS Inc, USA) via an independent sample t-test or ANOVA where statistical significance was set at $P \leq 0.05$. Additionally, an Excel spreadsheet (Hopkins, 2000c) was used to quantify the magnitude of differences observed. A difference was considered very likely if there was a ≥ 95% chance of surpassing the smallest worthwhile effect and most likely if it was ≥ 99.5%.

*3.2.6.2 Test-retest reliability*

Reliability data was analysed using an Excel spreadsheet developed by Hopkins (2000a) and used to determine an intraclass correlation (ICC) with 90% confidence intervals. Data arising from the spreadsheet was used to calculate the smallest worthwhile effect of the true between subject variation for both the TRT and CRT (Hopkins, 2000b).

**3.3 Results**

The descriptive characteristics of the participants involved in the construct validity section of the study are presented in table 2. Analysing the descriptive characteristics revealed no significant difference between groups on all measures. This result was repeated whether the analysis was separated to compare males or females only, or the group as a whole.

There was a significant difference between the junior athletes and the recreational group across both the TRT (Best TRT, t(46) = -2.18, p=0.035, Average TRT, t(46) = -3.07, p=0.004) and CRT, t(46) = 4.54, p<0.001 (Table 3). This result maintained significance for average TRT and CRT when the analysis was completed for males or females only (males, t(35) = -2.16, p=0.038 and t(35) = 4.40, p<-0.01 respectively, females t(11) = -2.55, p=0.027 and t(11) = 2.29, p=0.043 respectively. The influence of maturation was analysed with no significant difference between participants who were classified as either early, average or late in relation to their estimated age of PHV (Best TRT, F(2, 47) = 0.27, p=0.763, Average TRT, F(2, 47) = 0.01, p=0.995, Sum CRT, F(2, 47) = 0.26, p=0.775) (Figure 11). The relationship between the sport that the junior athletes had been previously talent identified in was investigated. There were no significant differences when comparing tennis to either AFL or basketball. When comparing individual sports to the recreational population tennis performed significantly better on the CRT, t(36) = 3.65, p=0.001), whilst the AFL group performed better for average TRT, t(33) = -2.77, p=0.009) and CRT, t(33) = 4.68, p<0.001). Due to low group numbers, tennis athletes were also compared to the combined results of the AFL and basketball groups, again this yielded no significant difference (Figure 12). Athletes from the combined AFL and basketball group significantly outperformed the recreational group across both the TRT and CRT (Best TRT, t(36) = -2.21, p=0.033, Average TRT, t(36) = -3.17, p=0.03, CRT, t(36) = 4.33, p<0.001).

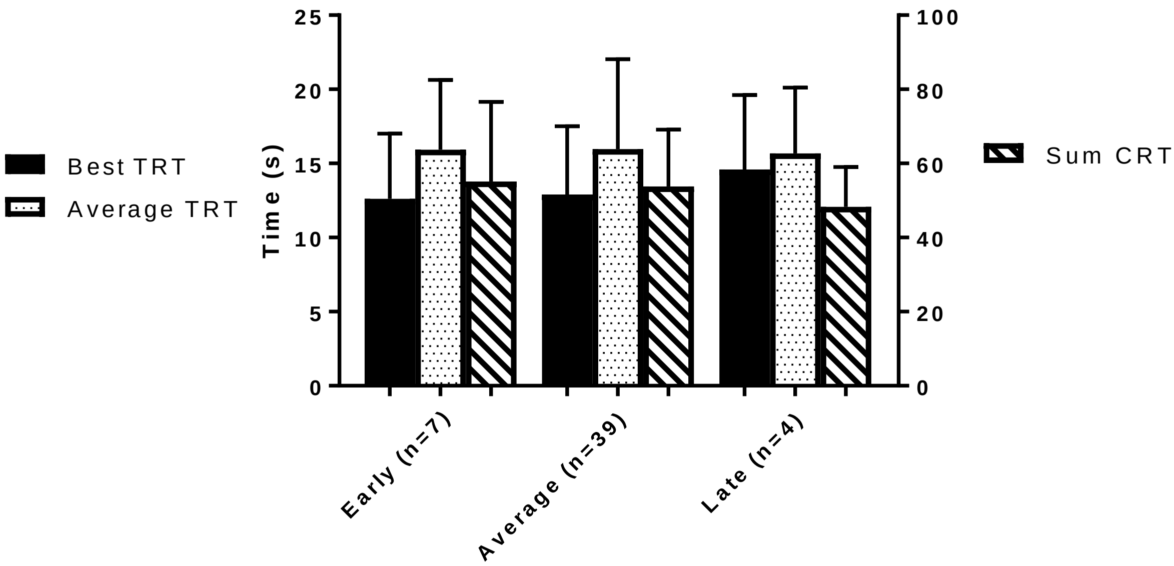


**Figure 11**. Results of TRT (best and average) and CRT (sum) relative to participants' biological maturation classification

**Table 2.** Results of characterisation tests performed by construct validity participants. Results are Mean ± SD

| | **Skilled junior athlete group (n=24)** | | | **Recreational group (n=26)** | | |
|---|---|---|---|---|---|---|
| | Male (n=19) | Female (n=5) | Combined | Male (n=18) | Female (n=8) | Combined |
| **Age (yr)** | 13.58±0.63 | 13.48±0.56 | 13.56±0.61 | 13.18±0.97 | 14.01±0.55 | 13.44±0.94 |
| **Height (cm)** | 165.7±10.7 | 162.2±6.4 | 164.9±9.9 | 163.5±10.4 | 158.0±7.5 | 161.8±9.7 |
| **Weight (kg)** | 54.0±9.2 | 55.8±12.7 | 54.4±9.8 | 55.3±16.8 | 47.5±8.2 | 52.9±15.0 |
| **Sitting Height (cm)** | 85.2±5.5 | 84.0±4.1 | 84.9±5.2 | 82.1±5.6 | 80.9±5.1 | 81.8±5.3 |
| **Estimated age of peak height velocity (PHV) (yr)** | 13.68±0.75 | 12.05±0.68 | 13.34±0.99 | 13.79±0.67 | 12.68±0.51 | 13.45±0.81 |
| **Predicted adult height (cm)** | 182.5±6.8 | 167.9±5.8 | 179.4±8.9 | 184.2±4.8 | 163.6±5.3 | 177.8±10.8 |

**Table 3.** Construct validity results. Results are Mean ± SD

| | **Junior athlete** | | | **Recreational group** | | | **% Difference in means** | **Smallest worthwhile effect** | **% Smallest worthwhile effect** |
|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Combined | Male | Female | Combined | Combined | Combined | Combined |
| **TRT** | | | | | | | | | |
| **Best** | 11.41 ± 3.64 | 11.44 ± 2.55 | 11.41 ± 3.39# | 13.27 ± 3.82 | 17.15 ± 6.53 | 14.46 ± 5.02# | 24.3 ± 16.6* | 0.36s | 3.22 |
| **Average** | 13.12 ± 3.82# | 14.51 ± 1.65# | 13.41 ± 3.50^ | 16.54 ± 5.68# | 22.15 ± 6.46# | 18.27 ± 6.37^ | 32.1 ± 18.9** | 0.45s | 3.65 |
| **CRT** | 65.21 ± 11.61^ | 54.2 ± 17.04# | 62.92 ± 13.30^ | 49 ± 10.78^ | 35.5 ± 12.55# | 44.85 ± 12.79^ | 30.5 ± 9.5** | 2.47 | 3.50 |

# $p<0.05$, ^ $p<0.01$, * ≥95% likely difference between groups, ** ≥99.5% likely difference between groups, TRT – target and rebound task, CRT – continuous rebounding task.

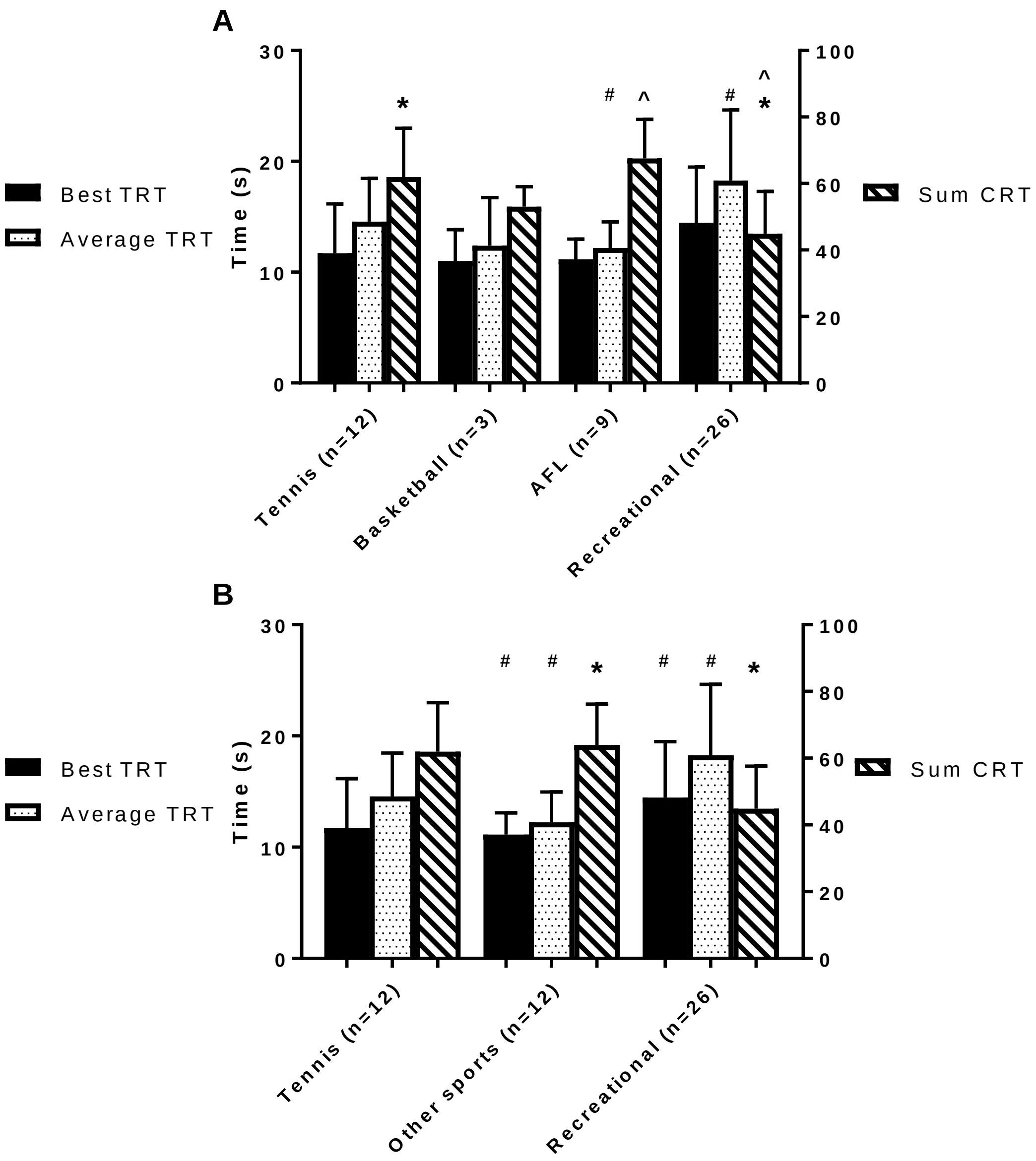


**Figure 12**. Comparison of results of TRT (best and average) and CRT (sum) between the different sports of skilled junior athlete group and the recreational group. #, ^ equals $p<0.05$, * equals $p\leq0.001$.

The face validity component resulted in the TRT receiving an average score of 4.5 ± 0.55 and the CRT scoring 4.66 ± 0.52. The frequency of scores received for each test can be seen in Figure 13 and shows that all experts either agreed or strongly agreed that both tests had face validity.

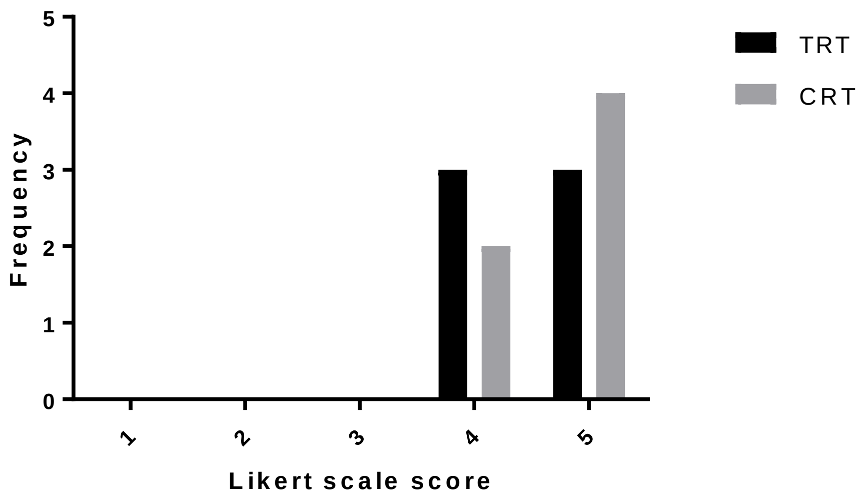


**Figure 13**. Frequency distribution of expert consensus on a 5-point Likert scale.

The descriptive characteristics of the participants involved in the test re-test reliability section of the study are presented in table 4. The predicted adult height for the 8-11 year old males and combined (males and females) were calculated but are not reported. This is due to seven of the males returning a result outside the parameters of the calculation (>4 years to estimated age of PHV). The ICC's with 90% confidence limits for both the 8-11 year old age group and the 12-14 year old age group are presented in table 5. The smallest worthwhile effect was also calculated for the 8-11 year old age group. For the TRT, the smallest worthwhile effect was 2.17 (9.30%) and 3.09 seconds (9.96%) when using the best and average score respectively. In the CRT the smallest worthwhile effect was 3.15 (12.43%).

**Table 4.** Results of characterisation tests performed by test re-test reliability participants. Results are Mean ± SD *Not reported as seven boys were outside the parameters of the calculation (>4 years to age of PHV).

| | **8-11 year old group (n=16)** | | | **12-14 year old group (n=24)** | | |
|---|---|---|---|---|---|---|
| | Male (n=13) | Female (n=3) | Combined | Male (n=19) | Female (n=5) | Combined |
| **Age (yr)** | 8.81±1.15 | 11.13±0.59 | 9.24±1.40 | 13.58±0.63 | 13.48±0.56 | 13.56±0.61 |
| **Height (cm)** | 135.5±7.4 | 149.2±3.6 | 138.1±8.7 | 165.7±10.7 | 162.2±6.4 | 164.9±9.9 |
| **Weight (kg)** | 30.9±6.5 | 50.3±8.9 | 34.5±10.3 | 54.0±9.2 | 55.8±12.7 | 54.4±9.8 |
| **Sitting Height (cm)** | 69.9±5.9 | 72.7±0.3 | 70.5±5.4 | 85.2±5.5 | 84.0±4.1 | 84.9±5.2 |
| **Estimated age of peak height velocity (PHV) (yr)** | 12.76±0.41 | 11.77±0.24 | 12.55±0.55 | 13.68±0.75 | 12.05±0.68 | 13.34±0.99 |
| **Predicted adult height (cm)** | -* | 168.6±1.4 | -* | 182.5±6.8 | 167.9±5.8 | 179.4±8.9 |

**Table 5.** ICC's for the TRT and CRT with 90% confidence intervals

| | **8-11 years of age** | **12-14 years of age** |
|---|---|---|
| **TRT** | | |
| **Best** | 0.79 (0.57-0.91) | 0.52 (0.22-0.73) |
| **Average** | 0.81 (0.59-0.91) | 0.59 (0.31-0.77) |
| **CRT** | 0.88 (0.73-0.95) | 0.72 (0.51-0.85) |

### 3.4 Discussion

The main finding of this study was that both the TRT (best and average time) and CRT were able to discriminate between a group of junior athletes and an age matched recreational group, confirming construct validity. There is a paucity of research concerning skill tests that have the capability to identify relevant abilities which may assist with identifying talent in tennis and this study begins to address that need (Falk et al., 2004). Previous research has focused on discriminating between junior tennis players of different levels assessing physical (e.g. sprint testing) or tennis performance measures only (e.g. forehand testing) (Elliot et al., 1990; Girard & Millet, 2009; Roetert et al., 1996; Roetert et al., 1992; Vergauwen, Madou, & Behets, 2004). Despite the significant and informative nature of this work, its relevance for TI is questionable as it is largely descriptive in nature and may not actually identify talent. Due to the young target age range of TI testing it is critical that tests are not fixated on current performance but instead future potential (Vaeyens et al., 2008). It is acknowledged that longitudinal research is needed to assess the ability of the TRT and CRT to accurately identify potential.

With the acknowledgment that using a performance based approach to TI is counterproductive (Abbott & Collins, 2002; Brouwers et al., 2012; Martindale et al., 2005; Vaeyens et al., 2008), it is imperative that the TRT and CRT did not merely unfairly promote those who had a significant tennis background. The results of the current study support this premise. Firstly, half of the junior athlete group was comprised of athletes from sports outside of tennis, yet they still significantly outperformed the recreational group. Furthermore, when the skilled junior athlete group was separated into the sports from which they were talent identified (tennis, basketball and AFL) there was no significant difference between the groups for the TRT and CRT. To account for the low numbers in the basketball group, the AFL and basketball group was combined to form a talent identified sporting group with a non-tennis background. They were compared to the tennis group, still producing no significant difference on the

TRT and CRT. The combination of these results implies that skills other than those directly related to tennis, such as movement and skill adaptability may have influenced the result.

The use of a generic movement or skill test for the purpose of identifying talent is becoming more prevalent in the literature, due to minimising the effect of sport-specific training on results (Faber et al., 2014; Vaeyens et al., 2008). Furthermore, motor skills are relatively stable beyond the age of 6 (Vandorpe, Vandendriessche, Vaeyens, Pion, Matthys, et al., 2012). In gymnastics, the KTK was a better predictor of future performance than sprint, agility and even coach's ranking (Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). The KTK is a test of locomotive stability (Cools et al., 2008) and therefore clearly has some relevance to gymnastics whilst not being sport specific. A study examining a similar theory has been conducted in the field of table tennis (Faber et al., 2014). In this study participants (aged 7-12 years) were required to throw a ball against a wall with one hand and catch with the opposite hand as many times as possible in 30 seconds. The task was designed to be similar to table tennis but not practiced in training. This test was able to discriminate between local, regional and national players. The TRT and CRT operate in a similar vein, in that, the skills and movement pattern required for success maintain a relationship to tennis whilst not being sport specific.

No significant difference between biological maturation classifications (early, average and late) is a promising but unexpected result based on previous research. It has been regularly noted in the literature of the impact that maturation can have when trying to perform TI processes (Burgess & Naughton, 2010; Coelho et al., 2010; Lidor et al., 2009; Malina et al., 2007; Mohamed et al., 2009; Pearson et al., 2006; Pienaar & Spamer, 1998; Unierzyski, 2002; Vaeyens et al., 2008). The superior physical stature results in improved speed, strength and tennis performance (Abbott & Collins, 2002; Pearson et al., 2006). These results unduly influence TI and can result in incorrect selections or de-selections. The absence of a significant difference between the different maturation classifications demonstrates that the test results are not impacted by maturation. However, a potential limitation of the result in this study is that the majority of participants were categorised as average (n=39) resulting in very low numbers in both the early (n=7) and late (n=4) groups. To be classified as average biological maturation an individual had to be ±1 year from the average age of PHV, which was 12 years of age for girls and 14 for boys (Sherar et al., 2005). Despite the encouraging results, to ensure that the TRT and CRT are being conducted with best practice and provide maximal relevance, it is recommended that biological maturation data is always collected on participants.

The expert consensus confirmed that the TRT and CRT reflected movement and skill adaptability. The support of the research and coaching community is a valuable asset as both are vital cogs that need to work harmoniously to alter current TI practices (Pankhurst, 2013). Research has identified the need to move away from ranking and results driven TI models (Pankhurst, 2013; Unierzyski, 2006). This is a view that is well supported in the literature (Martindale et al., 2005; Vaeyens et al., 2008).

The reliability of both the TRT and CRT was higher with the 8-11 year old age group when compared to the 12-14 year old age group. Both groups returned acceptable results with the 8-11 year olds returning ICC's categorised as very high, whilst the 12-14 year old group had high and very high reliability on the TRT and CRT respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). A plausible explanation for this result is twofold. Firstly, the 12-14 year old group was the skilled junior athlete population and their background (being previously talent identified and involved in a talent development program) may have created a homogenisation effect. This homogeneity, and therefore tight clumping of results, could have negatively impacted the ICC (Hopkins, 2000b). Secondly, the lower result on the TRT could be attributed to time being the variable analysed. Due to the significantly faster performance of the TRT in the 12-14 year old group the percentage change in mean is higher even though the raw data was comparable. For example, a 10% change in mean for skilled athlete group equates to 1.14 seconds, whereas for the 8-11 year old group this is 3.94% difference. However, reliability with the 12-14 year old group was conducted to ensure that meaningful inferences could be derived from comparing the athlete and recreational groups. The target age range for these tests is the 8-11 year old group and the very high reliability results in this population are encouraging.

### 3.5 Conclusion

This study has established the validity and reliability of two novel movement and skill adaptability tests, the TRT and CRT. Both tests can reliably discriminate between an athlete and recreational population and are deemed appropriate by an expert consensus of sports scientists and tennis coaches, in the assessment of adaptability amongst youth. The assessment of movement and skill adaptability provides a unique element to these tests that better reflects the dynamic environment of tennis without preferentially favouring those with more tennis experience or advanced biological maturation. The departure from incumbent performance based methods of TI better reflects the views of the tennis TI literature and governing bodies. The TRT and CRT now have the potential to be incorporated into existing tennis TI programs and future studies examining TI in tennis. Future research should examine the longitudinal validity of the tests, in reference to their ability to assess potential.

# Chapter 4. Study 2: Investigating the influence of adaptability, motor skill and physical testing on tennis skill performance

## 4.1 Introduction

Tennis requires the performance of open skills that need constant adjustment in relation to changing stimuli. Movement and skill adaptability, defined as an individual's ability to acutely adjust their performance based on new, changing and/or uncertain constraints (Martin et al., 2012; Newell, 1986), may be an important construct for tennis performance in addition to previous well-established required attributes (physical, technical, tactical psychological) (Fernandez-Fernandez et al., 2009; Hornery et al., 2007a; Kovacs, 2006, 2007; Unierzyski, 2002).

Specific examples of adaptability have been demonstrated with a junior population (10-13 years of age) in tennis (Hernandez-Davo et al., 2014; Whiteside et al., 2013; Whiteside et al., 2015). Ensuring athletes have a highly adaptable movement system, rather than striving for a repeatable service motion, was advocated for successful performance of the tennis serve (Whiteside et al., 2013). This conclusion was reached as no single mechanical element was able to discriminate between successful tennis serves or faults and there was variability in both the ball toss and distal mechanics (Whiteside et al., 2013; Whiteside et al., 2015). There is increased variability at impact as compared to zenith in the ball toss (Whiteside et al., 2015). However, this variability did not affect the temporal organisation of joint mechanics, suggesting the ball toss dictated the service motion and that an adaptable movement system will optimise performance as the system will adjust (distal mechanics) to the changing stimuli (ball toss) (Whiteside et al., 2015). These principles were investigated via deliberate service manipulations (e.g. modified base of support, modified position of player, modified spatial orientation and modified length of movement), reporting improvements in serve velocity and accuracy (Hernandez-Davo et al., 2014). This group was superior to a consistent training group (no manipulations) who improved only on their velocity (Hernandez-Davo et al., 2014). This demonstrates the practical benefit to performance adaptability can provide. Movement and skill adaptability is a trainable attribute that contributes to skilled tennis performance and therefore should be examined when attempting to understand tennis performance.

Fundamental motor skills can be classified as either locomotive (e.g. running, jumping, and hopping) or object control skills (e.g. throwing, catching, kicking and striking) (Logan et al., 2012). Athlete's development can be suppressed if key fundamental motor skills are not acquired (Abbott & Collins, 2002; Balyi & Hamilton, 2003). The development of these skills is not a natural occurring process, they must be practiced and learned (Adamo et al., 2016; Logan et al., 2012). Object control skills have been reported to account for 26% of the variation in fitness levels in later life, with proficiency in the skills allowing for a greater willingness to participate in sports, therefore influencing the development of sport-specific skills (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008). These established links dictate the necessity to test fundamental motor skills with a junior sport population.

Specific to tennis, a fundamental motor skill (running, throwing, catching, jumping and hitting) training program significantly improved all skills tested and hence readiness for tennis specific learning for the entire population of 5 year old children (Quezada et al., 2000). The KTK, which assesses the gross motor coordination in children (Cools et al., 2008; Vandorpe, Vandendriessche, Lefevre, et al., 2011), identified junior tennis players (6-14 years of age) as displaying at least normal levels of fundamental motor skills, with 40.6% above normal (Söğüt, 2016). This result is specific to tennis as declining levels of motor skill competence in children is a consistently reported result in the literature (Bardid et al., 2015; Hardy et al., 2010; Okely & Booth, 2004; Vandorpe, Vandendriessche, Lefevre, et al., 2011). Therefore, to fully understand skilled tennis performance, fundamental motor skill development should form part of the investigation.

The physical demands of tennis are significantly impacted by the need for athletes to repeatedly accelerate, decelerate, change direction, maintain balance and generate coordinated stroke play (Barber-Westin et al., 2010; Fernandez-Fernandez et al., 2009). Research has attempted to elucidate the most influential physical variables for skilled tennis performance. Agility can discriminate between playing level (high performance tennis players, competitive tennis players and control) across all age groups (11, 13 and 15 years old) (Elliot et al., 1990). A correlation (r=0.23) was found between the hexagon text, a test measuring agility and speed, and tennis performance, with all other physical tests yielding no significant correlations (Roetert et al., 1992). Speed, agility, strength and flexibility measures correctly classified 91.5% participants across 3 different levels of junior tennis players (Roetert et al., 1996). Sprint speed, leg power and maximal strength in the dominant limbs were also reported to be good predictors of tennis performance for junior (13.6±1.4 years) male tennis players (Girard & Millet, 2009). Despite different physical variables correlating to junior tennis performance (e.g. agility, sprint speed), it is clear that physical variables generally impact junior performance. The lack of one clear influential physical variable may be explained by the development history of the players in these studies; exposure to greater training loads, better coaching, and strength and conditioning programs may have potentially biased the results towards a particular physical variable. Biological maturation is another variable which has been found to impact the physical development of junior athletes (Coelho et al., 2010; Malina et al., 2007; Mohamed et al., 2009). Regardless, physical performance variables should be incorporated into a test battery exploring skilled tennis performance.

Therefore, the aim of this study was to incorporate the aforementioned attributes (adaptability, fundamental motor skills, physical performance measures and maturation) in a test battery and elucidate the contribution that each had on tennis performance.

## 4.2 Methods

### *4.2.1 Participants*

Forty-nine children with limited experience in tennis (<6 months) volunteered to participate in the study (37 male and 12 female). Previous sport experience outside of tennis (e.g. 2 years playing basketball) was permitted. Participants were recruited from a local primary school in Melbourne, Australia. Participants were deemed to be healthy and met the inclusion criteria as determined via a health screening questionnaire (Appendix A). The participant group had a mean ± SD age of 8.93 ± 0.75 years, height of 137.89 ± 7.96 cm, body mass of 36.48 ± 10.12 kg.

Prior to the commencement of their involvement, each participant provided written, informed assent and consent via a parent/guardian for their voluntary participation in the study. The study was approved by the Victoria University Human Research Ethics Committee (HRE14-311) and the Department of Education and Early Childhood Development ethics committee (2015_002698).

### *4.2.2 Study design*

An applied tennis performance test and a qualitative evaluation of the forehand strike provided an objective and subjective measure of tennis performance. A cross-sectional study design was used to examine the influence of a number of variables on both measures of tennis performance. The variables included, adaptability, which was assessed via the Throwing and Rebound Task (TRT) and Continuous Rebounding Task (CRT), whilst the KTK was used as a measure of fundamental motor skills. A 20m sprint and 5-0-5 agility test formed the physical performance measures whilst height, weight and sitting height were recorded as the anthropometric data and provided the required data for an estimate of biological maturity.

### *4.2.3 Preliminary testing*

Participants' height, sitting height (0.1cm, Seca, Chino, U.S.A) and weight (0.1kg, Tanita Australia, Kewdale, Australia) were measured (Beunen et al., 2011) to estimate biological maturity (years to peak height velocity) (Mirwald et al., 2002). This information was used to provide a description of their biological maturation (e.g. early, average or late), an estimation of the age of PHV.

*4.2.4 Tennis performance measures*

*4.2.4.1 Volley test*

Participants began 3m from a solid wall that was marked with a target area of 1.5m by 1m. The target area is marked at a height that is 0.1m above a tennis net. After receiving the command to begin the test, participants self-fed the ball towards the target area and continued volleying against the wall. Maximum number of hits was performed in 30s ensuring that the participant switched between forehand and backhand volleys. Only shots played in the correct sequence were deemed successful. If control of the ball was lost inside the 30s period, participants were encouraged to regain control and continue the test. Three attempts were provided with the number of shots made in the target area recorded as well as the number of shots missed. This is a protocol that has been used successfully with this age group in the applied setting and was therefore preferred over a serve test despite the serve's importance to senior tennis (Ma et al., 2013)(Tennis Australia [Appendix C – Volley Test]).

*4.2.4.2 Forehand stroke evaluation*

Participants were required to perform a one handed forehand strike on 6 separate occasions. A tennis ball was thrown to them, bouncing once prior to being struck. Participants were given a demonstration on how to successfully perform a forehand strike, with specific instruction given on the performance criteria. These were:

1. Eyes are focused on the ball throughout the strike
2. Stand side-on to the target with bat held in one hand

3. Striking hand nearly straightened behind shoulder at end of backswing
4. Step towards target with foot opposite striking arm during the strike
5. Marked sequential hip to shoulder rotation during the strike
6. Ball contact made opposite front foot with straight arm
7. Follow through towards the target then around body

Participants were 5m away from the person throwing the ball and told to strike the ball so that it travelled past the thrower without bouncing. An experienced tennis coach (~8 years coaching with a similar population) performed the demonstration and assessment for all participants, with the number of successfully performed criteria recorded for analysis (e.g. 4/7).

*4.2.5. Movement and skill adaptability tests*

*4.2.5.1 Throwing and rebound task*

The Throwing and Rebound Task was performed with the same methodology as detailed in Chapter 3 of this thesis (3.2.4.1 Throwing and Rebound Task).

*4.2.5.2 Continuous rebounding task*

The Continuous Rebounding Task was performed with the same methodology as detailed in Chapter 3 of this thesis (3.2.4.2 Continuous Rebounding Task).

*4.2.6 General motor skill testing*

The KTK (Kiphard & Schilling, 1974) was used to assess the general motor skills of the participants. The raw scores of each test were transformed into gender and age specific motor quotient values based on the norms of the original research (Kiphard & Schilling, 1974). An overall motor quotient was also calculated based on the sum of the four tests; this provided a general measure of motor control. The KTK comprises four different sub-tests.

*4.2.6.1. Walking backwards*

Participants walked backwards on a balance beam, 3m in length, for a maximum of 8 steps per trial. Three beams of different widths (6cm, 4.5cm and 3cm) were used with 3 trials conducted per width. A point is awarded for every step resulting in a maximum score of 24 per beam. Therefore, a maximum score for this test is 72 (24 steps multiplied by 3 beams).

*4.2.6.2. Moving sideways*

Participants began standing on a wooden platform (25cm x 25cm x 5.7cm) holding an identical platform in their hands. They were instructed to place the platform in their hands next to the platform they were standing on and move on to it. This process is repeated as many times as possible in 20s, with the number of relocations recorded. The sum of two trials is used for analysis.

*4.2.6.3. Hopping for height*

Participants were instructed to hop on one foot over an increasing pile of foam blocks (60cm x 20cm x 5cm) after a short hopping run-up. After the foam blocks were cleared participants were required to continue for at least two hops post landing. Three points were awarded for clearing a height on the first attempt, two points for the second attempt and one point for the third attempt. A maximum of 39 points could be achieved for each leg (ground level plus 12 foam blocks) resulting in a total maximum score of 78 for both legs.

*4.2.6.4. Jumping sideways*

Participants were required to jump as many times as possible from side to side over a small wooden beam (60cm x 4cm x 2cm) in 15s. An individual's feet must remain together and the total number of jumps over two trials is recorded for analysis.

### *4.2.7 Physical performance testing*

#### *4.2.7.1 20m sprint test*

Participants completed a 20m sprint test to assess their straight line acceleration and speed. Light gates (Fusion Sport, Sumner Park, Australia) were set up at intervals of 0m and 20m and participants completed 3 trials. All trials were completed outdoor on an asphalt surface. The best trial was used for analysis. A detailed description of the procedure followed can be found in Reid, Sibte, Clark, and Whiteside (2012).

#### *4.2.7.2 Modified 5-0-5 agility test*

Participants completed a modified 5-0-5 agility test to assess their ability to perform a rapid change of direction. To make the test more applicable to tennis, the modified test does not include the 10m lead in sprint of the standard 5-0-5 agility test. Tennis players will routinely change directions after travelling less than 15m, especially junior players playing on modified courts. One set of light gates (Fusion Sport, Sumner Park, Australia) were set up at 0m with a pivot line marked out at 5m. Participants were encouraged to sprint to the pivot line, turn 180° and sprint back through the start/finish line. Participants completed six trials, three turning in each direction, with the best time for each used for analysis. A detailed description of the procedure followed can be found in Reid et al. (2012).

### 4.2.8. Statistical analysis

Descriptive statistics are reported for all variables measured. Regression analyses were performed with a forward selection and enter method with the IBM Statistical Package for the Social Sciences (IBM SPSS Statistics 21.0.0, SPSS Inc, USA). Forward selection was used to determine the most influential variables for each of the tennis performance tests. All variables from the anthropometric, maturation, adaptability, general motor skill and physical performance tests were included as independent variables. For the forced entry regression, all variables within each group of tests (anthropometric, maturation, adaptability, general motor skill and physical performance) were entered into a regression model to understand the links between each group of tests and tennis performance. Shots made and total shots were not included as independent variables in the regression analysis of the opposing variable (e.g. Shots made was not included when total shots was the dependent variable).

### 4.3 Results

Anthropometric, maturation, tennis performance, adaptability, general motor skill and physical performance test results are displayed in table 6.

**Table 6.** Descriptive statistics of all variables tested, results are mean ± SD. BMI – Body mass index, PHV – Peak height velocity, TRT – Throwing and rebound task, CRT – Continuous rebounding task, KTK - KörperKoordinations Test Für Kinder

| Test group | Test | Result |
|---|---|---|
| **Anthropometric** | Height | 137.89±7.96cm |
| | Weight | 36.48±10.12kg |
| | BMI | 18.98±3.97 |
| | Sitting height | 72.82±3.90cm |
| **Maturation** | Age | 8.92±0.75 years |
| | Years to PHV | 3.30±0.70 years |
| | Age at PHV | 12.22±0.66 years |
| **Tennis performance** | Volley test - Shots made | 10.78±10.26 |
| | Volley test – Total shots | 31.31±13.26 |
| | Forehand strike | 4.00±1.40 |
| **Adaptability** | Best TRT | 33.47±17.81s |
| | Average TRT | 42.69±20.55s |
| | Sum CRT | 17.47±9.03 |
| **General motor skill** | Sideways jumping | 55.78±13.56 |
| | Platforms | 30.27±7.55 |
| | Balance | 32.02±13.81 |
| | Hopping | 40.18±14.55 |
| | KTK total | 158.24±42.32 |
| **Physical performance** | 20m Sprint | 4.52±0.51s |
| | 5-0-5 agility left | 3.54±0.38s |
| | 5-0-5 agility right | 3.51±0.39s |

The forward selection regression reported that for Shots Made on the volley test the only significant variable was the Sum CRT, t(46) = 4.98, p<0.001. The prediction equation obtained was Shots Made = 0.667*Sum CRT – 0.880 (Figure 14), with an $R^2$ value of 0.345 and an adjusted $R^2$ value of 0.331. Using Total Shots on the volley test as the dependent variable, there were three significant variables reported, Sum CRT, t(44) = 3.97, p<0.001, Height t(44) = 2.56, p=0.014 and Best TRT t(44) = -2.26, p=0.029. The prediction equation realised was Total Shots = 0.674*Sum CRT + 0.433*Height – 0.194*Best TRT – 33.638 (Figure 14), resulting in an $R^2$ value of 0.591 and an adjusted $R^2$ value of 0.564. Regression analysis on the forehand stroke evaluation did not yield any significant independent variables.

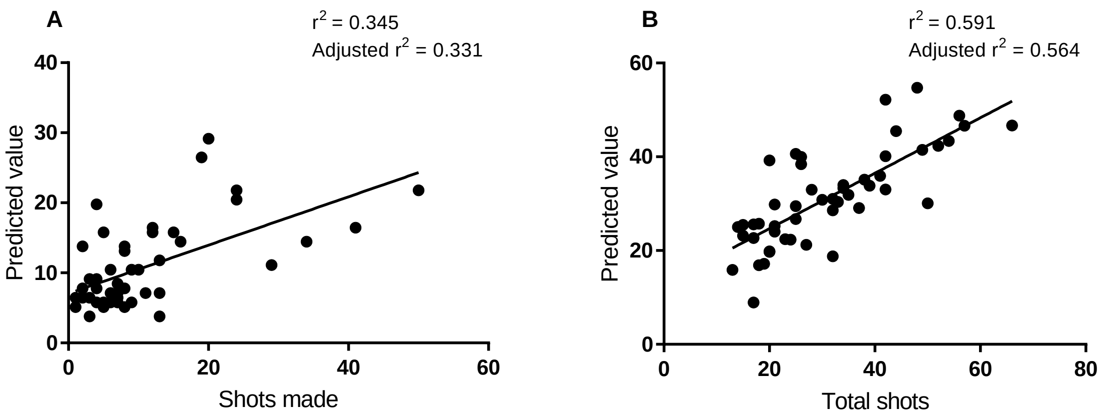


**Figure 14**. Graphical representation of regression analysis, showing predicted values in comparison to recorded values of Shots Made (A) and Total Shots (B) on the volley test

The forced entry regression revealed the adaptability group of tests was the most influential when examining both the shots made and total shots whilst for the forehand stroke evaluation anthropometric measures provided the strongest result (Table 7). The lower magnitude of $R^2$ and adjusted $R^2$ on the forehand stroke evaluation suggest that there may be other variables which account for the variance in the forehand stroke evaluation. Age and hopping were excluded from calculations due to collinearity.

**Table 7.** Test group results from forced entry regression analysis. * p<0.01

| **Test group** | **Shots made** | | **Total Shots** | | **Forehand stroke evaluation** | |
|---|---|---|---|---|---|---|
| | $R^2$ | Adjusted $R^2$ | $R^2$ | Adjusted $R^2$ | $R^2$ | Adjusted $R^2$ |
| **Anthropometric** | 0.185 | 0.111 | 0.325* | 0.264 | 0.163 | 0.087 |
| **Maturation** | 0.091 | 0.052 | 0.200* | 0.165 | 0.034 | -0.008 |
| **Adaptability** | 0.352* | 0.309 | 0.532* | 0.501 | 0.064 | 0.001 |
| **General motor skill** | 0.154 | 0.077 | 0.278* | 0.212 | 0.129 | 0.050 |
| **Physical performance** | 0.106 | 0.046 | 0.287* | 0.239 | 0.032 | -0.032 |

### 4.4 Discussion

The aim of this study was to investigate the attributes required for tennis performance assessed via an objective and subjective measure. Sum CRT was found to be the most influential variable for shots made and total shots on the volley test (p<0.001 for both). When total shots was the dependent variable, height and best time on the TRT were also significant (p=0.014 and 0.029 respectively). None of the 18 independent variables included in the regression analysis reported a significant result for the forehand stroke evaluation. When variables were grouped into their respective categories (for example, best TRT, average TRT and sum CRT grouped under adaptability) adaptability was the most influential for both measures on the volley test whilst anthropometric was the most influential for the forehand stroke evaluation.

The influence of the adaptability variables (sum CRT and best TRT) on tennis performance further confirmed the validity of adaptability established in Chapter 3 of this thesis. This research is the first to incorporate adaptability into a test battery attempting to understand the contributing attributes to junior tennis performance. Previous research on junior tennis performance has focused mainly on physical performance variables or subjective stroke evaluations (Elliot et al., 1990; Girard &

Millet, 2009; Roetert et al., 1996; Roetert et al., 1992; Ulbricht et al., 2016). Additionally, the majority of this research also contained previously talent identified populations. Different physical performance and stroke mechanics would be expected due to increased training loads, exposure to strength and conditioning programs and better coaching. As a result, using physical performance variables and subjective stroke evaluations for predictive purposes is questionable, they should be interpreted as descriptive of the current population. Despite using comparable methodology, (e.g. rankings or match performance to differentiate groups) a consensus on the most important variable has not been reached (Table 8). Adaptability outperformed a number of variables which reported significance in previous research (anthropometric, agility, speed, stroke evaluation). The use of a more developmentally appropriate measure of tennis performance (volley test compared to rankings/match play) and the introduction of adaptability provide a unique aspect to this research that warrants further investigation.

**Table 8.** Studies attempting to identify relationships between variables and junior tennis performance

| Study | Participant groups | Results |
|---|---|---|
| **Elliot et al. (1990)** | High performing<br>Competition<br>Control | High performing significantly better:<br>Males – Agility<br>Females – Grip strength, speed (40m sprint) and vertical power |
| **Roetert et al. (1992)** | Ranked tennis players (national and sectional) | Stroke ratings significantly related to national and sectional rankings<br>Agility significantly related to and explained 8% sectional rankings |
| **Roetert et al. (1996)** | National team<br>Development squad<br>Competition | Side shuffle (agility), vertical jump, push-ups and sit and reach correctly classified 67.65% of participants |
| **Girard and Millet (2009)** | Junior ranked tennis players | Speed (5, 10 and 20m sprint), vertical power, dominant side grip and plantar flexor strength significantly correlated to tennis performance |
| **Ulbricht et al. (2016)** | National squad<br>Regional squad | Serve velocity and medicine ball throws (forehand, backhand and overhead) were the most correlated to performance |

The lack of a significant variable emerging from the forehand stroke analysis may be due to not sufficiently discriminating participants. The test was designed to measure competence in technical aspects of the forehand strike in a primary school setting. Stroke ratings have previously been reported in a ranked fashion (e.g. 1-10) via video footage from match play (Roetert et al., 1992). The opponent and outcome of the stroke may have influenced these ratings, by incorporating match play elements. This therefore may alter the true assessment of the stroke in comparison to the isolated stroke assessment performed in this research. Additionally, a ranked approach may be applicable with an elite or skilled tennis population as they have experienced opportunities via coaching and practice to develop and refine their stroke. However, the novice population used in this research had not experienced these opportunities and therefore a competency based approach was favoured, despite potentially impacting the results.

Grouping the variables into their respective categories (anthropometric, maturation, adaptability, general motor skill and physical performance) appeared to mirror the results when the variables were considered independently for shots made and total shots. Adaptability returned the strongest correlation for both shots made and total shots with the anthropometric group returning the second strongest relationship. These are logical results considering adaptability (sum CRT and best TRT) and anthropometric (height) measures were the significant independent variables in the initial regression analysis. The resulting implication is that adding variables which analysed similar traits did not significantly impact the result.

The forehand stroke evaluation reported no significant relationships with any of the grouped variables. The anthropometric group returned the strongest link but did not reach significance (p=0.092). As discussed earlier, the forehand stroke evaluation being a measure of competence rather than performance may have influenced the lack of significant results. It appears that there are more pertinent variables (e.g. tennis training age) that influence competence levels of the forehand strike than those tested in this study.

Despite having a small sample size (n=49) for completing regression analysis, previous research has demonstrated that minimum requirements are two subjects per variable (Austin & Steyerberg, 2015). The subject: variable ratio approached 3 in the current study. The adjusted $R^2$ values, which accounts for the number of predictors in the model should be the primary statistic considered as this did not experience any bias in comparison to the $R^2$ value (Austin & Steyerberg, 2015). The adjusted $R^2$ values closely matched the $R^2$ values therefore not effecting the interpretations made.

### 4.5 Conclusion

Adaptability in the form of sum CRT has been demonstrated to be the most influential variable when analysing shots made on the volley test, explaining approximately 34% of the difference. The resultant predictive equation was: Shots Made = 0.667*Sum CRT – 0.880. Sum CRT, height and best TRT formed a model which predicted approximately 59% of total shots on the volley test, with sum CRT again being the most influential. The model for total shots was: Total Shots = 0.674*Sum CRT + 0.433*Height – 0.194*Best TRT – 33.638. There were no significant variables when analysing the forehand stroke evaluation, which may be due to it being a competence based assessment rather than performance. When variables were grouped into their respective categories (anthropometric, maturation, adaptability, general motor skill and physical performance) similar results emerged. Adaptability exhibited the strongest influence on shots made and total shots, while no significant relationships were reported for the forehand stroke evaluation. This research solidifies the importance of adaptability when investigating junior tennis performance.

# Chapter 5. Study 3: Comparing the effects of a conventional tennis training program to a movement and skill adaptability training program

## 5.1 Introduction

Identifying talent in sport is a contentious issue as its legitimacy in terms of being able to accurately predict the players that will achieve senior success has been questioned (Brouwers et al., 2012; Martindale et al., 2005; Pankhurst & Collins, 2013). Changing the marker of success for TI protocols may allow their worth to be more accurately assessed (Abbott & Collins, 2002; Vaeyens et al., 2008). For example, using progress to the next level of the development pathway rather than senior success. Current methods of TI in tennis and sport generally, tend to focus on a single or combination of single components and how they 'predict' performance (Lidor et al., 2009; Nieuwenhuis et al., 2002; Phillips et al., 2010b; Reilly et al., 2000; Roetert et al., 1996; Roetert et al., 1992; Vergauwen et al., 1998). Most commonly, these components are either physical or technical (e.g. sprint-speed, agility and serve speed) and may have been preferred due to the comparative ease in assessing these measures. The limitation of these methods is that they do not include a perception component and therefore don't reflect the dynamic individual-task-environment relationship that is critical for success in tennis (Davids et al., 2013; Del Villar et al., 2007; Faber et al., 2016; Falk et al., 2004; Nielsen & McPherson, 2001).

The importance of perception-action coupling has been repeatedly demonstrated with experts experiencing an advantage when perception and action are combined compared to examining each element individually (Del Villar et al., 2007; Mann et al., 2010; Mann et al., 2007). Therefore, it would appear necessary to incorporate perception-action coupling into any new TI protocol. It could be argued that this is occurring in the field currently, as the majority of TI in tennis occurs via performance based measures, which satisfy the demands of perception-action coupling. However, identifying talent via performance based measures alone is fraught with danger and has been detailed in depth in both Chapter 2 and Chapter 3 of this thesis. This presents a gap in the TI literature whereby a novel protocol should incorporate the best of both methods. The scientific validity, repeatability and simplicity of testing a singular element integrated with perception-action coupling allowing an expert advantage to present itself.

Traditional coaching and development programs in tennis follow similar mechanisms to TI, focusing on a single element (e.g. forehand) with a repetitive, specialised approach that lacks a dynamic perceptual stimulus (Gonzalez & Ochoa, 2003; Reid, Crespo, Lay, et al., 2007). When trying to develop expertise, the two most examined development pathways have contrasting features. Early sport specialisation, which is high in domain specific deliberate practice and conversely, sport sampling, provides an environment that allows for participation in a range of sports (Côté, 1999; Ericsson et al., 1993).

Early sport specialisation mirrors a number of components in the theory of deliberate practice (Ericsson et al., 1993). Across a number of fields, (music, chess and sport) the theory of deliberate practice has been clearly demonstrated (Ericsson, 1998; Ericsson & Charness, 1994; Ericsson et al., 1993). Although this will almost certainly produce a competitive advantage for junior athletes, this does not necessarily correlate to success at the senior level (Brouwers et al., 2012; Carlson, 1988; Reid et al., 2009; Reid, Crespo, Santilli, et al., 2007). Furthermore, any competitive advantage obtained may be negated by a major tenet of deliberate practice, that is, that it is not inherently enjoyable (Ericsson et al., 1993), This is due to a lack of enjoyment being the main factor in children withdrawing from sport (Hecimovich, 2004). However, in the field of sport deliberate practice was reported as enjoyable in contrast to the fields of music and chess (Ericsson et al., 1993; Helsen, 1998).

The benefits associated with sampling a range of sports are the underlying fundamental motor skills required for sports participation such as running, jumping and throwing are developed, refined and potentially transferable to sports which share similar characteristics (Baker et al., 2003; Côté, 1999). A number of studies have demonstrated benefit from undertaking a sampling path of development suggesting early sport specialisation is not a requirement for the development of expertise (Baker et al., 2003; Baker et al., 2005; Berry et al., 2008; Fransen et al., 2012; Gullich, 2016).

Despite the support for sampling in the literature, the translation to practical changes in the field is not as evident. Governing bodies of tennis (Australia, U.S.A. and UK as examples) actively promote the value of sampling and fun during junior development however their TI and TD processes are not aligned to these principles, with players rewarded based on their junior performance ("Athlete development scholarship criteria," 2015; Pankhurst & Collins, 2013).

The novel construct of adaptability can serve as an alternative method of development for junior players. Adaptability, as defined previously in this thesis, uses constantly changing constraints to develop the individual. This allows for a unique, outcome orientated response which may be highly variable. Evidence for adaptability has been reported in unstructured, non-coached games of cricket and soccer (Araujo et al., 2010; Phillips et al., 2010a; Weissensteiner et al., 2009). The variability (e.g. different environment, different ball) experienced by players provided them with an opportunity to develop their sport-specific adaptability; although appearing to specialise early, the extreme variability in constraints they experienced allowed them to benefit from important aspects of both early specialisation (accumulation of practice hours) and sampling (variety of motor control experiences)(Table 9).

A number of established training principles underpin practical methods of adaptability training: implicit learning, variable practice, contextual interference and skill transfer. The benefits of implicit learning when compared to explicit learning is well supported in the literature and include being less susceptible to breakdown during periods of stress (psychological, physical, performance of simultaneous tasks)(Buszard et al., 2013; Liao & Masters, 2001; Masters, 1992; Reid, Crespo, Lay, et al., 2007).

Variable practice has been reported as a potential means to improve tennis performance (Hernandez-Davo et al., 2014). Additionally, it has been hypothesised to operate via similar mechanisms to implicit learning; promoting a greater intrinsic understanding of the task (Hernandez-Davo et al., 2014; Whiteside et al., 2015). A training environment of high contextual interference produces participants who are more adaptable to a transfer task, can improve learning and is widely established across a range of sporting and skill environments (e.g. tennis, golf and basketball) (Babo et al., 2008; Brady, 2008; Broadbent et al., 2015; Porter & Magill, 2010; Van Merrienboer et al., 2006). Positive skill transfer occurs with a variety of attributes that are important for skilled sport performance (e.g. decision making, spatial awareness, physical fitness) (Baker et al., 2003; Berry et al., 2008; Gullich, 2016). The evidence for positive transfer is strengthened by the variety of sports where it has been demonstrated (e.g. Olympic sports, invasion games)

Despite the importance of understanding development theories, skill acquisition and learning practices, the challenging next step is synthesising these theories into a practical outcome that can be applied in the field. This is the current specific gap in the TD literature. The aim of this study was to create a training program that contained the beneficial elements of two diametrically opposed theories (early sport specialisation and sampling) whilst minimising their risks. Thus, the concept of movement and skill adaptability was used to underpin the training program and compared to a conventional tennis training program.

**Table 9** Comparing early sport specialisation, sampling and adaptability

| Variable | Early sport specialisation | Sampling | Adaptability |
|---|---|---|---|
| **Ability to develop expertise** | ✓ | ✓ | ? |
| **Increased level of domain specific practice** | ✓ | ✗ | ✓ |
| **Increased risk of early de-selection, burnout and injury** | ✓ | ✗ | ✗ |
| **Improved general motor skills** | ✗ | ✓ | ✓ |
| **Exposure to a broader range of environments** | ✗ | ✓ | ✓ |
| **Explicit or implicit learning** | Explicit | Implicit | Implicit |
| **Variable or constant practice** | Constant | Variable | Variable |
| **Contextual interference level** | Low | High | High |
| **Opportunities for skill transfer** | ✗ | ✓ | ✓ |

## 5.2 Methods

### *5.2.1 Participants*

Forty-nine children with limited experience in tennis (<6 months) volunteered to participate in the study (37 male and 12 female). A variety of other previous sporting experiences outside of tennis (e.g. 2 years playing basketball) was permitted and recorded. Participants were recruited from a local primary school in Melbourne, Australia. Despite being the same participants from Chapter 4 there is no impact on task familiarisation or data collection due to the study design and analysis. Forty-four participants completed the study, two voluntarily withdrew after the mid test, two began at the mid test (they changed schools to the local primary school), therefore only completing one full block of training (their results were analysed as pre to mid) and one withdrew prior to mid test due to relocating schools. Participants were deemed to be healthy and met the inclusion criteria as determined via a health screening questionnaire (Appendix A). Prior to the commencement of their involvement, each participant provided written, informed assent and consent via a parent/guardian for their voluntary participation in the study. The study was approved by the Victoria University Human Research Ethics Committee (HRE14-311) and the Department of Education and Early Childhood Development ethics committee (2015_002698).

### *5.2.2 Study design*

A semi-longitudinal, cross sectional design was employed to compare the effects of an adaptability training program and a conventional tennis training program. Two training blocks were conducted interspersed with a pre, mid and post-test battery. The duration of the training program was 24 sessions in total. This was broken down across 2 training blocks, where 6 weeks of lessons were provided per block and 2 lessons per week. At the conclusion of the first 6 weeks participants were re-tested with the pre-test battery, which was repeated again upon completion of the training program. A schematic of the study design is shown below (Figure 15).

The intervention group received 1 session per week of adaptability training and 1 session per week of conventional tennis training, whilst the control group received 2 sessions per week of conventional tennis training. The conventional tennis training sessions followed the ANZ hot shots program endorsed by Tennis Australia. The adaptability training sessions involved manipulating the tasks performed in the ANZ hot shots program via constraints led approach (Newell, 1986). The adaptability program contained tasks that, in comparison to the conventional tennis training program, had one or more constraints (individual, task or environmental) manipulated. The aim of this manipulation was to incorporate the most beneficial elements of the development and learning principles described in 5.1 Introduction.

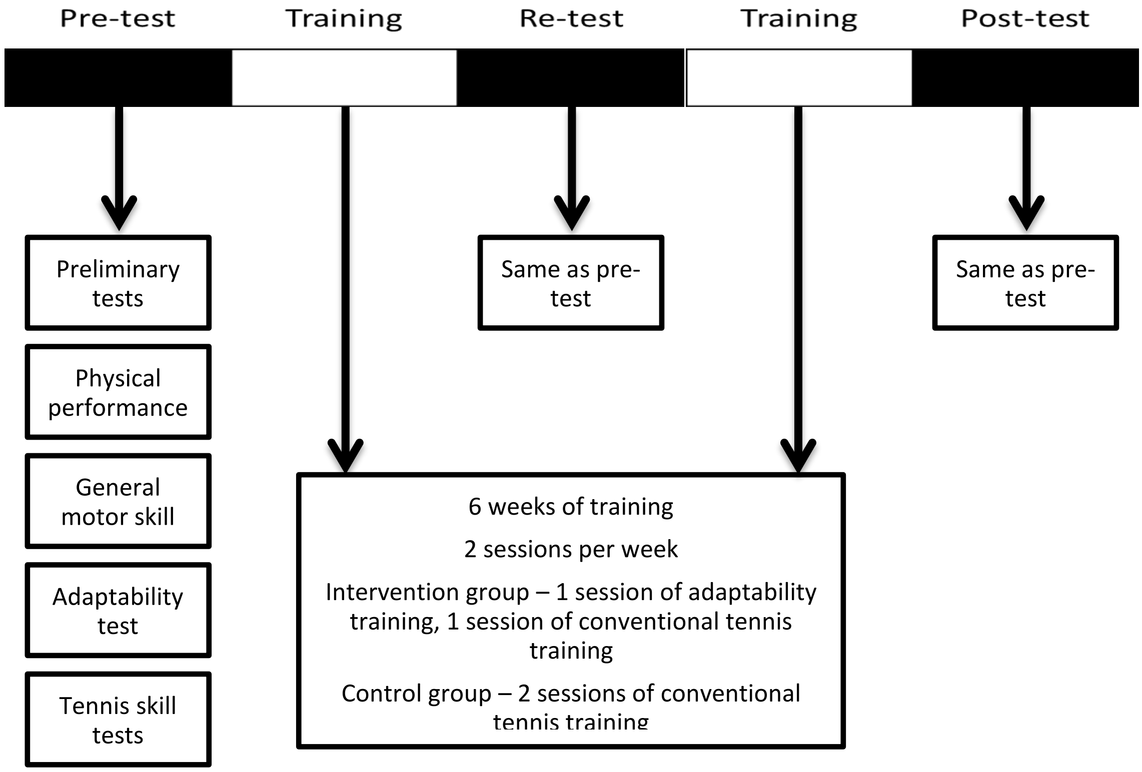


**Figure 15**. Study design

*5.2.3 Preliminary testing*

Participants height, sitting height (0.1cm, Seca, Chino, U.S.A) and weight (0.1kg, Tanita Australia, Kewdale, Australia) were measured (Beunen et al., 2011) and an estimate of biological maturity (years to peak height velocity) was calculated (Mirwald et al., 2002). This information was used to provide a description of their biological maturation (e.g. early, average or late), an estimation of the age of PHV.

*5.2.4 Physical performance testing*

*5.2.4.1 20m sprint test*

Participants completed a 20m sprint test to assess their straight-line acceleration and speed. Light gates (Fusion Sport, Sumner Park, Australia) were set up at intervals of 0m and 20m and participants completed 3 trials. All trials were completed outdoor on an asphalt surface. The best trial was used for analysis. A detailed description of the procedure followed can be found in Reid et al. (2012).

*5.2.4.2 Modified 5-0-5 agility test*

Participants completed a modified 5-0-5 agility test to assess their ability to perform a rapid change of direction. One set of light gates (Fusion Sport, Sumner Park, Australia) were set up at 0m with a pivot line marked out at 5m. Participants were encouraged to sprint to the pivot line, turn 180° and sprint back through the start/finish line. Six trials were completed, three turning in each direction, with the best time for each used for analysis. A detailed description of the procedure followed can be found in Reid et al. (2012).

*5.2.5 General motor skill testing*

The KTK (Kiphard & Schilling, 1974) was used to assess the general motor skills of the participants. The raw scores of each test were transformed into gender and age specific motor quotient values based on the norms of the original research (Kiphard & Schilling, 1974). An overall motor quotient was also calculated based on the sum of the four tests; this provided a general measure of motor control. The KTK comprises four different sub-tests.

*5.2.5.1. Walking backwards*

Participants walked backwards on a balance beam, 3m in length, for a maximum of 8 steps per trial. Three beams of different widths (6cm, 4.5cm and 3cm) were used with 3 trials conducted per width. A point is awarded for every step resulting in a maximum score of 24 per beam. Therefore, a maximum score for this test is 72 (24 steps multiplied by 3 beams).

*5.2.5.2. Moving sideways*

Participants began standing on a wooden platform (25cm x 25cm x 5.7cm) and holding an identical platform in their hands. They were instructed to place the platform in their hands next to the platform they were standing on and move on to it. This process is repeated as many times as possible in 20s, with the number of relocations recorded. The sum of two trials is used for analysis.

*5.2.5.3. Hopping for height*

Participants were instructed to hop on one foot over an increasing pile of foam blocks (60cm x 20cm x 5cm) after a short hopping run-up. After the foam blocks were cleared participants were required to continue for at least two hops post landing. Three points were awarded for clearing a height on the first attempt, two points for the second attempt and one point for the third attempt. A maximum of 39 points could be achieved for each leg (ground level plus 12 foam blocks) resulting in a total maximum score of 78 for both legs.

*5.2.5.4. Jumping sideways*

Participants were required to jump as many times as possible from side to side over a small wooden beam (60cm x 4cm x 2cm) in 15s. An individual's feet must remain together and the total number of jumps over two trials is recorded for analysis.

*5.2.6 Movement and skill adaptability tests*

*5.2.6.1 Throwing and rebound task*

The purpose of this task was to throw a ball towards five targets as quickly as possible. Participants began with a red (25% compression) tennis ball (Wilson, Chicago, U.S.A.) in their dominant hand and threw towards a self-selected target. They were required to retrieve the rebounding ball after each throw, alternating throwing arms until all targets were hit. If the pattern of alternating arms was broken a successful throw would not count and that specific target would have to be hit again in the correct manner. The time taken to complete the task was recorded on a stopwatch (0.01s, Apple, Cupertino, U.S.A) for analysis and two trials were completed in an attempt to gain maximal performance per session. To minimise potential learning effects, no demonstration was provided and participants were not allowed to watch each other complete the task.

The minimum throwing distance was 3m and the participants' started 1m wider than the closest target. This created an angle for the first throw which encouraged movement and the use of alternate throwing arms. Five square, 50cm diameter targets (Sioux Archery, Tiaro, Australia) were used and the targets differing positions were designed to encourage movement and changes in throwing patterns (e.g. overarm, underarm).

*5.2.6.2 Continuous rebounding task*

Participants struck a ball with alternating hands against a wall as many times as possible in a 30 second period. Similar to the throwing and rebound task, if a strike was performed in the incorrect sequence (e.g. with the incorrect hand) then it was not counted, with the count only being restarted when the participant returned to the correct sequence. The ball had to reach the wall without bouncing and was allowed one bounce before being struck again. If this pattern was not maintained (e.g. ball is struck but rolls along the ground) inside the 30s period, participants were encouraged to regain the ball and continue the test. This did not incur a direct penalty to a participant's score however indirectly their performance would be impacted due to the extra time taken to recover the ball and restart the striking pattern. The starting position was 3m away from a wall however this was for the first strike with the dominant hand only. After this initial strike, the participants could move forward to a distance of 1.5m from the wall. This provided some autonomy for participants in regards to how the task was completed.

This task was performed three times with three balls of different compression levels and sizes used for each individual trial (Spalding high bounce ball [Spalding, Scoresby, Australia], red [25% compression] tennis ball [Wilson, Chicago, U.S.A] and a Hart foam ball [Hart Sport, Aspley, Australia). The properties of these balls were not disclosed to the participant. The aim of utilising balls of different size, feel and bounce was to encourage participants to adapt their overall technique (movement and strike pattern) in order to maximise success. The number of successful strikes in 30 seconds was recorded, with the variable analysed being the sum of the three different balls used in each individual trial.

*5.2.7 Tennis skill tests*

*5.2.7.1 Volley test*

Participants began 3m from a solid wall that was marked with a target area of 1.5m by 1m. The target area is marked at a height that is 0.1m above a tennis net. After receiving the command to begin the test, participants self-fed the ball towards the target area and continued volleying against the wall. As many hits as possible in 30s were performed ensuring that the participant switched between forehand and backhand volleys. Only shots played in the correct sequence were deemed successful. If control of the ball was lost inside the 30s period, participants were encouraged to regain control and continue the test. Three attempts were provided with the number of shots made in the target area recorded as well as the number of shots missed. This is a protocol that has been used successfully with this age group in the applied setting (Tennis Australia [Appendix C – Volley Test]).

*5.2.7.2 Forehand stroke evaluation*

The procedures for the forehand stroke evaluation were taken from a publication by the Department of Education, Victoria, Australia, detailing how to assess fundamental motor skill competence in a primary school setting ("Fundamental motor skills: A manual for classroom teachers," 2009). Participants were informed that they would be required to perform a one handed forehand strike on 6 separate occasions. A tennis ball would be thrown to them and had to bounce once before it was struck. Participants were given a demonstration on how to successfully perform a forehand strike, with specific instruction given on the performance criteria. These were:

1. Eyes are focused on the ball throughout the strike
2. Stand side-on to the target with bat held in one hand
3. Striking hand nearly straightened behind shoulder at end of backswing
4. Step towards target with foot opposite striking arm during the strike
5. Marked sequential hip to shoulder rotation during the strike
6. Ball contact made opposite front foot with straight arm
7. Follow through towards the target then around body

Participants were set up 5m away from the person throwing the ball and told to strike the ball so that it travelled past the thrower without bouncing. An experienced tennis coach (~8 years coaching with a similar population) performed the demonstration and assessment for all participants, with the number of successfully performed criteria recorded for analysis (e.g. 4/7).

*5.2.8 Training programs*

A 5-minute standardised warm up that involved throwing and jogging was conducted with both groups prior to beginning their lesson. The complete lesson plan for both the conventional tennis training and adaptability training program can be found in Appendix D – Training Program. The program was repeated for the second block of training.

*5.2.8.1 Conventional tennis training program*

The conventional tennis training program was derived from the Tennis Australia endorsed ANZ hot shots program. The training activities were taken from the 'red' stage of lesson plans which is designed for beginners and matches the tennis history of the participant population. A modified tennis ball, which does not bounce as high and fast as a normal tennis ball (25% compression compared to a normal tennis ball) was used in conjunction with modified racquets (smaller size). The court size and net height used were consistent with red court guidelines (11 x 5.5m court size and 80cm net height). The court size was scaled to be more developmentally appropriate to the participants. An example activity (Red serve – overarm throw) is provided in Figure 16. Four activities were allocated 10 minutes each per lesson, which when incorporated with the standardised 5 minutes warm up, resulted in a 45 minute lesson.

Activity: Red serve – overarm throw

**Purpose:**

Learn to start the point with a simple action

**Coordinate both arms – Overarm throw**

Working in pairs, throw over different lengths making sure non-throwing arm works in opposition to the throwing arm.

Throw as high as possible, stretching the non-throwing arm up.

Concentrate on player stance and remaining balanced.

**Bullseye**

Players hold a ball in each hand – they lift with left hand (toss) and throw overarm with their right arm (for right-handed players).

They aim to throw the ball in the dominant hand under the ball tossed with the non-dominant one.

More importantly for the coach they are coordinating the toss with an overarm motion.

**Cylinder serve**

Player serves overarm from a normal stance – the swing can be shortened but the coordination and rhythm between the two arms should remain.

**Coaching notes:**

Teach the students to start the point themselves from the earliest possible time. Children who rely on the coach to start the rally (feed) all the time will not be able to practice away from the coach.

Underarm throwing and serving is ideal as they begin, and can move to overarm as they develop.

**Adaptability intervention group:**

Manipulate task constraint – Modified base of support

After every attempt students change their position by completing the task either:

- Standing on the ground
- On one leg (dominant and non-dominant)
- With a narrow base of support
- With a wide base of support

**Figure 16.** Example activity from training program

*5.2.8.2 Adaptability training program*

A constraints led approach (Newell, 1986) was used as the underlying theory for transforming the original ANZ hot shots lessons into adaptability lessons. Each individual activity taken from the ANZ hot shots program was analysed for potential individual, task or environmental elements that could be manipulated to give the participant the opportunity to adapt. The majority of manipulations were on task constraints however some environmental constraints were altered. The specific manipulations that occurred are shown in Table 10. Using Figure 16 as an example, the activity (Red Serve – overarm throw) was completed with the addition of the manipulated constraint (modified base of support). Every activity completed in the adaptability training program featured a manipulated constraint.

**Table 10.** Constraints manipulated in the adaptability training program

| **Task** | **Environmental** |
|---|---|
| Different types of balls (modified size, bounce) | Different surface (gravel, grass, uneven) |
| Different types of equipment (table tennis bat, adult racquet, hand) | |
| Use of non-dominant/alternating hands | |
| Modified base of support (standing one leg) | |
| Modified spatial orientation (serving from 45° or 90°) | |

Additionally, the practice schedule was manipulated with a number of constraints occurring in a random schedule. For example, when a task was being completed with different types of balls, these balls were placed into a bucket for use in the activity. The coach or participant (depending on the activity) would randomly select a ball to be used for that specific shot/rally. From a practical perspective it was not possible to do this across all manipulations without being logistically problematic and reducing the time the participants were performing the activities (For example, changing racquets after every individual rally).

*5.2.9 Enjoyment scale*

After the first 6 weeks and at the completion of the training program all participants anonymously completed a questionnaire assessing their enjoyment levels. The Physical Activity Enjoyment Scale (PACES) (Kendzierski & DeCarlo, 1991; Moore et al., 2009) was used with a slightly modified initial statement (Figure 17).

When I am in the adaptability/conventional tennis training program. . . (1) Disagree a lot. . . (3) Neither agree or disagree. . . (5) Agree a lot

1. I enjoy it
2. I feel bored
3. I dislike it
4. I find it pleasurable
5. It’s no fun at all
6. It gives me energy
7. It makes me depressed
8. It’s very pleasant
9. My body feels good
10. I get something out of it
11. It’s very exciting
12. It frustrates me
13. It’s not at all interesting
14. It gives me a strong feeling of success
15. It feels good
16. I feel as though I would rather be doing something else

**Figure 17.** Modified PACES scale (Kendzierski & DeCarlo, 1991; Moore et al., 2009)

*5.2.10 Statistical analysis*

Data is expressed as mean ± SD. Differences between groups, gender and time (pre, mid and post) were analysed with the IBM Statistical Package for the Social

Sciences (IBM SPSS Statistics 21.0.0, SPSS Inc, USA) via an independent sample t-test where statistical significance was set at $P \leq 0.05$. A Pearson correlation was used to assess the relationship between attendance, test performance and change scores between pre, mid and post data, significance was set at $p<0.05$. Data analysing the predictability of the novel tests was evaluated by a mixed between-within subject ANOVA, where statistical significance was set at $p \leq 0.05$.

### 5.3 Results

Descriptive statistics of the variables assessed at pre, mid and post-test are reported in table 11.

**Table 11.** Descriptive statistics for pre, mid and post-test. * denotes difference to pre-test, p<0.05, ^ denotes difference to pre-test, p<0.01, # denotes difference to mid-test, p<0.05

| Variable | Pre | | Mid | | Post | |
|---|---|---|---|---|---|---|
| | Adaptability (n=24) | Control (n=25) | Adaptability (n=23) | Control (n=25) | Adaptability (n=21) | Control (n=23) |
| **Age (years)** | 8.90 ± 0.72 | 8.95 ± 0.79 | 9.03 ± 0.73 | 9.10 ± 0.79 | 9.09 ± 0.72 | 9.10 ± 0.68 |
| **Height (cm)** | 138.85 ± 8.71 | 136.96 ± 7.23 | 139.26 ± 8.08 | 137.92 ± 7.83 | 139.52 ± 8.37 | 138.72 ± 7.38 |
| **Weight (kg)** | 36.11 ± 8.59 | 36.84 ± 11.57 | 36.80 ± 8.89 | 37.87 ± 12.16 | 37.11 ± 9.07 | 38.43 ± 12.55 |
| **Sitting height (cm)** | 73.04 ± 4.40 | 72.62 ± 3.44 | 73.22 ± 3.62 | 72.65 ± 2.94 | 73.23 ± 4.20 | 73.04 ± 3.05 |
| **Years to PHV** | 3.29 ± 0.67 | 3.31 ± 0.74 | 3.20 ± 0.66 | 3.22 ± 0.75 | 3.12 ± 0.70 | 3.21 ± 0.74 |
| **Age at PHV** | 12.19 ± 0.58 | 12.26 ± 0.73 | 12.23 ± 0.60 | 12.32 ± 0.76 | 12.21 ± 0.60 | 12.31 ± 0.81 |
| **Best TRT** | 31.44 ± 18.42 | 35.41 ± 17.36 | 22.35 ± 9.53* | 26.86 ± 15.16 | 21.47 ± 14.15* | 24.08 ± 11.89* |
| **Average TRT** | 41.87 ± 22.35 | 43.48 ± 19.10 | 29.35 ± 17.39* | 32.32 ± 18.42* | 27.12 ± 21.13* | 29.75 ± 12.42^ |
| **Sum CRT** | 17.79 ± 9.23 | 17.16 ± 9.02 | 22.48 ± 9.80 | 19.68 ± 10.09 | 25.29 ± 8.57^ | 24.61 ± 11.23* |
| **20m sprint** | 4.42 ± 0.40 | 4.61 ± 0.59 | 4.41 ± 0.47 | 4.51 ± 0.60 | 4.36 ± 0.42 | 4.54 ± 0.54 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **5-0-5 left** | 3.53 ± 0.36 | 3.54 ± 0.40 | 3.45 ± 0.43 | 3.47 ± 0.31 | 3.38 ± 0.31 | 3.52 ± 0.42 |
| **5-0-5 right** | 3.46 ± 0.38 | 3.56 ± 0.39 | 3.51 ± 0.38 | 3.59 ± 0.47 | 3.46 ± 0.34 | 3.52 ± 0.36 |
| **KTK total** | 159.88 ± 38.31 | 156.68 ± 46.58 | 175.17 ± 42.70 | 175.80 ± 53.16 | 189.05 ± 39.13* | 188.43 ± 51.20* |
| **Volley test – shots made** | 9.63 ± 7.82 | 11.88 ± 12.22 | 10.78 ± 6.38 | 13.76 ± 11.55 | 16.43 ± 12.17* | 13.96 ± 12.08 |
| **Volley test – total shots** | 32.25 ± 11.40 | 30.40 ± 15.01 | 30.09 ± 11.65 | 30.84 ± 12.65 | 35.05 ± 12.01 | 32.87 ± 13.98 |
| **Forehand stroke evaluation** | 3.92 ± 1.47 | 4.08 ± 1.35 | 4.83 ± 0.94* | 4.68 ± 1.38 | 5.48 ± 1.17^ # | 5.09 ± 1.08^ |

There were no significant differences between the groups on any variables at pre, mid or post-test. However, when analysing for time the adaptability group improved significantly on the volley test for shots made ($t(43) = -2.26$, $p=0.029$, pre-to-post), which is in contrast to the control group where there was no significant difference. The forehand stroke evaluation improved significantly at all intervals (pre-to-mid, pre-to-post and mid-to-post) in the adaptability group, whereas the control group improved only from pre-to-post-test. When the analysis was separated by gender, there were no differences between intervention groups for females or males with any variable at any time point. Examining the population as a whole, there were no differences between genders at pre-test, whilst at mid-test males outperformed females on sum CRT, $t(46) = 2.09$, $p=0.042$ and the 20m sprint, $t(46) = -2.26$, $p=0.028$. Post-test revealed significant differences between genders for sum CRT, $t(42) = 2.12$, $p=0.040$, shots made $t(42) = 2.12$, $p=0.040$ and total shots $t(42) = 2.31$, $p=0.026$) on the volley test.

A mixed between-within subjects ANOVA was used to assess the predictive abilities of the TRT and CRT in relation to the tennis performance tests (volley test and forehand stroke evaluation). Additionally, the impact of training group and gender was investigated. The only significant outcome for shots made on the volley test was a main effect for gender, $F(1, 44) = 7.90$, $p=0.008$). Analysing total shots on the volley test revealed that there was a statistically significant effect for sum CRT across time $F(1, 44) = 5.49$, $p=0.025$), with a greater total shots score at post-test being related to a greater sum CRT score at pre-test. There were no significant effects for the forehand stroke evaluation.

Examining the gender and adaptability results further revealed males in the adaptability group reported a significant correlation ($p=0.017$) between pre-test best TRT scores and the change in shots made on the volley test (post-test minus pre-test). In contrast to males from the conventional training group or females in either training group (Figure 18). This result was reinforced by pre-test sum CRT scores also correlating to the change in shots made (p=0.028), signifying a potential predictive ability of the tests in relation to tennis development.

The average attendance for the program was 86.93 ± 12.73%, with significant correlations between attendance levels and a number of variables (Figure 19). Attendance in the first training block was significantly correlated to results at the mid-test for best TRT, Volley test – shots made and total shots (p=0.015, p=0.002 and p=0.01 respectively). Whole program attendance and sum CRT at post-test were also significantly correlated (p=0.046), with no relationships emerging from second training block attendance and any post-test results. Additionally, attendance levels were not significantly correlated to change scores (pre to mid, mid to post, pre to post) for any variables.

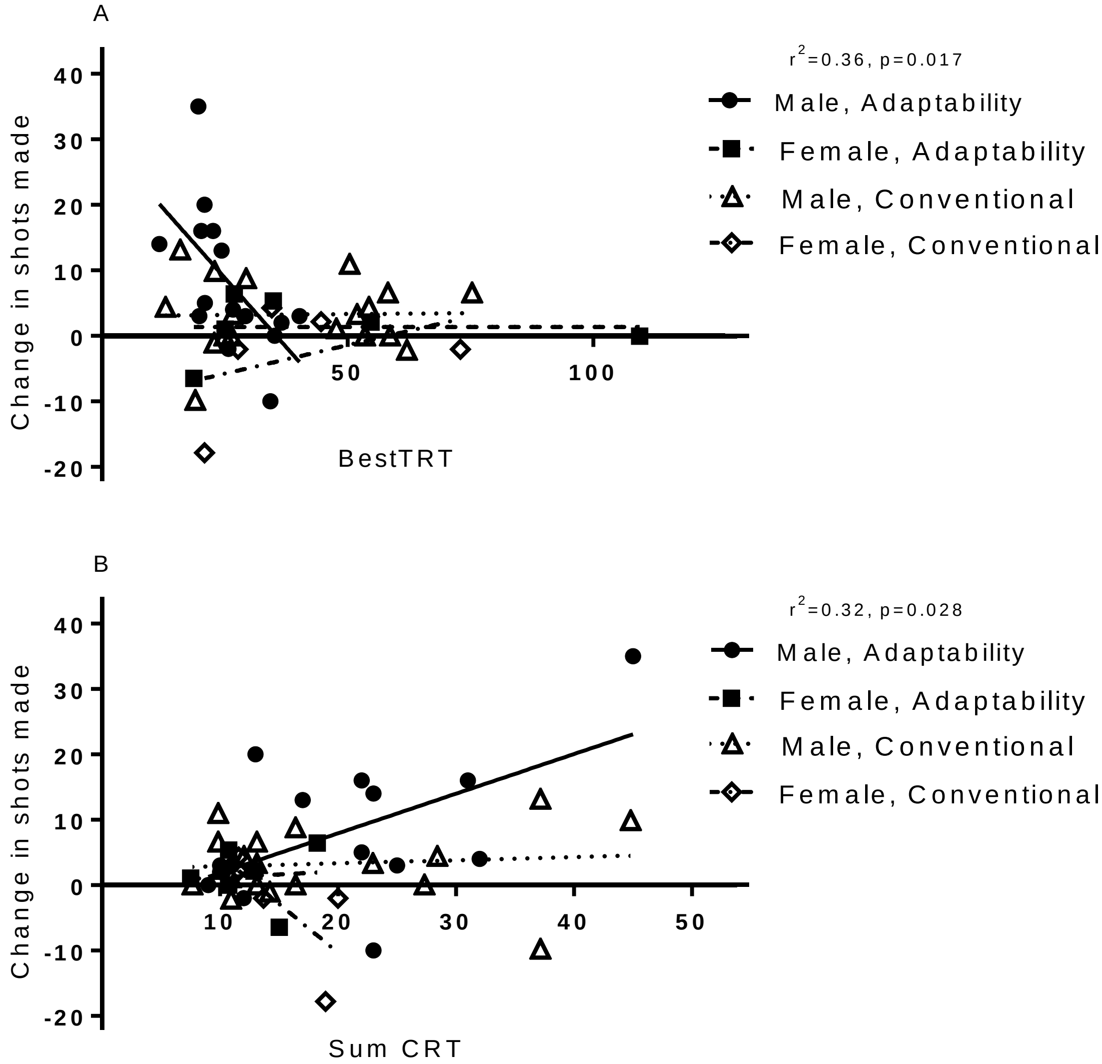


**Figure 18.** Correlations between gender, Best TRT (A), Sum CRT (B) and the change in shots made on the volley test. $R^2$ and p-values for males in the adaptability group only

There were no significant differences on any variable at pre-test when analysing the population via their maturation classification (early, average or late). At mid and post-test there was a significant difference between early and average maturing participants on the KTK (t[46] = -2.28, p=0.028 and t[42] = -2.05, p=0.046 respectively), with no participants being classified as late maturing. Years to PHV was not significantly correlated to any variables at pre or post-test, however there was a correlation at mid-test for the KTK (p=0.031). Chronological age was correlated to all performance variables (best TRT, average TRT, sum CRT, 20m sprint, 5-0-5 left and right, KTK, volley test – shots made and total shots, p<0.05) except the forehand stroke evaluation at pre and post-test. At mid-test, shots made on the volley test and the forehand stroke evaluation were not correlated with chronological age however, all remaining performance variables displayed a significant relationship (p<0.05).

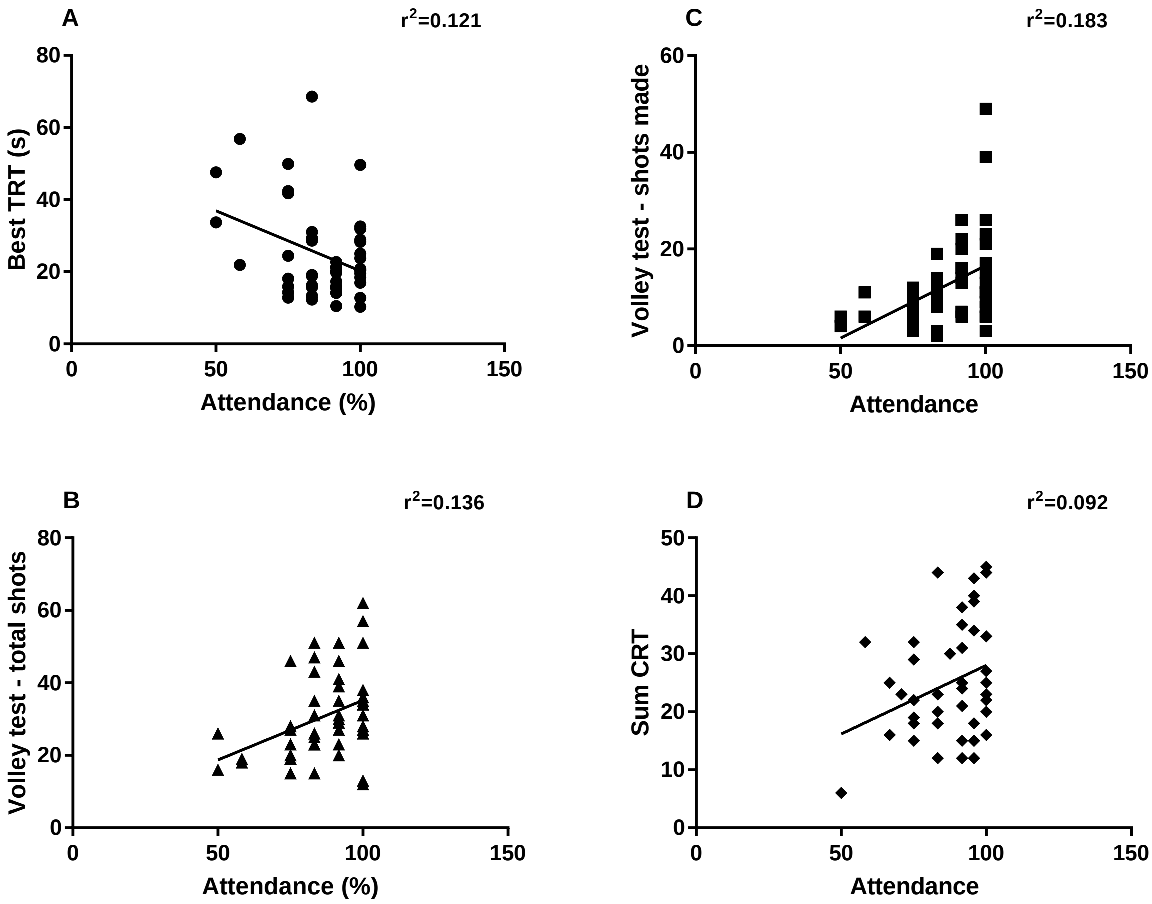


**Figure 19.** Relationship between (A) Training block 1 attendance and Best TRT at mid-test, (B) Training block 1 attendance and Volley test – total shots at mid-test, (C) Training block 1 attendance and Volley test – shot made at mid-test and (D) Whole program attendance and Sum CRT.

The adaptability group experienced higher levels of enjoyment at both the mid and post-test in comparison to the control group, $F(1, 46) = 6.33$, $p=0.015$ and $F(1, 42) = 6.34$, $p=0.16$, respectively) (Figure 20).

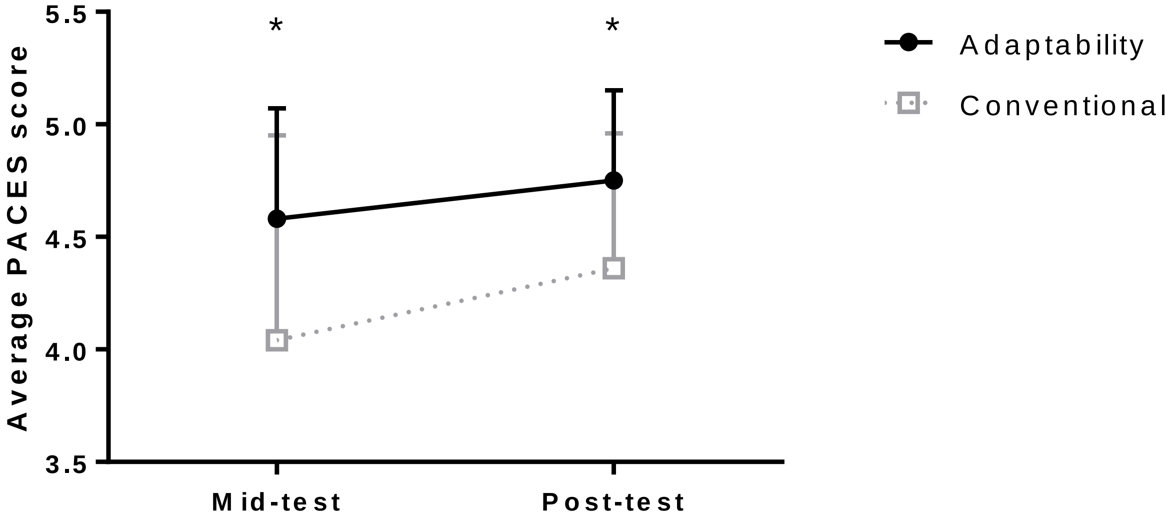


**Figure 20.** Training program enjoyment scores as per PACES. * denotes difference between groups, p<0.05

### 5.4 Discussion

The aim of this study was to assess the impact of an adaptability training program in comparison to a conventional tennis training program. The adaptability training produced a significant improvement in performance over time for shots made on the volley test, an objective, tennis specific, accuracy task. Additionally, the forehand stroke evaluation, a subjective measure of tennis performance improved across all time periods in the adaptability group, whilst only improving pre to post-test in the conventional training group. Males outperformed females on sum CRT at mid and post-test and both measures of the volley test on post testing. The ability of the TRT and CRT to predict tennis performance and development is met with cautious optimism; sum CRT was significantly related to total shots on the volley test. Best TRT and sum CRT were also correlated to the change in shots made in the volley test (post-test minus pre-test). From a maturation perspective (classification and years to PHV) there were minimal significant relationships, whilst comparatively, chronological age produced a number of significant correlations with performance variables. Enjoyment levels were significantly higher with participants in the adaptability program.

The improvement in shots made on the volley test and the forehand stroke evaluation begins to demonstrate adaptability's potential as a training method. Coupled with the conventional training group not significantly improving on shots made on the volley test and improving at less time points for the forehand evaluation, adaptability training appears to have merit. It is important to note, the adaptability group improved their performance via techniques which would be considered 'incorrect' from a traditional tennis coaching standpoint (Savelsbergh et al., 2010). This observation solidifies the importance of the result; despite learning 'incorrectly', the adaptability group improved more than the participants who learnt traditionally.

The adaptability training program produced significant improvements in all adaptability measures (best TRT, average TRT and sum CRT), the control group experienced similar significant improvements. A plausible explanation for this result is the tasks in both programs. Despite manipulating constraints in the adaptability group, the underlying task is the same in the conventional training group (e.g. both groups perform "rolling rally"). The tasks in Tennis Australia's "hot shots" program are varied. For example, participants are required to strike a ball and make it roll along the ground, catch a bouncing ball with a cone and co-ordinate throwing two balls at once (Appendix D – Training Program). This variation in practice may have improved the adaptability of the conventional training group. Unfortunately, the practical implementation of programs such as "hot shots" seldom occurs in the field with highly specialised, repetitive tennis training favoured (Reid, Crespo, Lay, et al., 2007). Using a repetitive, blocked program instead of "hot shots" may have elucidated a clearer distinction of results between adaptability and conventional tennis training.

Gender appears to have impacted results with males outperforming females on sum CRT and the 20m sprint at mid-test, whilst at post-test there was a significant difference from sum CRT, shots made and total shots on the volley test. Despite having a comparable number of males and females in each training group, males outnumbered females in the participation population (mid-test – males n = 36, females n = 12, post-test – males n = 33, females n = 11). This discrepancy may have influenced the results. Additionally, the relationship of gender and training group was explored. This was performed in the context of the adaptability tests and their ability to predict tennis development throughout the study (Figure 18). Best TRT and sum CRT had a significant correlation to change in shots made on the volley test (post-test minus pre-test) for males in the adaptability group only. This demonstrates the potential of both adaptability tests to predict tennis development. Despite further longitudinal research being required to substantiate this result, the ability to assess talent potential is a positive outcome and regularly noted as a requirement in the TI literature (Abbott & Collins, 2002; Martindale et al., 2005; Vaeyens et al., 2008). The absence of a significant result for females may be explained by the smaller number of participants as mentioned previously, or potentially males responded better to the adaptability program in comparison to females. Object control skills are more proficient among males in comparison to females (Barnett et al., 2008) and this may have influenced skill development.

The CRT demonstrated an ability to predict later tennis performance, with pre-test values significantly related to post-test scores on the volley test – total shots. This result adds to an emerging trend in the literature using generic skill tests for TI (Ericsson, 2013; Faber et al., 2014; Vandorpe, Vandendriessche, Vaeyens, et al., 2011; Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). Positive results have been reported in table tennis and gymnastics. In table tennis, a generic skill test was able to discriminate between local, regional and national players whilst in gymnastics the KTK was superior to coaches' judgement, anthropometric and physical attributes when assessing competition results in a two year longitudinal study (Faber et al., 2014; Vandorpe, Vandendriessche, Vaeyens, Pion, Lefevre, et al., 2012). The perceptual-motor tasks used share similar attributes to the particular sport but are not influenced by prior sport-specific training.

Although not as critical with this population (8-10 year of age) the potential for biological maturity to influence results is omnipresent and should be accounted for if research is striving to operate under best practice (Vaeyens et al., 2008). Maturation (classification and years to PHV) only possessed a significant relationship with KTK, with early maturing participants outperforming average maturing participants. Despite the apparent minimal influence of maturation chronological age was correlated to all performance variables except the forehand stroke evaluation at pre and post-test, whilst at mid-test shots made on the volley test in addition to the forehand stroke evaluation were the only performance variables not correlated. The combination of the substantial time to PHV (3.30 years, 3.21 years and 3.16 years at pre, mid and post-test respectively) and the frequency distribution of the chronological ages may explain this result (Figure 21a and Figure 21b). The bimodal, u-shaped distribution of chronological age is a result of the participants being recruited from 2 consecutive school years (year 3 and 4) and is in contrast to the more normally distributed years to PHV. The bi-modal distribution may have contributed to the results with the older children experiencing an extra year of physical development, physical education and skill development opportunities.

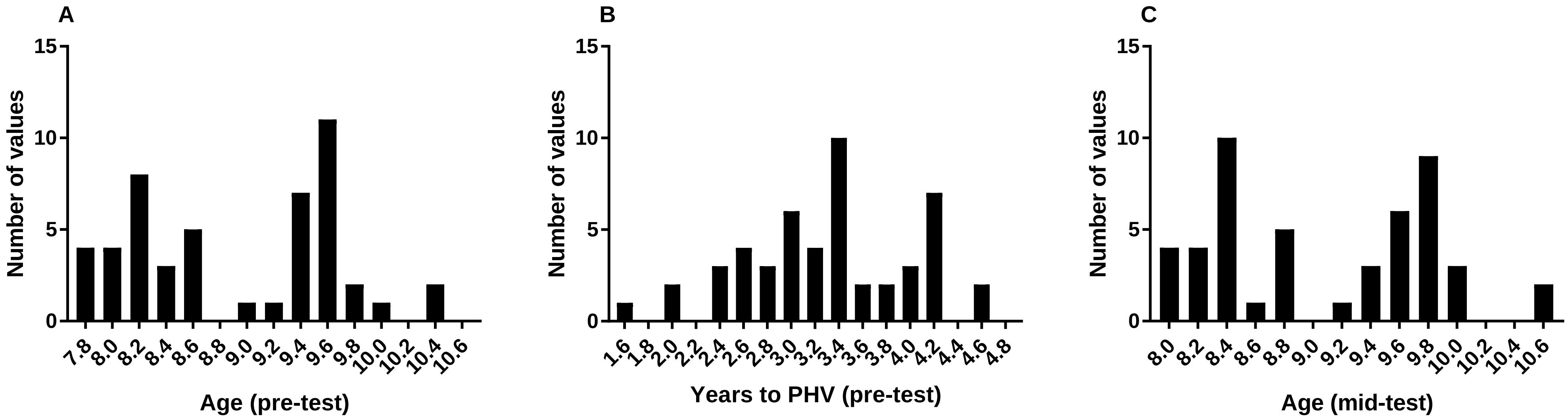


**Figure 21a.** Frequency distribution of (A) chronological age at pre-test, (B) years to PHV at pre-test, (C) chronological age at mid-test

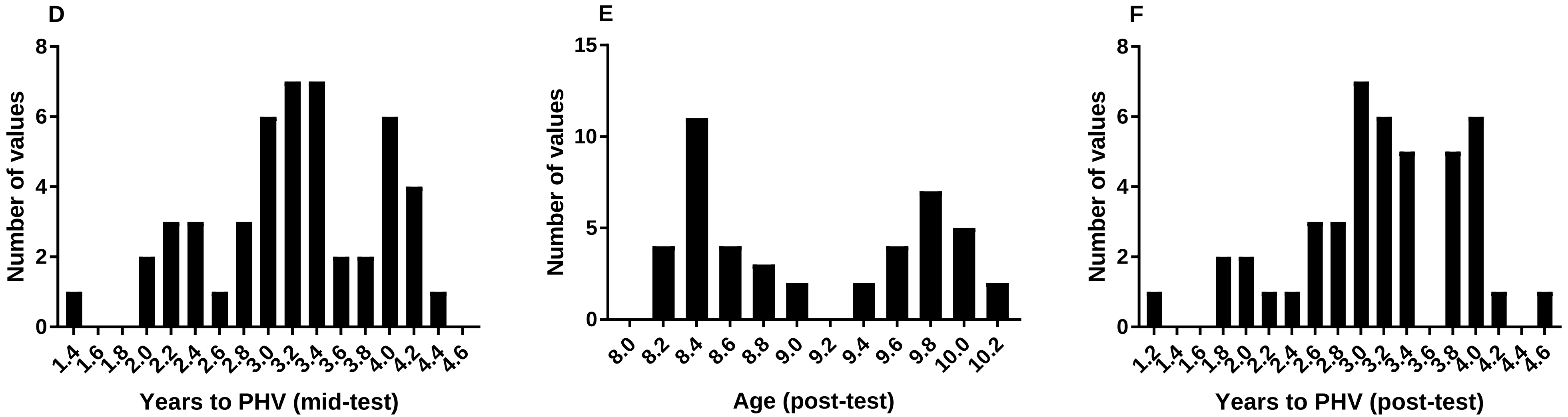


**Figure 21b.** Frequency distribution of (D) years to PHV at mid-test, (E) chronological age at post-test, (F) years to PHV at post-test

Enjoyment levels were significantly higher at both the mid and post-test for participants in the adaptability group in comparison to the conventional training group. This is an important finding as the psychological aspects of sport have been speculated to be more important than the physical (Abbott & Collins, 2002; Abbott & Collins, 2004). Enjoyment in junior populations was reported as the only consistent predictor of physical activity, with a lack of enjoyment the main cause of children ceasing to play sport (DiLorenzo et al., 1998; Hecimovich, 2004). Talent development programs should strive to maximise enjoyment, in turn helping maximise program adherence and minimise dropout.

A limitation of this study is that it is not longitudinal in nature, a common criticism of talent identification and development literature (Fransen et al., 2012; Gulbin, Croser, et al., 2013; Lidor et al., 2009; Morris, 2000). However, due to adaptability being a novel training construct in combination with logistical considerations, a semi-longitudinal training study was deemed more appropriate.

## 5.5 Conclusion

Training adaptability via the manipulation of individual, task and environmental constraints has been demonstrated to improve tennis performance in comparison to a conventional tennis training program. Adaptability tests, the TRT and CRT, have established their merit as potential TI measures, with significant relationships to tennis performance (at post-test) and development (change scores, post minus pre). Males outperformed females on a limited number of variables (sum CRT, volley test – shots made and total shots), with the response to the training stimuli more exaggerated for males in the adaptability group. Maturation (classification and years to PHV) reported minimal impact on results with age a more potent discriminator, potentially due to recruiting from two different school years (year 3 and 4). Participant enjoyment was significantly higher in the adaptability group compared to the conventional training group

Despite the acknowledged requirement for longitudinal research, adaptability's capacity to improve tennis performance combined with higher levels of enjoyment is a significant outcome. The potential for the adaptability tests to predict later tennis performance and development further reinforces the importance of adaptability. Movement and skill adaptability should be expanded to other sports that contain time-constrained perception-action and future longitudinal research undertaken to confirm these initial findings.

# Chapter 6. General discussion

## 6.1 Main findings

This thesis investigated the potential of movement and skill adaptability to be applied in tennis. Two objective measures of adaptability, the TRT and CRT were created to assess the concept of movement and skill adaptability. Validity and reliability was established by demonstrating construct validity, face validity and test-retest reliability. The impact of adaptability on junior tennis performance was more pronounced than previously investigated pertinent variables (fundamental motor skills, physical performance, maturation and anthropometric). An adaptability training program was compared to a conventional tennis training program. Both training programs produced significant improvements for best TRT, average TRT, sum CRT, KTK and the forehand stroke evaluation. However, only the adaptability program reported constant improvement on the forehand stroke evaluation, with significant improvement at mid-test and at post-test (when compared to pre and mid-test). Additionally, for "shots made" on the volley test there was only improvement in the adaptability group.

Movement and skill adaptability was used to underpin the development of the TRT and CRT. Construct validity was demonstrated by reporting the superiority of a skilled junior athlete group in comparison to a recreational group (best TRT $p=0.016$, average TRT $p=0.002$, sum CRT $p<0.001$). On a 5-point Likert scale, an expert consensus rated the TRT $4.5 \pm 0.55$ and the CRT $4.66 \pm 0.52$, signifying face validity. The reliability of both tests was assessed and confirmed via an ICC, best TRT = 0.79, average TRT = 0.81 and sum CRT = 0.88. The creation of two novel adaptability tests, which are valid, reliable and representative of the open skill performance environment, address previously identified gaps in the literature (Breitbach et al., 2014). Current methods of talent identification in tennis are performance based and can overlook the potential to develop, instead prioritising those who have matured or specialised early

(Martindale et al., 2005; Unierzyski, 2002; Unierzyski & Osinski, 2007). The TRT and CRT provide a practical alternative which can be incorporated into existing TI procedures.

The contribution that adaptability, fundamental motor skills, physical performance and maturation has on junior tennis performance was examined. Sum CRT was the most influential variable for both shots made and total shots on the volley test ($p<0.001$), with height and best TRT also significant variables for total shots on the volley test ($p=0.014$ and $p=0.029$ respectively). The predictive equations generated from this study were Shots Made = 0.667*Sum CRT – 0.880 and Total Shots = 0.674*Sum CRT + 0.433*Height – 0.194*Best TRT – 33.638. The significant result reported for adaptability measures (TRT and CRT) is made more meaningful as adaptability was compared to variables previously established to be important for junior tennis performance (Table 12). The importance of adaptability in junior tennis performance is recognised, further solidifying the validity established in Chapter 3.

An adaptability training program was compared to a conventional tennis training program. The potential to train adaptability is derived from the manipulation of existing proven practice/training methods (sampling, explicit/implicit learning, variable/constant practice, differential learning, contextual interference and skill transfer). Both training programs produced significant improvements for best TRT, average TRT, sum CRT, KTK and the forehand stroke evaluation. However, only the adaptability program reported constant improvement on the forehand stroke evaluation, with significant improvement at mid-test and at post-test (when compared to pre and mid-test). Additionally, for “shots made” on the volley test there was only improvement in the adaptability group. The predictive ability of the TRT and CRT is emerging with significant relationships to both post-test tennis scores and the change in tennis scores (post minus pre-test). The developmental benefits of adaptability have been reported and this research should encourage further investigations into adaptability.

**Table 12.** Variables related to junior tennis performance

| Study | Variable group | Variable related to junior tennis performance |
|---|---|---|
| **Söğüt (2016)** | Fundamental motor skill | KTK |
| **Elliot et al. (1990)** | Physical performance | Agility (males)<br>Speed (40m sprint, females) |
| **Roetert et al. (1992)** | Physical performance | Agility |
| **Roetert et al. (1996)** | Physical performance | Agility |
| **Girard and Millet (2009)** | Physical performance | Speed (5, 10 and 20m sprint) |
| **Unierzyski (2002)** | Maturation | Accelerated biological development |

**6.2 Adaptability for talent identification and development in tennis**

The success of a novel approach to talent identification and development is judged simplistically; does the novel approach identify/develop talent in tennis? For talent identification, does the novel approach at one time point recognise a participant who can excel at a later time point (Lidor et al., 2009; Mohamed et al., 2009; Vaeyens et al., 2008; Williams & Reilly, 2000)? Similarly, for talent development, is it the most appropriate learning environment for the participant to maximise their potential to excel (Lidor et al., 2009; Vaeyens et al., 2008; Williams & Reilly, 2000)? In this thesis, movement and skill adaptability as a testing measure (TRT and CRT) and training construct (adaptability training program) has demonstrated the potential to identify and develop talent in tennis.

Talent identification in tennis has previously been confined to tennis (e.g. rankings, match results) and physical performance measures (e.g. 20m sprint) (Brouwers et al., 2012; Miley & Nesbitt, 1995; Phillips et al., 2010b; Reid et al., 2009;

Reid, Crespo, Santilli, et al., 2007; Reid & Morris, 2013; Vergauwen et al., 1998). Aside from low success rates, these methods have either not been developmentally appropriate (tennis performance measures) or lacked the multidimensional perception-action coupling required to be representative of the sport (physical performance measures). The TRT and CRT were designed to be the intermediary between tennis and physical performance measures; developmentally appropriate, skill performance relatable to tennis and include perception-action coupling.

Talent identification research from sports other than tennis illustrate that an approach similar to tennis is adopted; sport-specific and physical attributes are tested in junior populations (Falk et al., 2004; Goto et al., 2015; Waldron et al., 2014). Swimming in water polo and running in soccer and rugby league are examples of this. However, in all of these sports there are recommendations to adopt a more holistic approach (Falk et al., 2004; Waldron et al., 2014; Williams & Reilly, 2000). Movement and skill adaptability and the creation of the TRT and CRT may provide a framework for these sports to produce alternative measures.

The TRT and CRT's potential to identify talent in tennis have been demonstrated. The CRT at pre-test was significantly related to total shots on the volley test at post-test. Additionally, males in the adaptability group reported significant relationships between best TRT, sum CRT and the change in shots made on the volley test (post-test minus pre-test). This data signifies that potential for the TRT and CRT to recognise participants who can excel at a later time point, both in absolute (post-test scores) and development (change scores) terms.

The significant relationship to development (change scores) is a promising finding as this supports recommendations from the TI literature to focus on progression rather than early selection/de-selection (Martindale et al., 2005; Vaeyens et al., 2008). Previous research using sport-specific measures reported opposing findings (Falk et al., 2004); selected athletes were superior throughout the entire testing period. This implies the testing mechanisms aren't identifying potential, rather evaluating current performance.

Applying the regression equations developed in chapter 4 to the data in chapter 5 may also provide some evidence for the predictive ability of the TRT and CRT. The models realised for Shots Made and Total Shots and data from Chapter 5 was inputted into these equations and results displayed in Figure 22. The correlation between scores predicted by the equations and actual scores was $r^2 = 0.637$ for shots made and $r^2 = 0.641$ for total shots on the volley test, reinforcing the potential of the TRT and CRT to recognise future talent.

Adaptability is suggested as an intermediary between existing talent development pathways; early sport specialisation (incorporating deliberate practice) and sampling. Individuals who engage in early sport specialisation focus on one sport from a young age, completing more sport-specific practice hours whilst sampling dictates participation in a range of sports (Côté, 1999; Ericsson et al., 1993; Mostafavifar et al., 2013). Through the manipulation of constraints, adaptability seeks to combine the advantageous elements of each pathway whilst addressing the weaknesses. For example, early sport specialisation has an increased level of domain specific practice which an adaptability program maintains, in contrast to sampling. Sampling, in comparison, provides for exposure to a broader range of movement and skill contexts, which adaptability training includes.

Adaptability training in Chapter 5 outperformed conventional tennis training by producing a significant improvement from pre to post-test with shots made on the volley test. Adaptability training also reported significantly higher levels of enjoyment at both mid and post-test. There were no test measures where conventional tennis training experienced significant improvement and adaptability training did not. Adaptability training may be a more appropriate learning environment than conventional methods, however further research is needed to strengthen this initial data.

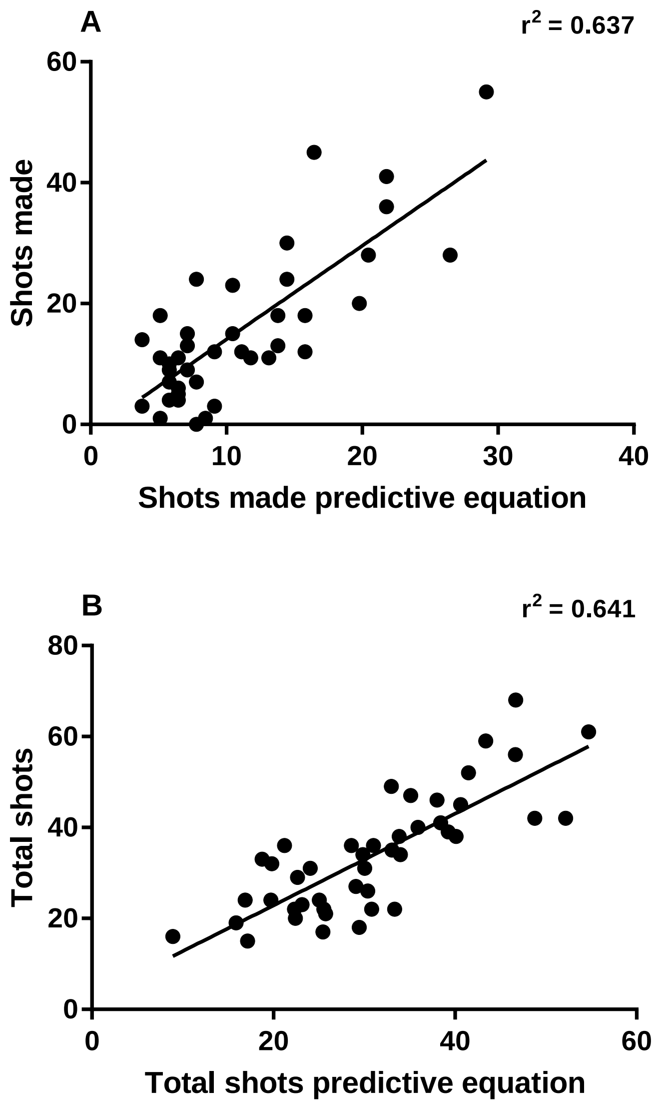


**Figure 22.** Comparison of predicted scores and actual scores for (A) shots made and (B) total shots on the volley test.

### 6.3 Limitations

The absence of true longitudinal research is an often cited limitation of talent identification and development research (Fransen et al., 2012; Gulbin, Croser, et al., 2013; Lidor et al., 2009; Morris, 2000). This is also a limitation of this research however there were some important overarching reasons for the current study design. Movement and skill adaptability is an emerging research area lacking in established test measures, norms and training programs. As such, it was necessary to first understand and define adaptability, prior to creating valid and reliable test measures.

From a training perspective, this research serves as proof of the concept of adaptability. It was prudent to assess the potential benefits of adaptability on a smaller scale prior to completing a longitudinal study.

The population used in chapter 5 did not have previous tennis experience which is in contrast to the majority of talent identification and development research. Further research is required to understand if the results in this thesis can be applied to those at different levels of the development pathway. Additionally, the sport/activity level of the participants was not accounted for. Previous tennis experience was noted at the beginning of the study to ensure the inclusion criteria was met (<6 months). However, participation in other sport/activity outside of the program was not monitored.

**6.4 Summary and conclusions**

This thesis has clearly demonstrated that movement and skill adaptability has a role in talent identification and development in tennis. The creation of two valid and reliable tests which assess adaptability, allow for the objective measurement of the emerging construct. The importance of being able to measure and track adaptability is that comparisons can be made to other tests/fields. This process was completed in Chapter 4, reporting that adaptability was more influential than other previously established areas (physical, general motor skill, anthropometric and maturation). Participants in an adaptability training program reported significant improvement in their tennis performance in comparison to those in the conventional training group. Additionally, the adaptability group experienced higher levels of enjoyment and were not outperformed on any test measure by the conventional training group.

The practical outputs from this thesis are the most significant. Two valid and reliable tests combined with an adaptability training program have the potential to be immediately used in the field. Furthermore, the detailed explanations of the methods used to manipulate tasks provide individuals with the opportunity to incorporate adaptability into their own activities. Despite adaptability being applied to tennis in this research, it is hypothesised that adaptability could be employed in a number of other sports which share similar perception-action challenges (e.g. football, basketball). The merit of movement and skill adaptability for talent identification and development in tennis has been established and requires further investigation to solidify and expand its applicability.

**6.5 Future research**

Due to the positive results reported in this thesis, the concept of movement and skill adaptability should be applied to other sports, specifically those that require time constrained perception-action. The definition of adaptability and underlying theoretical concepts have the ability to transfer to other movement and skill contexts. For example, the manipulations applied in the current training program (Table 10) could be applied to basketball (different balls [sizes, bounce], different equipment [modified basket height], use of non-dominant hand, modified spatial orientation [shooting from different positions] and different surface.

The use of different populations will further establish proof of the concept of adaptability. Extending the age range and development level (beginner, intermediate, elite) used in this research is essential future research. The full extent of the benefits (and potential limitations) of adaptability throughout the development pathway needs to be understood.

Movement and skill adaptability should be investigated with a longitudinal study design. This will elucidate the long-term development properties of adaptability and allow for a decisive conclusion to be drawn on its ability to accurately identify and develop talent. Additionally, adaptability training programs should be compared directly to both early sport specialisation and sampling development pathways. Adaptability research in a movement and skill context is in its infancy, and therefore further investigation is required to fully understand its potential.

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## APPENDIX A – Health screening questionnaire

# CARDIOVASCULAR AND OTHER RISK FACTORS QUESTIONNAIRE

In order to be eligible to participate in the study investigating: "RELIABILITY AND VALIDITY OF A NOVEL SKILL ADAPTABILITY TEST BATTERY FOR TENNIS" you are required to complete the following questionnaire for your child which is designed to assess the risk of you having a cardiovascular event occurring during an exhaustive exercise bout.

**Name of child:** ___________________________________________ **Date:** ____________________

**Age:** ________ **years** **Weight:** ________ **kg** **Height:** __________ **cms** **Gender (circle): M / F**

If there is an emergency, specify the person who should be contacted and their emergency phone number:
Name: ________________________________ Contact ph: ________________________________

Please note: In case of a medical emergency, an ambulance may be used to transport your child to the nearest medical treatment service.

**Circle the appropriate response to the following questions.**

**Does you child have, or has you child had**

| | | | |
|---|---|---|---|
| 1. | A heart condition? | Yes | No |
| 2. | Cystic Fibrosis? | Yes | No |
| 3. | Diabetes (Type I or Type II)? | Yes | No |
| 4. | High blood pressure? | Yes | No |
| 5. | High cholesterol? | Yes | No |
| 6. | Unexplained coughing during or after exercise? | Yes | No |
| 7. | Breathing problems or shortness of breath (for example, asthma) | Yes | No |
| 8. | Epilepsy or seizures/convulsions? | Yes | No |
| 9. | Does your child taken any medications? (please name) | Yes | No |

_______________________________________________________________________________

10. In the last six months has your child had any muscular pain or joint pain while exercising?

Yes No

If Yes, please explain and indicate where the pain has occurred (eg. Pain in the back of the right heel)

______________________________________________________________________

______________________________________________________________________

11. Has your child broken any bones or suffered injury to their bones in the last 12 months?

Yes No

If Yes, please explain where and how the break/injury occurred.

______________________________________________________________________

______________________________________________________________________

12. Does your child use “puffer” or “ventilator” for asthma? Yes No

13. Does your child self-administer insulin for diabetes Yes No

14. Is your child allergic to food, medications, pollens or other allergens or specific environments?

Yes No

If Yes, please explain what causes have been identified with this/these allergy/ies:

______________________________________________________________________

______________________________________________________________________

15. Are you aware of any medical reason/condition which might prevent your child from participating in this study? Yes No

If Yes, please explain

______________________________________________________________________

______________________________________________________________________

I, ______________________________________, believe that the answers to these questions are true and correct.

Signed (Parent/guardian): ________________________________ Date: _______________

**APPENDIX B – Health screening questionnaire**

# Expert Consensus of New Adaptability Tasks

## Date:

## Role (please circle):

Tennis Coach | Sports Scientist

## Aim:

**To confirm by expert consensus the new tests we have developed represent the elements of movement and skill adaptability.**

## Instructions:

Thank you for taking part in this important process. Please take the time to complete the two questions at the end of this document based on the information provided in this document and the accompanying video on USB. You will be directed to watch the videos at certain times throughout the document. The whole process will take between 10-15 minutes.

**Please watch video titled 'Practical Examples of Adaptability'**

*Scientific definition of adaptability*

An "individual's capacity to constructively regulate psycho-behavioural functions in response to new, changing and/or uncertain circumstances, conditions and situations" Martin et al. (2012).

*Practical definition of adaptability*

In any given movement or skill context (e.g. tennis stroke), individuals must adapt to a unique set of constraints that include individual (body composition, decision making), task (court size, equipment used) and environmental (weather, audience) to achieve the desired outcome. For example, if a player is moved wide in the forehand court, the decision of where, and what type of shot to hit are constrained by a number of factors; the opponent's position, opponent's speed, court size (singles/doubles), a player's own ability, wind and tactical considerations.

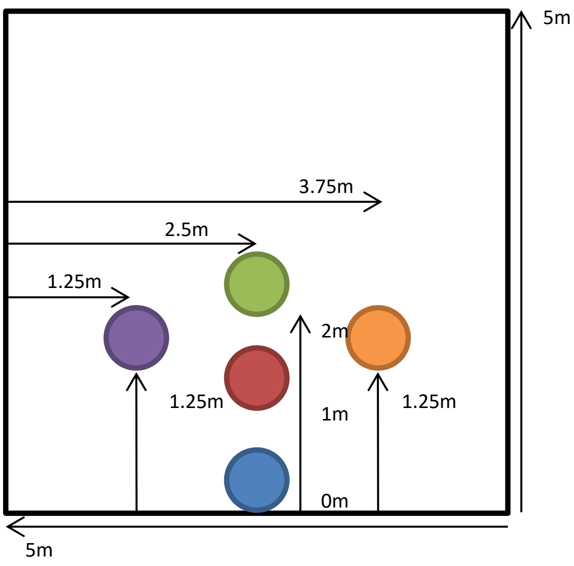
*Practical examples of adaptability*

- A tennis player who adjusts their shot after the ball hits a net
- A basketball player who can attack or defend a variety of opponents (e.g. point guard through to centre)
- In Australian Rules Football, a player who can adjust their games to the conditions (e.g. dry, wet)
- A tennis player who adjust their game when playing against a left handed player
- A tennis player who adjusts their game to perform well in the wind

**Please watch video titled 'Adaptability task explanation'**

*Description of tests – Throwing and rebound task*

- Participants throw a ball against a wall with five targets. Participants must retrieve the rebounding ball, and alternate throwing arms until all targets have been hit.
- The time taken to complete the task is recorded.
- Participants start with the ball in their dominant hand, 1m outside the line of the closest target.
- A diagram of the target set up is shown on the right.
- The starting point and targets differing positions are designed to encourage movement and possible changes in throwing patterns (e.g. overarm, underarm), forcing the participants to adapt to the changing circumstances.
- No demonstration will be



provided to participants. This will ensure the participant is not influenced on how to complete the task.

*Description of tests – Object striking and rebound task*

- Participants will play "up ball", striking the ball with alternating hands against a wall. The ball must reach the wall on the full and is allowed one bounce before it is to be struck again.
- Three balls with different compression levels and sizes (rubber ball, red tennis ball and a foam ball) will be used to challenge the participant's ability to adapt to the changing task constraint.
- A scale image and description of the balls is shown in the video.
- The number of successful strikes in 30 seconds is counted with the sum of the 3 different balls recorded for analysis. Using the sum of the 3 trials allows adaptability to be assessed as a participant may be proficient in one condition (e.g. foam ball) but unable to change their movement patterns to gain success across all of the changing conditions.

## Assessment of adaptability tests

Please ensure you have watched the video as well as reading the above information before completing below.

**For the purpose of this study, working with a population of 8-10 year old children, in your expert opinion, do you think the tasks we have developed will distinguish between participants with high and low levels of adaptability in their movement and skill coordination?**

As a result, in your opinion, does the:

| | Strongly disagree | Disagree | Neither agree or disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| 1. Throwing & rebound task reflect adaptability | 1 | 2 | 3 | 4 | 5 |
| 2. Object striking & rebound task reflect adaptability | 1 | 2 | 3 | 4 | 5 |

Please provide any comments that you feel are relevant:

________________________________________________

________________________________________________

________________________________________________

________________________________________________

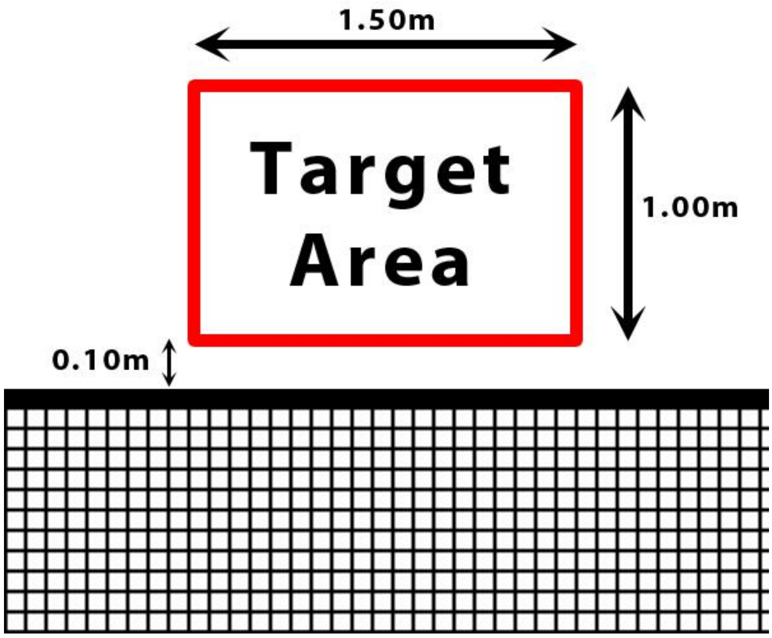
## APPENDIX C - Volley Test

### Equipment Set Up

- ☐ A wall that is made of concrete or solid wood is required.
- ☐ A flat marker is placed on the ground, 3 metres back from and parallel to the wall.
- ☐ Mark the height of the net on wall.
- ☐ Mark out the target area on the wall as illustrated in the Figure below. The target area should start 0.1m above the net and extend 1m high and 1.5m wide.

### Test Procedures

- ☐ Player stands 3m back from the wall at the flat marker.
- ☐ The tester, standing alongside the player and holding a stop watch, gives the following count-down: 3, 2, 1... GO.
- ☐ On GO, the tester starts the stop watch and the player self-feeds a ball to start volleying against the wall.
- ☐ The test lasts for 30 seconds and the tester lets the player know when time is up.
- ☐ The player is required to rotate hitting forehand and backhand volleys.
- ☐ If the player loses control of the ball, they are encouraged to regain control and restart the test.
- ☐ The player's score is the number of volleys that successfully hit the target area and that are played in the correct forehand-backhand sequence. If two consecutive forehand volleys are played, both hitting the target, only the first volley will be counted. If three consecutive forehand volleys are played, all hitting the target, only the first and third volley will be counted.
- ☐ The player is provided three attempts.
- ☐ Record the player's score for each trial as well as the number of volleys that miss the target area on the scoring sheet.




### Definition of Measures

The measure of this test is the number of volleys hit by the player in sequence and to the target area in 30 seconds.

**APPENDIX D – Training Program**

## LESSON PLANS

| | Lesson 1 | Lesson 2 | Lesson 3 | Lesson 4 | Lesson 5 | Lesson 6 |
|---|---|---|---|---|---|---|
| Activity 1 | Rolling rally – forehand/backhand | Red serve – overarm throw | Rolling rally – backhand, direction based | Cone catch – forehand/backhand | Battle cones – down the line | Cone catch |
| Activity 2 | Build a rally – bungee jumping/self rally | Rolling rally – forehand, direction based | Build a rally – bungee jumping, no hands | Battle cones – down the line | Cone catch | Serve star |
| Activity 3 | Red serve – under wonder | Red serve – stretch serve | Build a rally – partner rally | Serve star | Battle cones – cross court | Battle cones |
| Activity 4 | Build a rally – partner rally game | Serve (underarm) and rally | Serve (underarm) and rally | Battle cones - crosscourt | Serve (underarm) and rally | Serve (underarm) and rally |
| | **Lesson 7** | **Lesson 8** | **Lesson 9** | **Lesson 10** | **Lesson 11** | **Lesson 12** |
| Activity 1 | Switch rally | Court shapes – down the line forehands | Switch rally | Bounce | Top 10 serve | Bounce |
| Activity 2 | Court shapes – cross court forehands | Switch rally | Race to base | Court shapes – deep in the court, either side | Bounce | Court shapes – deep in the court, either side |
| Activity 3 | 3 ball serve | 3 ball serve | 3 ball serve | Top 10 serve | Top 10 serve | Top 10 serve |
| Activity 4 | Race to base | Court shapes – cross court backhands | Court shapes – down the line forehands to backhand | Court shapes cross court forehands | Cross court return | Cross court return |

# Lesson 1

Aim of lesson: To help develop racquet control and hand-eye coordination

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Rolling rally – forehand/backhand

**Purpose:**

Develop reception skills – begin forehand side for 5 minutes and promote a low centre of gravity. After 5 minutes switch to backhand side.

**Instruction:**

Players place racquet on ground and are told to pick up with their dominant hand. How they have picked up their racquet should be a correct grip (Forehand only).

Players start facing each other on opposite doubles lines, their court area can be a full red court.

They push the ball back and forth moving to trap the ball on the ground "SPLAT" (forehand); and roll back with their racquet. The trap must be in front between themselves and their partner.

**Coaching notes:**

This game will teach players to judge the correct distance from the body they need to contact the ball.

The players should trap the ball in front of the doubles line to create a contact point in front.

A rolling stroke can incorporate good technique including grip (wrist behind racquet), knee bend and controlling the "push" (no swing).

The 3 o'clock or 9 o'clock position on the racquet must be next to the ground.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Behind each pairing is a variety of different balls (rubber high bounce ball, tennis ball, foam ball, reaction ball).

Every time a rally ends, either by a ball being hit out or missed a change in ball occurs. Immediate/early task success is not critical, the exposure to novel and varied stimuli will provide for the training effect.

## Time: 16-20 minutes

## Activity: Build a rally – bungee jumping

**Purpose:**

Basic racquet face control in order to facilitate ball control.

**Instruction:**

Players are placed around the court with the ball balanced on their racquets – making sure they understand the boundaries of the court and that they are clearly set.

At the coach's call of "BUNGEE!" the players roll the ball off their racquet let it bounce and then catch it on their racquet strings by trapping it with their hand.

**Coaching notes:**

Make sure players keep their racquet face flat and level and bend the knees when they roll the ball from their racquet, getting under it and tracking the ball flight with their body.

Work towards players using a continental grip (See diagram).


**Progression:**

Players play with a partner, taking it in turns to roll the ball off the racquet and catch it.

Players catch with their racquet only, no hands.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

They then complete the task on 5 separate occasions with that racquet. After the 5 attempts they switch to a different racquet ensuring all variations are used.

## Time: 21-25 minutes

## Activity: Build a rally – self rally

**Purpose:**

Build a rally, control the racquet face.

**Instruction:**

Set the players up in a defined area appropriate to their age and ability with a ball and racquet.

They must hit the ball up, controlling the ball inside the set court area with one bounce only.

Score one point each time they achieve a five-shot rally.

Place a marker in the centre of the set area to form a focus that players try to have their ball bounce on (bonus point if achieved).

**Coaching notes:**

While the racquet is not aligned to hit the ball forwards like a forehand or a backhand – the coach can emphasise contact point around waist high and a flat and level racquet face to control the ball. To do this they must have a good knee bend and start to drive the shot with their body and not with their wrist.

Work towards players using a continental grip.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

They then complete the task on 5 separate occasions with that racquet. After the 5 attempts they switch to a different racquet ensuring all variations are used.

## Time: 26-35 minutes

## Activity: Red serve – under wonder

**Purpose:**

Learn to start the point with a simple action.

**Develop underarm serve – Under wonder**

Working in pairs, players throw over the net back and forth, coach looks at stance (ensuring side on position) – both arms moving together.

Start the motion with both arms together (like a serve), coach looks at arms separating smoothly over a short distance to create rhythm.

Introduce targets left and right, making the partner move and then recover to position and return.

Give each partner a ball that they throw alternately with a partner, developing rhythm and timing.

Combine a low toss with an underarm forehand swing to achieve an underarm serve.

**Coaching notes:**

Teach the students to start the point themselves from the earliest possible time. Children who rely on the coach to start the rally (feed) all the time will not be able to practice away from the coach.

Underarm throwing and serving is ideal as they begin, and can move to overarm as they develop.

**Adaptability intervention group:**

Manipulate task constraint – Non-dominant hand

Students complete one throw or strike on their dominant hand then one on their non-dominant hand for the entire drill. As the task is constantly changing there is no need for additional manipulations.

Time: 36-45 minutes

Activity: Build a rally – partner rally game

Same as build a rally – self rally however, put two players in the set area and have them hit alternating shots, using both sides of the racquet. Then progress to adding a net and get the players to hit the ball over the net by slightly adjusting their racquet face (one player can throw/catch and the other can hit to begin), aiming to get as high a rally total as possible.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

After each rally attempt students change the racquet they are using.

# Lesson 2

Aim of lesson: Introduce the overarm serve and incorporate the serve (underarm or overarm) into a rally

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Red serve – overarm throw

**Purpose:**

Learn to start the point with a simple action.

**Coordinate both arms – Overarm throw**

Working in pairs, throw over different lengths making sure non-throwing arm works in opposition to the throwing arm.

Throw as high as possible, stretching the non-throwing arm up.

Concentrate on player stance and remaining balanced.

**Bullseye**

Players hold a ball in each hand – they lift with left hand (toss) and throw overarm with their right arm (for right-handed players).

They aim to throw the ball in the dominant hand under the ball tossed with the non-dominant one.

More importantly for the coach they are coordinating the toss with an overarm motion.

**Cylinder serve**

Player serves overarm from a normal stance – the swing can be shortened but the coordination and rhythm between the two arms should remain.

**Coaching notes:**

Teach the students to start the point themselves from the earliest possible time. Children who rely on the coach to start the rally (feed) all the time will not be able to practice away from the coach.

Underarm throwing and serving is ideal as they begin, and can move to overarm as they develop.

**Adaptability intervention group:**

Manipulate task constraint – Modified base of support

After every attempt students change their position by completing the task either:

- Standing on the ground
- On one leg (dominant and non-dominant)
- With a narrow base of support
- With a wide base of support

## Time: 16-25 minutes

## Activity: Rolling rally – forehand, direction based (e.g. cross court and down the line

Same as rolling rally in lesson 1 with the addition of specified directional strikes.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

After each rally attempt students change the racquet they are using.

## Time: 26-35 minutes

## Activity: Red serve – stretch serve

**Coordinate upper and lower body – Stretch serve**

Players start in a position three racquet lengths from the net (very close). They must serve the ball over and in.

For each successful serve they step back one racquet length.

**Coaching notes:**

Teach the students to start the point themselves from the earliest possible time. Children who rely on the coach to start the rally (feed) all the time will not be able to practice away from the coach.

Underarm throwing and serving is ideal as they begin, and can move to overarm as they develop.

**Adaptability intervention group:**

Manipulate task constraint – Modified spatial orientation

Students change their spatial orientation after every serve between:

- Facing the net
- 45° angle to the baseline
- 90° angle to the baseline

Time: 36-45 minutes

Activity: Serve (underarm) and rally

**Purpose:**

Build a rally, including the serve.

**Instructions:**

Players start facing each other on opposite doubles lines, their court area can be a full red court.

One player commences the rally by serving underarm. This alternates half way through the drill.

Players rally counting how many shots they achieve per rally aiming for as higher number as possible.

**Adaptability intervention group:**

Manipulate task constraint – Balls

After each rally students change the type of ball they are using, these include:

- Rubber high bounce ball
- Tennis ball
- Foam ball
- Reaction ball

# Lesson 3

Aim of lesson: Continue to develop rally skills and advance the racquet control skills. Promote adaptability with multiple variations on drills that should now be familiar.

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Rolling rally – backhand, direction based (e.g. cross court and down the line

Same as rolling rally in lesson 1 with the addition of specified directional strikes.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After every rally both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

Time: 16-25 minutes

Activity: Build a rally – bungee jumping, no hands

Same as build a rally – bungee jumping in lesson 1 but without using hands to help trap the ball.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After 2 minutes students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

## Time: 26-35 minutes

## Activity: Build a rally – partner rally

Same as build a rally – partner rally in lesson 2.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After every rally both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

## Time: 36-45 minutes

## Activity: Serve (underarm) and rally

Same as serve (underarm) and rally in lesson 3.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After every rally both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)
- Modified base of support (standing on the ground, on one leg [dominant and non-dominant], narrow/wide base of support)
- Modified spatial orientation (facing the net, 45° angle to the baseline, 90° angle to the baseline)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

# Lesson 4

Aim of lesson: To understand ball flight

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets, cones

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Cone catch – forehand/backhand

**Purpose:**

Judge the flight of the ball to catch it as it falls.

**Instruction:**

Two players work together over the net.

Cooperatively underarm throw the ball in a rally over the net.

Players hold a cone like an ice-cream cone, and attempt to catch the ball in the cone.

Swap positions after five catches or play a competitive game with another pair.

**Coaching notes:**

This game teaches the students to catch the ball around waist height as it is dropping (it is difficult to catch in any other situation). Players will have to judge the depth, height and direction and move appropriately and position themselves for the catch.

Players who are successful in catching in front of the body should be encouraged to catch to the side of the body and in front.

**Progression:**

One player can be hitting and the other cone catching.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball
- Foam ball
- Reaction ball

After 5 catches students switch to a different ball ensuring all variations are used.

Time: 16-25 minutes

Activity: Battle cones – down the line

**Purpose:**

Develop accuracy from a simple contact point.

**Instruction:**

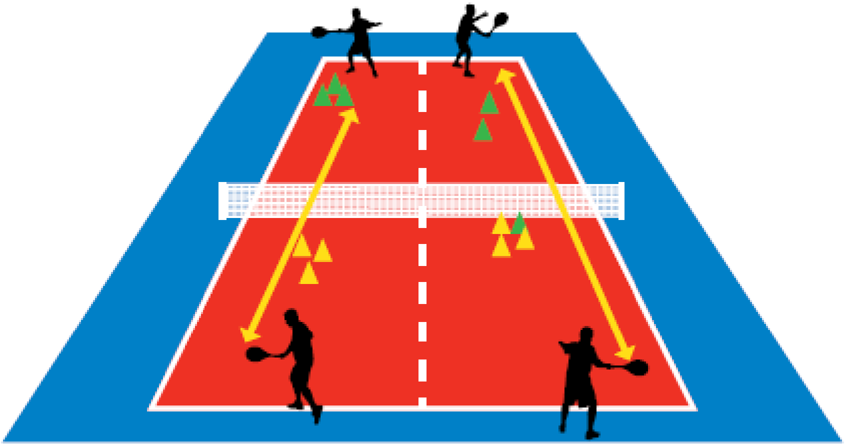
Place three-plus cones in a group on the court.

Players commence a cooperative rally concentrating on accuracy.

The aim of the game is to hit your partner's cones. If you are successful you add your partner's cone to your bunch.

The winning player will be the one who collects all their partner's cones; or is the one who has collected the most cones in the time limit.

Play down the line.



**Coaching notes:**

Target nature of the game will teach the players to control their swing length and align their racquet face to hit an accurate shot.

**Progression:**

Can be done throwing and catching for younger students.

Change the number or cones, or split the cones to create two targets.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball
- Foam ball
- Reaction ball

After a rally finishes students must change the type of ball they are using.

## Time: 26-35 minutes

## Activity: Serve star

**Purpose:**

Develop basic overarm serve. Include serve and return sequences.

**Instruction:**

Use a basic three-ball drill starting with a serve, followed by a return then the server hits a second shot and the ball is caught by the returning player who then takes on the role of the server.

Both players serve from the deuce court and then from the advantage court.

Can start with throwing or an underarm action and then can be developed into an overarm.

**Coaching notes:**

Start with a smaller version of a full swing, keeping the coordination between the two arms and simple rhythm.

The returning player should show good intensity and ready position.

Gradually increase the size of the action.

The server should impact the ball above their head and keep the action simple.

Emphasise the string pointing in the direction of the intended target.

**Progression:**

Add target areas for more accuracy on the serve.

Add an intended target for the returning player.

Add more strokes to make it a five-ball drill rather than a three-ball drill.

Use throwing and catching to first establish the pattern or to make things easier.

**Adaptability intervention group:**

Manipulate task constraint – Modified spatial orientation

Student when serving changes their spatial orientation after every serve between:

- Facing the net
- 45° angle to the baseline
- 90° angle to the baseline

## Time: 36-45 minutes

## Activity: Battle cones – cross court

Same as battle cones in lesson 4 except changing the direction to cross court

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

After each rally both students change racquets ensuring that they do not repeat a racquet until all have been selected.

## Lesson 5

Aim of lesson: Continue to develop rallies and directional control

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets, cones

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Battle cones – down the line

Same as battle cones – down the line in lesson 4.

**Adaptability intervention group:**

Manipulate task constraint – Non-dominant hand

Students complete one rally with their dominant and then switch to their non-dominant hand for the next rally.

Time: 16-25 minutes

Activity: Cone catch

Same as cone catch in lesson 4.

**Adaptability intervention group:**

Manipulate environmental constraint – Surface

Changes surfaces after a designated time period, this will depend on the amount of available surfaces in the vicinity. E.g. 3 different surfaces available ~3 minutes on each. Different surfaces to be used can include normal court, grass, gravel, and sloping surface.

Time: 26-35 minutes

Activity: Battle cones – cross court

Same as battle cones – cross court in lesson 4.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball
- Foam ball
- Reaction ball

After a rally finishes students must change the type of ball they are using.

## Time: 36-45 minutes

## Activity: Serve (underarm) and rally

Same as serve (underarm) and rally in lesson 3.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

After each rally both students change racquets ensuring that they do not repeat a racquet until all have been selected.

# Lesson 6

Aim of lesson: Continue to develop rally skills. Promote adaptability with multiple variations on drills that should now be familiar.

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets, cones

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Cone catch

Same as cone catch in lesson 4.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After every set of five catches both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

Time: 16-25 minutes

Activity: Serve star

Same as serve star in lesson 4.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After every rally both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)
- Modified base of support (standing on the ground, on one leg [dominant and non-dominant], narrow/wide base of support)
- Modified spatial orientation (facing the net, 45° angle to the baseline, 90° angle to the baseline)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

## Time: 26-35 minutes

## Activity: Battle cones

Same as battle cones in lesson 4.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After every rally both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

## Time: 36-45 minutes

## Activity: Serve (underarm) and rally

Same as serve (underarm) and rally in lesson 3.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After every rally both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)
- Modified base of support (standing on the ground, on one leg [dominant and non-dominant], narrow/wide base of support)
- Modified spatial orientation (facing the net, 45° angle to the baseline, 90° angle to the baseline)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

# Lesson 7

Aim of lesson: Promote rally and match simulation patterns

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Switch rally

**Purpose:**

Making the change between forehand and backhand, plus directing groundstrokes, and returning to ready position after each shot.

**Instruction:**

One player starts with a racquet at the red court baseline in a good ready position.

Their partner on or close to the other baseline tosses underarm to the baseline player making sure to:

- Throw alternately to forehands and backhands

- Only throw once their partner has recovered to ready position

- Set in a ready position after each bounce

Baseline player hits back to feeder who must catch after one bounce.

Once feeder has thrown eight balls players can rotate – aiming to take as many catches as possible.

**Coaching notes:**

Players return to a great ready position where grips can be adjusted.

Ensure good shoulder turn left and right and both forehand and backhand.

It may be necessary to set up targets to help both the feeder and the hitter to focus and develop better accuracy.

**Progression:**

Feeder must call out line or cross and hitter must direct their shot.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball

- Foam ball
- Reaction ball

Students have 2 of each ball and throw them in a random order. After 8 throws students switch positions.

## Time: 16-25 minutes

## Activity: Court shapes – cross court forehands

**Purpose:**

Groundstroke consistency from different areas of the court.

**Instruction:**

Player work cooperatively to try to build rallies in different court shapes.

After completing four in each shape they must do a rally of five in each shape, then six etc.

**Coaching notes:**

To ensure good direction emphasise racquet face control and hitting through the ball.

Ensure players maintain height over the net for depth and good recovery after each shot so they can always hit the specified shot.

Try to get players to develop a rhythm.

**Progression:**

Start with a throw and catch rally in each shape and progress to hitting.

Challenge the skill level by specifying shots must be hit with topspin.

Players have a time limit in which to reach each rally thereby developing intensity and ball speed.

Make the activity competitive.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

After each rally both students change racquets ensuring that they do not repeat a racquet until all have been selected.

## Time: 26-35 minutes

## Activity: 3 ball serve

**Purpose:**

Learn to start the point while developing a small over arm serve motion, incorporating return and server's second shot.

**Instruction:**

Players serve into the diagonal service box using any of the actions listed:

- Under arm serve

- Overarm throw

- Overarm serve with a short action

Partner returns and the server tries to hit the ball back over the net where the returner catches the ball.

Players then change roles with the original returner becoming the server.

Count the number of successful three ball rallies in two minutes.

**Coaching notes:**

Encourage the server to start sideways and work on a limited split of the arms.

Ball toss should be above the head.

Make sure returners start in a good ready position.

**Progression:**

Have players return away from the server.

Have servers try to direct the serve to one half of the service box.

Allow second serves which can be a simpler action.

After the third shot play out the point.

**Adaptability intervention group:**

Manipulate task constraint – Modified base of support

After 2 minutes both students change their position when serving by completing the task either:

- Standing on the ground
- On one leg (dominant and non-dominant)
- With a narrow base of support
- With a wide base of support

Time: 36-45 minutes

Activity: Race to base

**Purpose:**

Increase the length of the stroke as players progress back to the red baseline.

**Instruction:**

Players start three big steps from the net with a partner each and with a throw down line at their feet as a baseline.

Start by rallying to four shots with the forehand. If they are unsuccessful they must do a throw and catch rally before trying to rally with racquets again.

After each successful rally they take a step back (measured by the length of their racquet).

Then rally to four from the greater distance, gradually increasing the distance with each successful rally.

**Coaching notes:**

Ensure the length of stroke gradually gets longer.

Change the length of rally to help differentiate between players of different ability levels.

Impact points and balance should be emphasised along with ensuring players find the correct distance from the ball.

**Adaptability intervention group:**

Manipulate task constraint – Non-dominant hand

For the first 5 minutes students rally with their dominant hand but throw with their non-dominant hand if rally is unsuccessful.

For the final 5 minutes students rally with their non-dominant hand but throw with their dominant hand if rally is unsuccessful.

# Lesson 8

Aim of lesson: Increase the depth of shots

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Court shapes – down the line forehands

Same as court shapes in lesson 7 except altering the shape to down the line forehands.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball
- Foam ball
- Reaction ball

After a rally finishes students must change the type of ball they are using.

Time: 16-25 minutes

Activity: Switch rally

Same as switch rally in lesson 7.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

After each rally both students change racquets ensuring that they do not repeat a racquet until all have been selected.

Time: 26-35 minutes

Activity: 3 ball serve

Same as 3 ball serve in lesson 7.

**Adaptability intervention group:**

Manipulate task constraint – Modified spatial orientation

Student when serving changes their spatial orientation after every serve between:

- Facing the net
- 45° angle to the baseline
- 90° angle to the baseline

## Time: 36-45 minutes

## Activity: Court shapes – cross court backhands

Same as court shapes in lesson 7 except altering the shape to cross court backhands.

**Adaptability intervention group:**

Manipulate task constraint – Non-dominant hand

For the first 5 minutes students complete the drill using only their non-dominant hand (opposite handed forehand).

For the next 5 minutes students complete the drill switching between their dominant (backhand) and non-dominant hand (forehand).

# Lesson 9

Aim of lesson: Develop overarm serve motion

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Switch rally

**Purpose:**

Making the change between forehand and backhand, plus directing groundstrokes, and returning to ready position after each shot.

**Instruction:**

One player starts with a racquet at the red court baseline in a good ready position.

Their partner on or close to the other baseline tosses underarm to the baseline player making sure to:

- Throw alternately to forehands and backhands

- Only throw once their partner has recovered to ready position

- Set in a ready position after each bounce

Baseline player hits back to feeder who must catch after one bounce.

Once feeder has thrown eight balls players can rotate – aiming to take as many catches as possible.

**Coaching notes:**

Players return to a great ready position where grips can be adjusted.

Ensure good shoulder turn left and right and both forehand and backhand.

It may be necessary to set up targets to help both the feeder and the hitter to focus and develop better accuracy.

**Progression:**

Feeder must call out line or cross and hitter must direct their shot.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball

- Foam ball
- Reaction ball

Students have 2 of each ball and throw them in a random order. After 8 throws students switch positions.

## Time: 16-25 minutes

## Activity: Race to base

**Purpose:**

Increase the length of the stroke as players progress back to the red baseline.

**Instruction:**

Players start three big steps from the net with a partner each and with a throw down line at their feet as a baseline.

Start by rallying to four shots with the forehand. If they are unsuccessful they must do a throw and catch rally before trying to rally with racquets again.

After each successful rally they take a step back (measured by the length of their racquet).

Then rally to four from the greater distance, gradually increasing the distance with each successful rally.

**Coaching notes:**

Ensure the length of stroke gradually gets longer.

Change the length of rally to help differentiate between players of different ability levels.

Impact points and balance should be emphasised along with ensuring players find the correct distance from the ball.

**Adaptability intervention group:**

Manipulate task constraint – Non-dominant hand

For the first 5 minutes students rally with their dominant hand but throw with their non-dominant hand if rally is unsuccessful.

For the final 5 minutes students rally with their non-dominant hand but throw with their dominant hand if rally is unsuccessful.

## Time: 26-35 minutes

## Activity: 3 ball serve

**Purpose:**

Learn to start the point while developing a small over arm serve motion, incorporating return and server's second shot.

**Instruction:**

Players serve into the diagonal service box using any of the actions listed:

- Under arm serve

- Overarm throw

- Overarm serve with a short action

Partner returns and the server tries to hit the ball back over the net where the returner catches the ball.

Players then change roles with the original returner becoming the server.

Count the number of successful three ball rallies in two minutes.

**Coaching notes:**

Encourage the server to start sideways and work on a limited split of the arms.

Ball toss should be above the head.

Make sure returners start in a good ready position.

**Progression:**

Have players return away from the server.

Have servers try to direct the serve to one half of the service box.

Allow second serves which can be a simpler action.

After the third shot play out the point.

**Adaptability intervention group:**

Manipulate task constraint – Modified base of support

After 2 minutes both students change their position when serving by completing the task either:

- Standing on the ground
- On one leg (dominant and non-dominant)
- With a narrow base of support
- With a wide base of support

## Time: 36-45 minutes

## Activity: Court shapes – down the line forehand to backhand

Same as court shapes in lesson 7 except altering the shape to down the line forehands to backhands.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only

- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

After each rally both students change racquets ensuring that they do not repeat a racquet until all have been selected.

# Lesson 10

Aim of lesson: Introduce the volley and incorporate more movement into drills

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Bounce

**Purpose:**

Developing great ready position, reactions and directing the volley.

**Instruction:**

Complete with only throwing and catching for this time only.

One player is positioned on the baseline and must not move throughout the drill.

The other half way up the court on the other side of the net.

The baseline player tosses the ball and simultaneously calls out zero, one or two.

The other player must allow the ball to bounce that number of times and try to direct it back over the net and away from the tossing player. So “zero” they must volley, “one” bounce hit a ground stroke and “two” back up and hit after two bounces.

The hitter wins the point if they can direct the ball away from the thrower so they can’t touch it. The thrower wins the point if they can touch the returned ball.

**Coaching notes:**

Set up the practice with the hitter at an appropriate position based on the strength of the thrower.

All balls must be thrown underarm.

Encourage and teach good technique, relevant swing length and racquet face control for direction.

Change the roles every six points and get players to keep score.

**Progression:**

This game may be started with throwing and catching.

The thrower may choose to change their position on the court after every throw.

The thrower may be allowed to move but only in an area marked at the back and centre of the court to encourage the hitter to change the direction of the ball.

**Adaptability intervention group:**

Manipulate task constraint – Non-dominant hand

Students complete the drill switching between their dominant and non-dominant hand after every throw and catch.

## Time: 16-25 minutes

## Activity: Court shapes – deep in the court, either side

Same as court shapes in lesson 7 except altering the shape to hitting deep in the court.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball
- Foam ball
- Reaction ball

After a rally finishes students must change the type of ball they are using.

## Time: 26-35 minutes

## Activity: Top 10 serve

**Purpose:**

Develop greater control over the service action.

**Instruction:**

Players work in pairs - one server and one catcher.

Each player has a bucket or basket behind their baseline in the centre of the court. One player has 10 balls and the other has a cone to catch in.

The server can choose the level of the serve that they want to hit:

- For one point they can stand closer to the net (half way between the red court baseline and net)

- For two points they can serve from the baseline anywhere into the service box

- For three points they can choose to serve to one half of the service box

The server only scores if they are successful and the maximum number of points they can score is 30.

From each serve the catcher tries to catch in the cone and recovers to the centre and drops the collected ball back into their bucket. When all 10 balls have been served the players swap roles.

Players try to beat their own personal best rather than compete against the score of others.

**Coaching notes:**

Encourage players to challenge themselves but explain the choices.

Ensure both players make a recovery after the serve and catch.

Ensure that the racquet face is controlled well to create effective direction.

Players must serve to both the deuce and ad side.

**Progression**

Players must achieve a set score.

Players must take alternate serves from different positions.

Players must score a set number of points before moving to serve from the other side.

The catching player now hits a return and scores in a similar way based on depth and direction.

**Adaptability intervention group:**

Manipulate task constraint – Modified base of support

After every attempt students change their position by completing the task either:

- Standing on the ground
- On one leg (dominant and non-dominant)
- With a narrow base of support
- With a wide base of support

## Time: 36-45 minutes

## Activity: Court shapes – cross court forehands

Same as court shapes in lesson 7.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

After each rally both students change racquets ensuring that they do not repeat a racquet until all have been selected.

# Lesson 11

Aim of lesson: Focus on consistency of groundstrokes in a number of different directions.

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets, cones

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Top 10 serve

**Purpose:**

Develop greater control over the service action.

**Instruction:**

Players work in pairs - one server and one catcher.

Each player has a bucket or basket behind their baseline in the centre of the court. One player has 10 balls and the other has a cone to catch in.

The server can choose the level of the serve that they want to hit:

- For one point they can stand closer to the net (half way between the red court baseline and net)

- For two points they can serve from the baseline anywhere into the service box

- For three points they can choose to serve to one half of the service box

The server only scores if they are successful and the maximum number of points they can score is 30.

From each serve the catcher tries to catch in the cone and recovers to the centre and drops the collected ball back into their bucket. When all 10 balls have been served the players swap roles.

Players try to beat their own personal best rather than compete against the score of others.

**Coaching notes:**

Encourage players to challenge themselves but explain clearly the choices.

Ensure both players make a recovery after the serve and catch.

Ensure that the racquet face is controlled well to create effective direction.

Players must serve to both the deuce and ad side.

**Progression**

Players must achieve a set score.

Players must take alternate serves from different positions.

Players must score a set number of points before moving to serve from the other side.

The catching player now hits a return and scores in a similar way based on depth and direction.

**Adaptability intervention group:**

Manipulate task constraint – Modified base of support

After every attempt students change their position by completing the task either:

- Standing on the ground
- On one leg (dominant and non-dominant)
- With a narrow base of support
- With a wide base of support

## Time: 16-25 minutes

## Activity: Bounce

Same as bounce in lesson 10.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

The student who is reacting to the bounce call changes racquets after every strike, ensuring that they do not repeat a racquet until all have been selected.

## Time: 26-35 minutes

## Activity: Court shapes – cross court backhands

Same as court shapes in lesson 9 except the court shape is cross court backhands.

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball

- Foam ball
- Reaction ball

After a rally finishes students must change the type of ball they are using.

Time: 36-45 minutes

Activity: Cross court return

Play points where the return must go crosscourt. This will work at:

• Return players effectively selecting targets for their return

• The server being able to dictate from the first shot of the rally

**Adaptability intervention group:**

Manipulate task constraint – Balls

Students have one of:

- Rubber high bounce ball
- Tennis ball
- Foam ball
- Reaction ball

After a rally finishes students must change the type of ball they are using.

# Lesson 12

Aim of lesson: Develop control of the serve

Equipment required: Balls, racquets (including different variations for adaptability intervention group), mini tennis nets, cones

Time: 0-5 Minutes

Activity: Introduction, group warm up and split up into groups

Time: 6-15 minutes

Activity: Bounce

Same as bounce in lesson 10.

**Adaptability intervention group:**

Manipulate task constraint – Racquets

Students have one of:

- No racquet, using their hand only
- Table tennis/bat tennis bat
- Modified tennis racquet
- Adult tennis racquet

The student who is reacting to the bounce call changes racquets after every strike, ensuring that they do not repeat a racquet until all have been selected.

Time: 16-25 minutes

Activity: Court shapes – deep in the court, either side

Same as court shapes in lesson 9 except altering the shape to hitting deep in the court.

**Adaptability intervention group:**

Manipulate task and/or environmental constraints – Multiple

After every rally both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.

Time: 26-35 minutes

## Activity: Top 10 serve

Same as top 10 serve in lesson 10 ensuring students are serving from both sides of the court.

**Adaptability intervention group:**

Manipulate task constraint – Non-dominant hand

Students complete the drill switching between their dominant and non-dominant hand after every serve.

## Time: 36-45 minutes

## Activity: Cross court return

Same as cross court return in lesson 11.

**Adaptability intervention group:**

After every rally both students pick something to change, this includes:

- Balls (rubber high bounce ball, tennis ball, foam ball, reaction ball)
- Racquets (no racquet, table tennis/bat tennis, modified racquet, adult racquet)
- Use of non-dominant hand
- Surface (normal court, grass, gravel, sloping)
- Modified base of support (standing on the ground, on one leg [dominant and non-dominant], narrow/wide base of support)
- Modified spatial orientation (facing the net, 45° angle to the baseline, 90° angle to the baseline)

Once a student has selected a particular manipulation they cannot select that again until all have been selected.