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UNRAVELLING TENNIS PERFORMANCE

Creating monitoring tools to measure and understand technical and tactical skills

Nikki Kolman

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Unravelling tennis performance

Creating monitoring tools to measure and understand technical and tactical skills

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Contents

Chapter 1 | General introduction 7

Chapter 2 | Technical and tactical skills related to performance levels in tennis: A systematic review 15

Chapter 3 | The Dutch technical-tactical tennis test (D4T) for talent identification and development: Psychometric characteristics 41

Chapter 4 | The value of technical characteristics for future performance in youth tennis players: A prospective study 57

Chapter 5 | Technical skills in complex tennis situations: Dutch talented players U15 compared to players U17 73

Chapter 6 | Self-assessed tactical skills in tennis players: Psychometric evaluation of the Tactical Skills Questionnaire in Tennis (TSQT) 89

Chapter 7 | General discussion 111

Appendices 123

Summary 124

Samenvatting 126

About the author 128

List of publications 129

Dankwoord 131

CHAPTER 1

GENERAL INTRODUCTION

In the Netherlands, a small country with 17.7 million inhabitants, athletes and teams compete successfully – again and again – with the world's top athletes. The Dutch have been dominating in many sports, especially in swimming, speed skating and field-hockey (www.olympic.org). The Netherlands is also showing its dominance in wheelchair tennis, where Diede de Groot became the first player to complete the golden slam after winning all four majors and the Paralympic gold medal in Tokyo in 2021. In able-bodied tennis, a grand slam singles title has been missing since Richard Krajicek's Wimbledon victory in 1996. Nevertheless, tennis is the third most popular sport with around 0,6 million players active in clubs in the Netherlands (NOC*NSF, 2022). About 17 percent of all active players are youth players under 18 years, with slightly more boys (n=56.000) compared to girls (n=44.000). Some of those youth players aim to develop towards the elite level in the future. This aspiration is in line with the ambition of the National Olympic Committee (NOC*NSF) and Royal Dutch Lawn Tennis Association (KNLTB) to acquire a permanent position in the world's top major sporting events. All Dutch tennis fans long for a Dutch tennis player to win a grand slam in the near future. Unravelling tennis performance - or at least one small piece of the puzzle – will hopefully help to make dreams and ambitions come true.

Talent development in tennis

Tennis organizations start at a young age with talent identification and realizing talent development programs to increase the chances of success for their players on the international stage (Brouwers et al., 2012). However, there is a lack of clarity regarding what talent actually is and how it relates to player development (Baker et al., 2019). A proposed conceptualization of talent is that it is innate, multidimensional, emergenic (the result of diverse multiplicative processes), dynamic (its expression evolves over time due to interactions with the environment) and symbiotic (subject to environmental constraints) (Baker et al., 2019). Some innate factors play a key role in tennis performance and related phenotypes, such as strength, power, aerobic capacity, coordination and flexibility (Varillas-Delgado et al., 2022). The complex interaction of anthropometry and physiological, technical, tactical and psychological skills makes long-term prediction of success ambiguous (Elferink-Gemser et al., 2011; Elferink-Gemser et al., 2018; Gagné, 2004; Kovacs, 2007). Skills develop in a non-linear and dynamic way, making it extremely difficult to foresee whether or not a youth player can develop into a professional one in the future (Gulbin et al., 2013). Early participation in international tournaments, and selection of talent at a young age, is not a prerequisite for future success in a range of sports, including tennis (Barreiros et al., 2014; Brouwers et al., 2012; Li et al., 2020). However, offering the best facilities, training and guidance must be a priority for tennis associations in order to develop talented players optimally.

In adolescence, the age between 12 to 18 years, development occurs in combination with physical change, including puberty, the pubertal growth spurt, and accompanying maturational changes. Both boys and girls pass through identifiable stages of development, but the maturational time course is quite different (Malina et al., 2015). Adolescence is regarded as a key developmental phase in the course of talented players' careers, making it interesting to gain more insight into underlying skills that contribute to progression towards elite tennis performance. Earlier research in tennis mostly focused on anthropometry (e.g. height, weight, wingspan) and physiological skills (e.g. strength, power, speed, agility), which can be strongly influenced by differences in physical growth and maturation (Fett et al., 2020; Kramer et al., 2017; Ulbricht et al., 2016; Vaverka & Cernosek, 2013). At young age there are large differences between players in anthropometry and physiological skills which can be related to performance levels. Players with greater height, weight and strength have an advantage over relatively younger and less mature players (Myburgh et al., 2016; Söğüt et al., 2019). The performance benefit conferred by greater size decreases as tennis players get older. In a study among youth elite tennis players, physiological skills (i.e. upper and lower body power, speed, agility) were not able to predict future performance after puberty, suggesting the importance of other skills to progress towards elite tennis performance, including technical and tactical skills (Kramer, 2020; Kramer et al., 2017).

Technical and tactical skills

Technical skills are sport-specific, playing a crucial role for youth performance across a range of sports (Fernandez-Fernandez et al., 2017; Koopmann et al., 2020). In tennis, technical skills include ball and racket handling during groundstrokes, serves, returns and volleys. When focusing on outcome-related technical skills in tennis, ball speed appears one of the most significant attributes, as a higher ball speed reduces the time it takes for an opponent to return the ball successfully (González-González et al., 2018; Landlinger et al., 2012). To be in control in a match, players should also hit their strokes with sufficient accuracy as hitting the ball to a specific location on the court allows them to keep the ball far enough from their opponents to produce a winner or cause the opponent to make an error (Lyons et al., 2013). Although these technical skills appear essential for tennis performance, it is unknown which specific technical skills are important to progress towards elite tennis performance, especially in certain tennis-specific situations. Moreover, less is known about the development of technical skills among talented youth players aged 12 to 18 years. There are no reliable, valid and feasible tools to assess these skills in youth tennis players.

With respect to tactical skills, the ability to anticipate and make accurate decisions is fundamental to high-level performance in many sports, particularly in racket sports such as tennis (Williams & Jackson, 2019). Anticipating what an opponent is doing next is crucial, especially when significant time pressures exist. Those athletes who anticipate well can use contextual information and kinematic cues from an opponent's movement pattern (Murphy et al., 2019). The ability to perceive and interpret these cues is a precondition for selecting the appropriate response (e.g. decision-making) (Baker et al., 2003). Tennis players who anticipate effectively are described as being able to 'read the game', 'demonstrate superior game intelligence' or appearing as if 'they have all the time in the world' (Williams & Jackson, 2019). One of the factors affecting anticipation include the positioning of the opponent on court (Loffing & Hagemann, 2014). In addition to the opponents' position, players' own position on the court is crucial, as an optimal position enhances court coverage and enables an effective response to the opponent's most likely stroke direction. All of these tactical skills (i.e. anticipation, decision-making, game intelligence and positioning) must be well developed to meet the game's competitive demands. Monitoring them is important to assist player development, especially for talented youth players aiming to progress towards elite tennis performance. Still, no tool is available to assess these skills over the course of multiple tennis training and game situations.

Given the relevance of technical and tactical skills for reaching excellence and the lack of research in youth tennis players, this thesis aims to create tools to measure and understand technical and tactical skills in youth tennis players.

The relevance of monitoring tools

Monitoring tools are valuable for different purposes. Tools can be used for scientific purposes, contributing to theory development and increasing our understanding of technical and tactical skills in tennis. Appropriate measurement properties, including being reliable and valid alongside being feasible in the target population, are key for scientific relevance. In addition to scientific relevance, social relevance is particularly important, referring to the extent society directly benefits as a result of this increased understanding. Monitoring tools are also valuable for coaches and players to enhance sports performance. In addition to monitoring the progress of players, tools can assist in identifying relative strengths and weaknesses of players, provide essential information about underlying skills that require most attention to progress towards elite performance as well as offer a method of defining players' skill levels alternative to the position on the ranking list (Robertson et al., 2014; Schorer et al., 2017). Collecting and understanding useful and informative variables are imperative to a successful monitoring tool (Thornton et al., 2019).

To measure and understand the performance of youth tennis players, researchers and coaches often use laboratory settings or tools measuring skills in isolation from the performance context (Cocks et al., 2016; Lädermann et al., 2016). These tools provide interesting insights for tennis performance; however, the designs are not always representative of tennis performance demands. Some researchers have suggested that one reason why development programs are not effective in identifying, selecting, and developing talented players is because there is a tendency to split performance tasks into smaller subtasks, which are then tested in development programs (Pinder et al., 2013). There is an increased need for tools that are more representative of performance demands, and a framework that emphasizes this representativeness is the ecological dynamics model (Davids et al., 2013; Johnston et al., 2018).

Ecological dynamics forms the foundation of the constraints led-approach, suggesting that performance emerges from the interaction between the person (e.g. anthropometry, technical skills), task (e.g. complexity, intensity) and environment (e.g. court surface, type of competition). Constraints have been defined as boundaries which shape the emergence of behavior from a movement system (e.g. player) seeking a stable state of organization (Newell, 1986). To put it simpler, with specific boundaries players have to search and explore movement solutions based on the information present. Through systematically manipulating constraints it is possible to construct and mimic a tennis-specific situation. However, the challenge is to create tools with enough uncertainty to replicate game conditions and with enough precision in the protocol to make the tool reliable.

Thesis objective and outline

The aim of this thesis is twofold: (1) to create reliable, valid and feasible tools for monitoring technical and tactical skills in youth tennis players; and (2) to gain more insight into the importance of these skills for youth tennis performance. In chapter 2, an overview is provided of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis related to performance levels. Chapter 3 examines the reliability, validity and feasibility of a new field test to assess technical skills in various tactical situations: the Dutch Technical-Tactical Tennis Test (D4T). The D4T aims to measure ball speed, accuracy and percentage errors of youth tennis players in offensive, neutral and defensive tactical situations. In chapter 4, using the D4T, the role of technical skills in a tennis-specific situation for tennis performance under 14 (current performance) and under 18 (future performance) is examined. Chapter 5 compares the technical skills of talented youth tennis players under 15 and under 17 years to gain insight into differences between these age categories. By exploring the technical skills of talented players in different age categories, a better understanding of underlying technical skills that contribute to progression towards elite tennis performance is acquired. In chapter 6, the psychometric properties of a newly designed questionnaire - the Tactical Skills Questionnaire in Tennis (TSQT) – is evaluated. This questionnaire is relevant for assessing tactical skills in youth tennis players over the course of multiple tennis training and game situations. Finally, in chapter 7, the results of the different chapters are combined in the general discussion. Practical implications are considered and recommendations for future research are provided.

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CHAPTER 2

TECHNICAL AND TACTICAL SKILLS RELATED TO PERFORMANCE LEVELS IN TENNIS: A SYSTEMATIC REVIEW

Kolman, N. S., Kramer, T., Elferink-Gemser, M. T., Huijgen, B. C. H., & Visscher, C. (2018). Technical and tactical skills related to performance levels in tennis: A systematic review. Journal of Sports Sciences, 37(1), 108–121. https://doi.org/10.1080/02640414.2018.1483699

Abstract

The aim of this systematic review is to provide an overview of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis related to performance levels. Such instruments can be used to identify talent or the specific skill development training needs of particular players. Searches for this review were conducted using the *PubMed*, *Web of Science*, and *PsycInfo* databases. Out of 733 publications identified through these searches, 40 articles were considered relevant and included in this study. They were divided into three categories: (1) technical skills, (2) tactical skills and (3) integrated technical and tactical skills. There was strong evidence that technical skills (ball velocity and to a lesser extent ball accuracy) and tactical skills (decision making, anticipation, tactical knowledge and visual search strategies) differed among players according to their performance levels. However, integrated measurement of these skills is required, because winning a point largely hinges on a tactical decision to perform a particular stroke (i.e., technical execution). Therefore, future research should focus on examining the relationship between these skills and tennis performance and on the development of integrated methods for measuring these skills.

Keywords: motor skills, athletic performance, speed-accuracy trade-off, decision making, anticipation

Introduction

Performance in sports results from the interaction of multiple factors (Newell, 1986). According to Newell's constraints-led approach, motor performance is influenced by interactions of the task at hand, the environment and the concerned individual. This approach has been elaborated within the model for talent identification and development in sports (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2007). In this model, multidimensional performance characteristics are seen to affect sports performance. Specifically in tennis, performance is multidimensional, as revealed by the integration of anthropometrical, physiological, technical, tactical and psychological characteristics that all influence (future) performance (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2004; Kovacs, 2007). Anthropometrical characteristics include factors such as height and weight (Sánchez-Muñoz, Sanz, & Zabala, 2007), whereas physiological characteristics include speed, agility, strength and endurance (Kovacs, 2007). These characteristics are considered to be general ones, because they apply to many sports and not exclusively to tennis (Baker, Cote, & Abernethy, 2003). This is also true for psychological skills, such as motivation, attention and arousal regulation, all of which are important performative elements in a variety of sports (Birrer & Morgan, 2010). By contrast, technical and tactical skills are more specific to particular sports (Fernandez-Fernandez et al., 2011). In tennis, they include factors like ball and racket handling, recognition of on-court tactical situations and appropriate decision making (MacCurdy, 2006). Technical skills in tennis are mostly demonstrated through serves and groundstrokes. Two important variables of a serve include ball velocity and the percentage of correct first serves (Knudson, Noffal, Bahamonde, Bauer, & Blackwell, 2004). Tactical skills are defined as knowledge about in-game adaptations and decision-making activities on court (Elferink-Gemser, Kannekens, Lyons, Tromp, & Visscher, 2010). Compared with other factors, the combination of technical and tactical skills is more likely to differentiate players whose performance levels differ (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). This hypothesis is supported by the findings of other studies, suggesting that these skills may be important for identifying talent and for sporting prowess (Meylan, Cronin, Oliver, & Hughes, 2010; Strecker, Foster, & Pascoe, 2011).

A player's ball velocity and success rate, combined with ball accuracy, are key determinants of his or her stroke quality (Landlinger, Stöggl, Lindinger, Wagner, & Müller, 2012; Strecker et al., 2011; Vergauwen, Madou, & Behets, 2004). The key role of ball velocity in relation to tennis performance is supported by the findings of Ulbricht, Fernandez-Fernandez, Mendez-Villanueva and Ferrauti (2016), who measured correlations between players' physical qualities and tennis performance. Their findings revealed that serve velocity was most strongly correlated with players' rankings across all age categories, indicating the importance of ball velocity in tennis performance. This is demonstrated by the ability of professional tennis players to direct their strokes both forcefully and accurately to any intended location on the court (Elliott, Reid, & Crespo, 2009). An accurate stroke that lacks a high ball velocity benefits the opponent, giving this player more time to prepare. Therefore, the combination of ball velocity and accuracy is essential for almost every successful stroke. Accordingly, this review focused on ball velocity and ball accuracy as outcome measures of technical skills. These technical skills are also required for the execution of appropriate tactics. Thus, the quality of tactical skills may also improve with the development of technical skills (Wang, Liu, & Chen, 2013).

Expert players exhibit advanced decision-making skills. This is because the characteristics of knowledge structures that support motor performance gradually change over time, with a progressive increase in the degree of implicit (unconscious) control and a corresponding reduction in the degree of explicit (conscious) control (Masters, Poolton, Maxwell, & Raab, 2008). Declarative knowledge or 'knowing what to do', which is consciously accessible, can be distinguished from procedural knowledge that relates to 'doing it', which is implicit. The relationship between the two types of knowledge is such that knowing facilitates doing and vice versa (Williams & Davids, 1995). The ability of experts to apply complex visual information is essential for anticipating future events and is widely considered to be one of the core skills associated with motor performance (Abernethy, Gill, Parks, & Packer, 2001; Williams, Ward, Knowles, & Smeeton, 2002).

Previous studies have demonstrated that both technical and tactical skills are important for reaching the top ranks in tennis (MacCurdy, 2006; Strecker et al., 2011). The continued interplay of technical and tactical skills assumes critical importance in the winning of every point in a match. Technique plays a functional role in achieving a tactical goal. For example, if the tactical goal is to make the opponent move outside of the court, a short ball cross-court strategy entailing a certain ball velocity is required. Moreover, players' own positions prompt another technical execution. When a player is playing defensively, high and deep ball hits are useful for gaining time and covering the court more effectively. These examples illustrate how the interplay of technical and tactical skills occurs in practice. However, few studies have examined how these skills relate to performance levels. Moreover, little is known about the effects of specific technical and tactical skills on performance. Additionally, there is a need to explore practical solutions in relation to performance analyses, because few coaches and instructors use tools for assessing technical and tactical skills with the aim of improving performance levels in tennis. Therefore, the purpose of this review is to provide an overview of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis related to performance levels. Furthermore, recommendations are offered on the analysis of these skills in tennis.

Methods

The PubMed, Web of Science, and PsycInfo databases were used to search for articles that contained the following terms:

(1) Tennis AND (techni* OR accuracy OR velocity OR speed OR precision) AND (serv* OR groundstroke OR forehand OR backhand) AND (performance OR level OR expertise OR elite) NOT table.
(2) Tennis AND (tactic* OR knowledge OR decision OR anticipation OR declarative OR procedural) AND (performance OR level OR expertise OR elite) NOT table.

The following inclusion criteria were used to select articles for this review: English language content, studies focusing on sports-specific skills applied in tennis (i.e., technical and tactical skills), comparative studies of tennis players with different performance levels and original articles. The exclusion criteria applied in the review were studies on participants with health problems, studies focusing solely on kinematics and intervention studies.

Studies on participants with health problems were excluded, because an objective of this review was to acquire knowledge about the technical and tactical skills of players whose health status was not compromised. Studies that focused purely on kinematics were excluded, because this review targeted outcome measures of technical and tactical skills rather than the mechanisms underlying these skills. Last, intervention studies were excluded, because it is difficult to interpret the effect of an intervention.

Articles were initially analysed based on the inclusion criteria. Subsequently, the articles were evaluated based on the exclusion criteria. The steps used in the systematic search resulted in the identification of 40 relevant articles for further analysis (Figure 1).

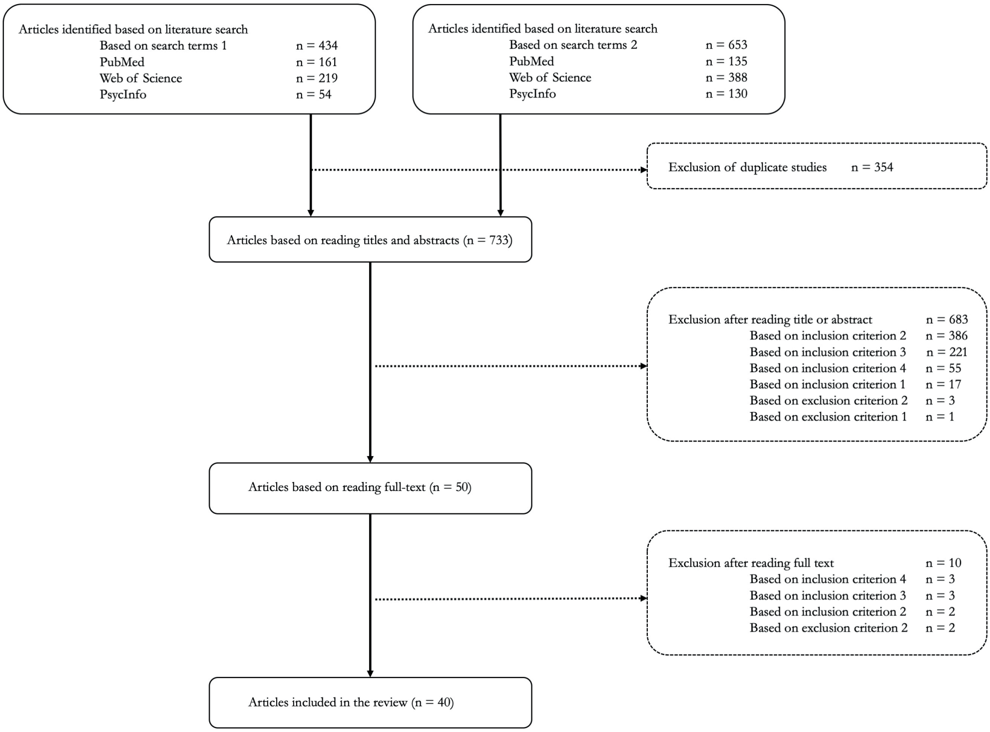

Figure 1. Stages adopted in the systematic selection of articles measuring technical and/or tactical skills in tennis players with different levels of performance.

The quality of the applied methodology in the included articles was assessed using the Critical Review Form – Qualitative Studies (Law et al., 1998). This tool can be used to evaluate many types of qualitative studies. This method was applied to assess each article according to the following categories: study purpose, literature background, study design, sample, outcomes, data analysis methods, results, conclusions and implications for future research (see the note below Table 1). These questions were assigned a score of either 1 (meet the criteria) or 0 (do not meet the criteria). The seventh and eighth questions were exceptional, as a NR (not registered) score could also be assigned to articles. A NR score indicated that no information was available on the reliability or validity of the instruments used in this systematic review. For the fifth question, articles reporting on studies with a sample size of at least 21 were assigned a score of 1, because this was the number required to obtain a statistical power of .80 or greater for detecting a large (one-tailed) difference at a 5% level of significance (Onwuegbuzie & Leech, 2005). The scores obtained for the 14 questions were summed for each article, with the NR score counted as 0. Table 1 shows the methodological quality of the reviewed studies. A total score below seven indicated low quality, a total score between seven and ten points indicated that the quality was good and a total score of 11 points or higher indicated high quality (van der Fels et al., 2015). Two researchers assessed the methodological quality of the included articles independently of one another. In less than 5% of all cases the researchers disagreed regarding scores. They discussed the disagreements and reached a consensus in all cases.

Table 1. Methodological quality of the reviewed articles[a]

	Question number[b]														
Author (year)*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Balser et al. (2014)	1	1	1	1	0	1	NR	NR	1	1	0	1	0	1	9
Buckholz et al. (1988)	1	1	1	0	1	0	NR	NR	1	1	0	1	1	0	8
Cañal-Bruland et al. (2011)	1	1	1	1	0	1	NR	NR	1	1	0	1	1	1	10
Cocks et al. (2015)	1	1	1	1	0	1	NR	NR	1	1	0	1	1	0	9
Del-Villar et al. (2007)	1	1	1	1	0	0	1	1	1	1	0	1	1	0	10
Farrow et al. (2003)	1	1	1	1	0	0	NR	NR	1	1	0	1	0	0	7
Farrow et al. (2005)	1	1	1	1	0	1	NR	NR	1	1	0	1	1	1	10
García-González et al. (2012)	1	1	1	1	0	1	1	NR	1	1	1	1	0	0	10
Girard et al. (2005)	1	1	1	1	0	1	NR	NR	1	1	1	1	0	0	9
Girard et al. (2007)	1	1	1	1	0	1	NR	NR	1	1	1	1	1	0	10
Goulet et al. (1989)	1	1	1	0	0	0	1	NR	1	1	1	1	0	0	8
Huys et al. (2008)	1	1	1	1	0	1	NR	1	1	1	0	1	1	0	10
Jackson and Mogan (2008)	1	1	1	1	0	1	1	NR	1	1	1	1	1	1	12
Kolman et al. (2017)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	13
Landlinger et al. (2012)	1	1	1	1	0	1	NR	NR	1	1	1	1	1	1	11
Loffing and Hagemann (2014)	1	1	1	1	1	1	NR	1	1	1	1	1	1	1	13
Loffing et al. (2011)	1	1	1	1	1	0	NR	1	1	1	0	1	1	0	10
Lyons et al. (2013)	1	1	1	1	0	1	NR	NR	1	1	1	1	1	1	11
Mahadas et al. (2015)	0	1	1	0	0	1	NR	NR	0	1	0	1	1	0	6
Martin et al. (2014)	1	1	1	1	0	1	NR	NR	1	1	1	1	1	0	10
McPherson (1999a)	1	1	1	0	0	1	1	1	1	1	1	1	1	0	11
McPherson (1999b)	1	1	1	0	0	1	1	NR	1	1	1	1	1	0	10
McPherson (2000)	1	1	1	0	0	1	1	NR	1	1	1	1	1	0	10
McPherson and Kernodle (2007)	1	1	1	0	0	1	1	NR	1	1	1	1	1	1	11
McPherson and Thomas (1989)	0	1	1	0	0	0	1	1	1	1	1	1	0	1	9
Murphy et al. (2016)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	13
Nielsen and McPherson (2001)	1	1	1	1	0	0	1	1	1	1	1	1	1	0	11
Rowe et al. (2009)	1	1	1	1	1	0	NR	NR	1	1	1	1	1	1	11
Rowe and McKenna (2001)	1	1	1	1	0	0	1	1	1	1	1	1	1	0	11
Shim, Carlton et al. (2005)	1	1	1	0	0	1	NR	NR	1	1	1	1	1	0	9
Shim, Miller et al. (2005)	1	1	1	0	0	0	NR	NR	1	1	0	1	0	0	6
Singer et al. (1996)	1	1	1	0	1	0	NR	NR	1	1	1	1	0	0	8
Smeeton and Huys (2011)	1	1	1	1	0	1	NR	NR	1	1	0	1	1	0	9
Söğüt (2017)	1	1	1	1	0	1	NR	NR	1	1	1	1	1	1	11
Tenenbaum et al. (1996)	1	1	1	1	0	0	NR	NR	1	1	1	1	1	0	9
Tenenbaum et al. (2000)	1	1	1	1	1	0	NR	1	1	1	1	1	0	0	10
Vergauwen et al. (2004)	1	1	1	1	0	1	1	1	1	1	1	1	0	0	11
Vergauwen et al. (1998)	1	0	1	1	0	1	1	1	1	1	1	1	0	0	10
Williams et al. (2009)	1	1	1	1	0	1	NR	NR	1	1	1	1	0	0	9
Williams et al. (2002)	1	1	1	1	0	1	NR	NR	1	1	1	1	1	1	11

Notes: *Only first author is mentioned, except for the author Shim; NR = not registered; [a] 1 = meet criteria; 0 = does not meet criteria; [b] (1) Was the aim of the study stated clearly? (2) Was relevant background literature reviewed? (3) Was the design appropriate for the research question? (4) Was the sample described in detail? (5) Was sample size justified? (6) Was informed consent obtained? (7) Were the outcome measures reliable? (8) Were the outcome measures valid? (9) Were results reported in terms of statistical significance? (10) Were the analysis methods appropriate for the research design? (11) Was practical importance reported? (12) Were conclusions appropriate given the study findings? (13) Are there any implications for future research given the results of the study? (14) Were limitations of the study acknowledged and described by the authors?

Studies that satisfied certain conditions, discussed below, were considered to demonstrate one of four categories of evidence of the relationship between knowledge of technical and tactical skills and performance levels. Consistent results, reported by at least three studies of high methodological quality, were ranked as 'strong evidence'. Alternatively, consistent results reported by 66% of more than four studies, with no more than 25% of these studies reporting conflicting results, indicated strong evidence. Consistent findings presented by two out of three studies, or reported by at least two high or good quality studies were interpreted as 'weak evidence'. Inconsistent results reported by low or moderate quality studies, or by fewer studies of any quality were indicative of 'insufficient evidence'. Last, 'no evidence' was considered to be demonstrated when only one study was available.

Articles were divided into three categories: (1) technical skills (n = 9), (2) tactical skills (n = 27) and (3) technical and tactical skills (n = 4). Technical skills comprised the ball velocity, ball accuracy, efficiency, success rates and percentage errors of players. Tactical skills comprised anticipatory and decision-making skills, tactical knowledge and visual search strategies. Studies that assessed technical as well as tactical skills examined at least one aspect of each of the two skill types.

The subjects in the studies included in the review were classified as professionals, advanced players, intermediate players or novices according to their performance levels described in the studies. Players were defined as professionals if they had a position in the ranking lists of the Women's Tennis Association or of the Association of Tennis Professionals or an International Tennis Number (ITN) of 1. Players were defined as advanced if they had a national ranking or an ITN ranging between 2 and 4. Players were defined as intermediate if they had competitive tennis experience, at least 5 years of tennis experience or an ITN of 5 or 6. Players who were beginners, had no competitive tennis experience or had ITNs ranging between 7 and 10.1 were defined as novices.

Results

Table 2 shows the study authors; number, sex, age, performance level and tennis experience of subjects; measures of technical and tactical skills; and results reported in the 40 articles included in the review. Nine studies were included in the technical skills category (Girard, Micallef, & Millet, 2005; Girard, Micallef, & Millet, 2007; Kolman, Huijgen, Kramer, Elferink-Gemser, & Visscher, 2017; Landlinger et al., 2012; Lyons, Al Nakeeb, Hankey, & Nevill, 2013; Martin, Bideau, Ropars, Delamarche, & Kulpa, 2014; Söğüt, 2017; Vergauwen, Spaepen, Lefevre, & Hespel, 1998; Vergauwen et al., 2004). Five of these studies were of high methodological quality and four were of good methodological quality. There was strong evidence that ball velocity produced in serves and/or groundstrokes differentiates professionals from advanced players and advanced players from intermediate players and novices (Girard et al., 2005, 2007; Kolman et al., 2017; Landlinger et al., 2012; Martin et al., 2014; Söğüt, 2017; Vergauwen et al., 1998; Vergauwen et al., 2004). The findings of Landlinger et al. (2012) and Vergauwen et al. (1998) showed higher ball velocities produced by forehand strokes compared with backhand strokes. However, no statistical tests were performed to confirm these visible differences.

There was weak evidence for greater accuracy of ball placement among advanced players compared with players demonstrating lower performance levels (Girard et al., 2005; Kolman et al., 2017; Lyons et al., 2013; Vergauwen et al., 2004). No evidence was found for differences in serve success rates or serve efficiency in relation to performance levels (Girard et al., 2005; Martin et al., 2014).

Twenty-seven studies belonging to the tactical skills category were included in the review. Seven of these studies were of high methodological quality, eighteen were of good methodological quality and two studies were of low methodological quality. There was strong evidence that advanced players have greater and more elaborate tactical knowledge than players with lower performance levels (García-González, Iglesias, Moreno, Moreno, & Del Villar, 2012; McPherson, 1999a; McPherson, 2000; McPherson & Kernodle, 2007). There was also evidence that superior visual search strategies are deployed by players with higher performance levels compared with those in the intermediate or novice categories. Specifically, high-performing players required less time to predict the directions of serves or groundstrokes (Balser et al., 2014; Cañal-Bruland, van Ginneken, van der Meer, Bart, & Williams, 2011; Goulet, Bard, & Fleury, 1989; Jackson & Mogan, 2007; Loffing & Hagemann, 2014; Loffing, Wilkes, & Hagemann, 2011; Mahadas et al., 2015; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996; Tenenbaum, Levy-Kolker, & Sade, 1996; Williams et al., 2002).

The studies provided strong evidence that professionals and advanced players are able to predict final ball locations or the performed stroke types more accurately compared with novices (Balser et al., 2014; Farrow, Abernethy, & Jackson, 2005; Goulet et al., 1989; Huys, Smeeton, Hodges, Beek, & Wiliams, 2008; Jackson & Mogan, 2007; Loffing & Hagemann, 2014; Loffing et al., 2011; Rowe, Horswill, Kronvall-Parkinson, Poulter, & McKenna, 2009; Shim, Carlton, Chow, & Chae, 2005; Shim, Miller, & Lutz, 2005; Singer et al., 1996; Tenenbaum et al., 1996; Tenenbaum, Sar-El, & Bar-Eli, 2000). However, there was weak evidence for the differentiation of professionals and advanced players, advanced players and intermediate players and intermediate players and novices based on players' predictions of final ball locations (Cañal-Bruland et al., 2011; Cocks, Jackson, Bishop, & Williams, 2016; Farrow et al., 2005; Farrow & Abernethy, 2003; Jackson & Mogan, 2007; Murphy et al., 2016; Smeeton & Huys, 2011; Williams et al., 2002; Williams, Huys, Cañal-Bruland, & Hagemann, 2009). Six out of the nine studies revealed differences between professionals and advanced players, advanced players and intermediate players or intermediate players and novices (Buckolz, Prapavesis, & Fairs, 1988; Cañal-Bruland et al., 2011; Cocks et al., 2016; Murphy et al., 2016; Smeeton & Huys, 2011; Williams et al., 2009), whereas three studies did not find any differences between players whose performance levels differed (Farrow et al., 2005; Jackson & Mogan, 2007; Williams et al., 2002). One study revealed differences between advanced and intermediate players in their movement-based responses but not in their verbal responses (Farrow & Abernethy, 2003).

Four of the studies included in the review examined both technical and tactical skills (Del Villar et al., 2007; McPherson & Thomas, 1989; McPherson, 1999b; Nielsen & McPherson, 2001). Two studies were deemed to be of high methodological quality, whereas the other two studies were of good methodological quality. There was strong evidence that advanced players outscored novices in their serve and groundstroke performances (i.e., technical skills) and in the quality of their decision making (Del Villar et al., 2007; McPherson & Thomas, 1989; McPherson, 1999a; Nielsen & McPherson, 2001). However, there was weak evidence that advanced players outscored novices in terms of their demonstrated tactical knowledge (McPherson & Thomas, 1989; McPherson, 1999a).

Table 2. Characteristics of the 40 studies reviewed measuring technical and/or tactical skills in players with different levels of performance

Author	Sample size, sex	Age (years) ± SD	Level of performance, playing experience (years), number of participants	Measure(s) of skill(s)	Results
Technical and tactical skills					
Del-Villar et al. (2007)	12, male	21.7 ± 1.3 12.3 ± 0.8	A, 14.7 ± 1.8, (n = 6) N, 3.8 ± 1.0, (n = 6)	Observational instrument to measure decision-making and outcome of serves and groundstrokes during real match situation	A≈N successful control of serve and groundstroke A>N decision-making and forceful outcome of serve and groundstroke
McPherson and Thomas (1989)	40, male	11.1 ± 0.4 11.1 ± 0.7 13.1 ± 0.6 12.9 ± 0.7	A, (n = 10) N, (n = 10) A, (n = 10) N, (n = 10)	Skill test, observational instrument to measure decision-making and outcome of serves and groundstrokes including verbal reports during real match situation	A>N serve and groundstroke performance A>N decision-making and forceful outcome of serve and groundstroke A>N declarative and procedural knowledge
McPherson (1999a)	12, female	19-22 18-22	A, 3.2, (n = 6) N, 0.2, (n = 6)	Observational instrument to measure decision-making and outcome of serves and groundstrokes including verbal reports during real match situation	A>N serve and groundstroke performance A>N decision-making and forceful outcome of serve and groundstroke A≈N total and variety of goal concepts A>N more total and variety of condition, action and do concepts A≈N total regulatory concepts A>N double concepts A≈N single and triple concepts
Nielsen and McPherson (2001)	12, male	27.3 22.6	A, 17.3 ± 4.9, (n = 6) N, 5.3 ± 2.7, (n = 6)	Observational instrument to measure decision-making and outcome of serves and groundstrokes during real match situation	A≈N successful control of serve A>N successful control of groundstroke, decision-making, forceful outcome of serve and groundstroke
Technical skills					
Girard et al. (2005)	32, male	23.2 ± 2.9 18.8 ± 4.6 21.7 ± 2.1	A, 14.9 ± 2.8, (n =15) I, 6.9 ± 3.8, (n = 10) N, 0.9 ± 1.1, (n = 7)	Serve test	A≈I≈N serve success rate A>I+N peak ball velocity groundstroke
Girard et al. (2007)	30, male	21.3 ± 3.8	A, 14.9 ± 2.8, (n = 13) I, 6.9 ± 3.8, (n = 10) N, 0.9 ± 1.1, (n = 7)	Serve test	A>I>N peak ball velocity serve
Kolman et al. (2017)	32, male	13.6 ± 0.5 13.2 ± 0.5	A, 8.8 ± 1.6 (n = 15) I, 7.1 ± 1.4 (n = 17)	Groundstroke test (D4T)	A>I peak ball velocity groundstroke, ball accuracy, percentage errors
Landlinger et al. (2012)	13, male	23.0 ± 2.3 16.3 ± 0.5	P, (n = 6) A, (n = 7)	Groundstroke test	P≈A strokes inside target area P<A strokes outside court P≈A strokes in the net P>A peak ball velocity groundstroke P≈A ball accuracy

Author	Sample size, sex	Age (years) ± SD	Level of performance, playing experience (years), number of participants	Measure(s) of skill(s)	Results
Lyons et al. (2013)	30, male/ female	19.5 ± 3.0 24.9 ± 9.6	A, (n = 13) N, (n = 17)	Groundstroke test (mLTST)	A>N ball accuracy and consistency A<N strokes outside court
Martin et al. (2014)	18, male	25.5 ± 4.3 25.3 ± 7.3	P, (n = 11) A, (n = 7)	Serve test	P>A peak ball velocity serve P>A serve efficiency
Söğüt (2017)	35, male/ female	12.7 ± 1.1 12.9 ± 1.5	A, 6.2 ± 1.1 (n = 15) I, 5.0 ± 1.3 (n = 20)	Serve test	A>I peak ball velocity serve
Vergauwen et al. (2004)	23, male	12.7 ± 0.7	A, 3-4, (n = 7) I, 2-3, (n = 9) N, 0, (n = 7)	Groundstroke test (ForeGround)	A+I>N success rate, peak ball velocity, ball accuracy baseline and sideline, VP, VPS A>I success rate, peak ball velocity, ball accuracy sideling, VP, VPS A≈I ball accuracy longitudinal I>N, 62% success rate, 34% ball velocity, 19% ball accuracy baseline, 14% ball accuracy sideline, 73% VP, 367% VPS. A> I, 19% success rate, 17% peak ball velocity, 14% ball accuracy sideline, 66% VP, 93% VPS

Author	Sample size, sex	Age (years) ± SD	Level of performance, playing experience (years), number of participants	Measure(s) of skill(s)	Results
Vergauwen et al. (1998)	27, male	21.0 ± 1.0	P, 24 ± 4, (n = 7) A, 10 ± 1, (n = 20)	Groundstroke and serve test (LTPT)	Down the center 1st serve P≈A percentage errors, peak ball velocity, ball accuracy and VPE index P>A VP index Wide 1st serve P≈A percentage errors, ball accuracy sideline, VP index, and VPE index P>A peak ball velocity and ball accuracy service line Down the center 2nd serve P<A percentage errors P≈A peak ball velocity, VP index, and ball accuracy sideline P>A ball accuracy service line, and VPE index Wide 2nd serve P<A percentage errors P≈A peak ball velocity, ball accuracy, and VP index P>A VPE index Neutral situation P<A percentage errors, and ball accuracy sideline P>A peak ball velocity, VP index, and VPE index P≈A ball accuracy baseline Defensive situation P<A percentage errors P≈A peak ball velocity, ball accuracy, and VP index P>A VPE index Offensive situation P<A percentage errors P≈A peak ball velocity, ball accuracy sideline, and VP index P>A ball accuracy baseline
Tactical skills					
Balser et al. (2014)	32, male/ female	22.6 ± 5.1 25.4 ± 3.9	A, 16 ± 5.7, (n = 16) N, 0.2 ± 0.5, (n = 16)	Video-clips were used to predict the direction of the ball (spatial anticipation) and to decide forehand or backhand stroke to observed action (motor anticipation)	A>N response accuracy in motor and spatial condition A≈N mean response time in motor and spatial condition Non-significant interaction (level of performance × response condition) for response accuracy
Buckholz et al. (1988)	44, male/ female	15-16	A, (n = 21) I, (n = 23)	Temporal occlusion paradigm was used to examine the type of passing shot performed	A>I response accuracy Non-significant interaction (level of performance × information available) for response accuracy

Author	Sample size, sex	Age (years) ± SD	Level of performance, playing experience (years), number of participants	Measure(s) of skill(s)	Results
Cañal-Bruland et al. (2011)	40	25.7 ± 10.2 33.3 ± 20.7	A, (n = 19) I, (n = 21)	Temporal occlusion paradigm was used for body (parts) to examine spatiotemporal characteristics of visual information pick-up when anticipating groundstroke direction	A>I response accuracy in control, legs, hips, trunk, arms manipulation A<I response accuracy in arm-racket manipulation Non-significant interaction (level of performance × temporal occlusion) for response accuracy
Cocks et al. (2016)	24, male	20.7 ± 2.4 21.8 ± 3.5	A, 10.5 ± 4.4, (n = 12) I, 7.8 ± 7.3, (n = 12)	Temporal occlusion paradigm was used at racket-ball contact to examine spatiotemporal characteristics of visual information pick-up when anticipating groundstroke direction	A>I response accuracy A<I directional errors A≈I depth errors Non-significant interaction (level of performance × contextual condition) for response accuracy
Farrow et al. (2003)	Exp. 1: 27, male/female	Exp. 1: 19.7 22.3 ± 2.65	Exp. 1: A, 11.4, (n = 11) N, (n = 16)	Exp. 1: Temporal occlusion paradigm with moving window condition was used to examine verbal predictions of stroke direction	Exp. 1: A≈N response accuracy Non-significant interaction (level of performance × display condition), (level of performance × temporal occlusion) and (level of performance × display condition × temporal occlusion) for response accuracy
	Exp. 2: 29, male/female	Exp. 2: 17.6 19.8	Exp. 2: A, 10.2, (n = 15) I, 5.8, (n = 14)	Exp. 2: Liquid crystal occluding in combination with temporal occlusion paradigm with moving window condition was used to examine real movement responses to serves on court	Exp. 2: A≈I response accuracy Significant interaction (level of performance × display condition) and (level of performance × display condition × temporal occlusion) for response accuracy
Farrow et al. (2005)	16	17.5 19.6	A, 9, (n = 8) I, 5.8, (n = 8)	Temporal occlusion paradigm was used to examine the direction of serves with a movement based response and a verbal response	A>I response accuracy in movement based response A≈I response accuracy in verbal response Significant interaction (level of performance × type of perception-action coupling) for response accuracy Non-significant interaction (level of performance × response mode × temporal occlusion) for response accuracy
García-González et al. (2012)	12	16.1 ± 2.3 16.3 ± 2.3	A, (n = 6) I, (n = 6)	Interview procedure including verbal reports were used to examine knowledge representation	A>N in total and variety of condition and regulatory concepts. A>N in total action concepts. A≈N in variety of action concepts. A≈N in total and variety of goal concepts. A>N concept linkages.

2

Author	Sample size, sex	Age (years) ± SD	Level of performance, playing experience (years), number of participants	Measure(s) of skill(s)	Results
Goulet et al. (1989)	Exp. 1: 29, male/ female	Exp. 1: 22.3 21.6	Exp. 1: A, (n = 15) N, (n = 14)	Exp. 1+2: Temporal occlusion paradigm was used to predict the type of serve (flat, topspin, slice), number and source of eye fixations	Exp 1: A>N response accuracy A>N number of fixations A>N organize search more frequently around head and shoulder/trunk complex Significant interaction (level of performance × type of exchange) for scan paths Significant interaction (level of performance × server's handedness), (level of performance × type of serve) and (level of performance × server's handedness × type of serve) for response accuracy Significant interaction (level of performance × phase of serve) for number of fixations
	Exp. 2: 20, male/ female	Exp. 2: 22.1 21.2	Exp. 2: A, (n = 10) N, (n = 10)		Exp 2: A>N response accuracy A>N decision-time Significant interaction (level of performance × situation) for response accuracy Significant interaction (level of performance × situation) for decision time
Huys et al. (2008)	Exp. 1: 25	Exp. 1: 26.6 ± 11.1 34.0 ± 11.6	Exp.1: A, (n = 13) I, (n = 12)	Exp. 1+2: Stick figures were used to examine anticipation accuracy of groundstroke direction	Exp. 1: A>N response accuracy Non-significant interaction (level of performance × situation) for response accuracy
	Exp. 2A: 28	Exp. 2A: 22.1 ± 4.5 39.9 ± 11.7	Exp. 2A A, (n = 14) I, (n = 14)		Exp. 2A+2B: A≈N response accuracy
	Exp. 2B: 28	Exp. 2B: 26.8 ± 11.4 38.3 ± 10.8	Exp. 2B: A, (n = 14) I, (n = 14)		
Jackson and Mogan (2008)	37	20.4 ± 1.9 20.7 ± 1.7 21.6 ± 3.1	A, 9.6 ± 2.5, (n = 13) I, 8.9 ± 2.4, (n = 13) N, 0.6 ± 0.6, (n = 11)	Temporal occlusion paradigm was used to examine the ability to predict direction tennis serve by viewing video footage that was occluded on the last frame before racquet-ball contact. Verbal reports were used to examine visual information processing	A>N response accuracy A≈I response accuracy I≈N response accuracy A>N amount of information sources reported in verbal report A≈I amount of information sources reported in verbal report I≈N amount of information sources reported in verbal report Non-significant interaction (level of performance × occlusion condition) for response accuracy

Author	Sample size, sex	Age (years) ± SD	Level of performance, playing experience (years), number of participants	Measure(s) of skill(s)	Results
Loffing and Hagemann (2014)	52, male	24.7 ± 4.3 26.0 ± 3.8	A, 16.7 ± 4.7, (n = 26) N, (n = 26)	Temporal occlusion paradigm was used in a video-based experiment with point-light condition to examine the anticipation of groundstroke direction	A>N response accuracy A≈N information pick-up from early to late occlusion conditions A>N expect more cross-court groundstrokes A>N more varied expectations as a function of stroke position across temporal occlusion conditions Non-significant interaction (level of performance × temporal occlusion) and (level of performance × shot position) for response accuracy
Loffing et al. (2011)	48, male	26 ± 6.04 26.17 ± 3.84	A, 17.9 ± 5.7 N	Video-based experiment with point-light condition was used to anticipate groundstroke direction	A>N response accuracy A>N perceptual sensitivity Non-significant interaction (level of performance × display condition) for response accuracy and perceptual sensitivity
Mahadas et al. (2015)	4, male/female	19-22	I, 5, (n = 2) N, 1, (n = 2)	Biosensors and eye sensors were used to measure eye and head motions	I>N earlier eye movement initiation I≈N head movement initiation
McPherson (1999b)	12, female	19-22 18-22	A N	Verbal reports during real match situation were used to examine planning strategies	A>N plans concerning higher level goals. A≈N total reactive, literal and concentration concepts A>N more total and variety of condition, goal, action and do concepts A≈N total and variety of regulatory concepts
McPherson (2000)	12, female	19-22 18-22	A, (n = 6) N, 0.2, (n = 6)	Interview procedure including verbal reports were used to examine tactical problem representation	A>N higher levels of tactical plans. A>N in total and variety of condition, action and do concepts A≈N in total and variety of goal concepts. A>N concept linkages
McPherson and Kernodle (2007)	12, male	27.3 22.6	A, 17.3 ± 4.9, (n = 6) N, 5.3 ± 2.7, (n = 6)	Verbal reports during real match situation were used to examine problem representations	A>N total and variety condition concepts A≈N total and variety action and goal concepts A<N do concepts A≈N regulatory concepts A>N detailed conditions and actions A>N total concept linkages A≈N total connections

Author	Sample size, sex	Age (years) ± SD	Level of performance, playing experience (years), number of participants	Measure(s) of skill(s)	Results
Rowe and McKenna (2001)	Exp. 1+2: 40	Exp. 1+2: 21.6 ± 9.0 20.2 ± 1.5 19.5 ± 1.5	Exp. 1+2: A, 9.0 ± 5.5, (n = 8) I, 6.0 ± 3.5, (n = 14) N, 1.6 ± 1.7, (n = 18)	Exp. 1: Video-based simulation test was used to examine anticipatory skill Exp. 2: Real-world footage was used to examine anticipatory skill	Exp 1: A>I+N for response latency I≈N response latency A≈I≈N reaction time Exp. 2: A>N for response latency
	Exp. 3: 32	Exp. 3: 20.8 ± 1.8 20.5 ± 3.2	Exp. 3: A, 11.5 ± 3.0, (n = 16) N, 1.4 ± 1.4, (n = 16)	Exp. 3: Video-test with dual-task condition was used to examine anticipatory skills	Exp. 3: A<N response time under single and dual task condition Significant interaction (level of performance × task condition) for response time Non-significant interaction (level of performance × task) for missed target shots
Murphy et al. (2016)	Exp. 1 36, male	Exp. 1 24.0 ± 5.6 24.1 ± 4.7	Exp. 1 P, 17.8 ± 5.5 (n = 16) I, 7.0 ± 4.8 (n = 20)	Exp. 1 Video-based experiment with normal and animated videos was used to examine the anticipation of groundstroke direction and depth	Exp. 1 P>I response accuracy for direction, depth and combination Significant interaction (level of performance × display) for response accuracy
	Exp. 2 20, male	Exp. 2 28.6 ± 4.7 23.7 ± 4.4	Exp. 2 P, 22.0 ± 5.3 (n = 10) I, 3.8 ± 3.9 (n = 10)	Exp. 2 Video-based experiment with animated videos was used to examine the anticipation of groundstroke direction and depth Verbal reports and visual search data were used to examine visual information	Exp. 2 P>I response accuracy for depth and combination, evaluation statements, different keywords, ball flight fixations P≈I response accuracy direction, number of words verbal report, prediction statements, number of fixations, fixation duration Non-significant interaction (level of performance × statement type) and (level of performance × keyword type)
Rowe et al. (2009)	80, male/ female	24.7 ± 9.5 22.3 ± 5.2	A N	Temporal occlusion paradigm was used to examine the anticipation of disguised and non-disguised groundstroke direction	A>N response accuracy Significant interaction (level of performance × shot type × temporal occlusion) for response accuracy
Shim, Miller et al. (2005)	28, male/ female		A, (n = 14) N, (n = 14)	Temporal occlusion paradigm was used for body (parts) to examine the anticipation of groundstroke type and direction	A>N response accuracy A≈N response delay time Non-significant interaction (level of performance × shot type × display) for response accuracy

Author	Sample size, sex	Age (years) ± SD	Level of performance, playing experience (years), number of participants	Measure(s) of skill(s)	Results
Shim, Carlton et al. (2005)	25, male/ female	18-35 20-34	A, (n = 13) N, (n = 12)	Video-based experiment with point-light, full-sized 2D and 3D live conditions was used to examine the anticipation of groundstroke type and direction	A>N overall prediction accuracy A>N response accuracy 2D and 3D live conditions A≈N response accuracy point-light display Significant interaction (level of performance × shot type × display) for response accuracy
Singer et al. (1996)	60, male/ female		A N	Visual search and anticipation task was used to examine visual tracking, type and direction of serve, direction of groundstrokes, reaction time and movement time	A<N number of fixations and total duration time towards head A<N time to make prediction about serve and groundstroke A>N response accuracy type and direction serve and groundstroke A<N reaction and movement time Significant interaction (level of performance × body area) for viewing time
Smeeton and Huys (2011)	34	22.7 ± 3.5 22.2 ± 3.4	I, (n = 15) N, (n = 19)	Video-based experiment with point-light condition was used to examine the anticipation of groundstroke direction	I>N response accuracy Non-significant interaction (level of performance × condition) for response accuracy
Tenenbaum et al. (1996)	45, male	22.2 ± 3.5 13.0 ± 2.7 11.0 ± 1.2	P, 12.4 ± 2.3, (n = 15) I, 4.4 ± 1.7, (n = 15) N, 1.1 ± 0.6, (n = 15)	Temporal occlusion paradigm in a video-based experiment was used to examine the anticipation of the final ball landing location	P>I>N response accuracy Significant interaction (level of performance × temporal occlusion) for response accuracy
Tenenbaum et al. (2000)	80, male	8-18+	A, 2.1-12.4, (n = 40) N, 2.1-12.4, (n = 40)	Temporal occlusion paradigm in a video-based experiment was used to examine the anticipation of the final ball landing location	A>N response accuracy Non-significant interaction (level of performance × exposure duration) for response accuracy
Williams et al. (2009)	24	19.3 ± 1.2 21.0 ± 1.7	A, 10.2 ± 3.6 I, 3.8 ± 1.0	Video-based experiment using stick figure clips was used to examine groundstroke direction	A>I response accuracy Significant interaction (level of performance × body area) for response accuracy
Williams et al. (2002)	16, male	23.0 ± 7.3 27.2 ± 4.4	A, 11.9 ± 4.7, (n = 8) I, 3.8 ± 1.0, (n = 8)	Temporal occlusion paradigm in a video-based experiment was used to examine movement-based response and visual information processing	A>I quicker response time A≈I response accuracy A<I time fixating on racket A≈I number of locations fixed per trial, number of fixations per trial, mean fixation duration A>I successive fixations within and between the head-shoulder and trunk-hip regions Significant interaction (level of performance × body area) for viewing time

Abbreviations: A = advanced players; Exp. = experiment; I = intermediates; LTPT = Leuven Tennis Performance Test; mLTST = modified Loughborough Tennis Skill Test; N = novices; P = professionals; VP = velocity-precision; VPE = velocity-precision-error; VPS = velocity-precision-success.

Discussion

The aim of this review was to provide an overview of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis in relation to performance levels and to provide recommendations for the analysis of these skills in tennis performance. Studies in which only technical skills were measured revealed that ball velocity distinguished high-performing players from lower-performing players. However, there was weak evidence that advanced players demonstrated greater accuracy in their ball placement compared with their counterparts with less advanced skills. The finding that advanced players outscored players whose performance levels were lower in terms of ball velocity is supported by the results of studies done on other sports, such as handball and volleyball. These studies showed that highly skilled players produced higher ball velocities than their less skilled counterparts (Laffaye, Debanne, & Choukou, 2012). Although few studies have assessed the relationship between ball accuracy and performance level, it seems that differences only exist between advanced and intermediate players and between advanced players and novices (Lyons et al., 2013; Vergauwen et al., 2004). No differences were found between professionals and advanced players (Landlinger et al., 2012). However, it is noteworthy that the studies applied different methodologies (relating to size and target areas). Consequently, it is difficult to draw definitive conclusions about the relationship between ball accuracy and performance level. Studies done on other sports have revealed differences in ball accuracy that exist not only between experts and novices (Beilock, Bertenthal, McCoy, & Carr, 2004) but also between players whose performance levels are more homogeneous (Huijgen, Elferink-Gemser, Ali, & Visscher, 2013). Two studies that assessed technical skills revealed that young players with more experience scored higher than less experienced players for ball velocity and ball accuracy, and their success rates were higher than those of players with less experience (Kolman et al., 2017; Vergauwen et al., 2004). However, more research is needed to examine the relationship between ball velocity and accuracy, as these factors appear to be important for future performance levels. According to the speed-accuracy trade-off hypothesis, an increase in the execution time of a movement is required to achieve greater accuracy (Fitts, 1954). A previous study conducted on soccer revealed that top players demonstrated greater accuracy in their ball control, especially under time pressure, compared with lower ranked players (Huijgen et al., 2013). Future studies should focus especially on investigating whether more experienced players are able to maintain accurate strokes under conditions of increasing demands (e.g. speed) in tennis. However, other characteristics such as anthropometry and physiology could affect serve velocity (Kraemer et al., 2003; Perry, Wang, Feldman, Ruth & Signorile, 2004).

The studies that assessed only tactical skills showed strong evidence that performance levels were differentiated according to decision-making and anticipatory skills, tactical knowledge and visual search strategies. Advanced players make better decisions than novices, possibly because of their acquisition of a greater degree of implicit (unconscious) control (Masters et al., 2008). Implicit processes are organized and occur faster than conscious control processes, because unlike the latter, the application of advanced procedural knowledge does not entail conscious thought (e.g. Masters et al., 2008; Raab, 2003). Implicit processes are therefore independent of working memory (Baddeley, 2003), which explains why experts have sufficient remaining resources to make reasonable decisions. By contrast, explicit processes depend on working memory for the retrieval of consciously accessible (declarative) knowledge (Maxwell, Masters, & Eves, 2003). Because novices' performances are more dependent on explicit processes and working memory, the demands of a complex task are likely to overload them and reduce their performance.

Advanced players were found to be faster and more accurate in their anticipation of the directions of their opponents' strokes than players whose performance levels were lower. This finding is supported by those of a soccer study, which showed that advanced players' predictions of the directions of penalty kicks were more accurate than those of novices (Savelsbergh, Williams, Kamp, & Ward, 2002). Advanced players use more selective visual search patterns than do novices, as reflected by the higher response accuracy in anticipatory tasks reported in several studies (Balser et al., 2014; Buckolz et al., 1988; Cocks et al., 2016; Farrow & Abernethy, 2003; Goulet et al., 1989; Jackson & Mogan, 2007; Loffing & Hagemann, 2014; Loffing et al., 2011; Murphy et al., 2016; Rowe et al., 2009; Shim et al., 2005; Shim et al., 2005; Singer et al., 1996; Smeeton & Huys, 2011; Tenenbaum et al., 1996; Tenenbaum et al., 2000; Williams et al., 2009). Moreover, Farrow and Reid (2012) showed that the anticipatory capability of players is also dependent on age, with older players demonstrating more advanced anticipatory skills than younger players. Anticipatory tasks entail mostly temporal occlusion paradigms, but point-light displays and stick-figure conditions are used as well to examine these abilities. Singer et al. (1996) found that whereas advanced players focused their attention on the wrist and shoulder of the opponent when anticipating the ball's direction, novices focused more on the opponent's head and non-dominant side. It seems that advanced players focus on relevant proximal cues (e.g., those associated with the opponent's trunk, arm and hips), whereas novices focus more on distal cues like the opponent's head (Goulet et al., 1989; Singer et al., 1996). However, tennis performance entails multidimensional performance characteristics that include technical and tactical skills among others. This review did not examine other performance characteristics, such as perception, that may also be relevant, particularly in relation to technical and tactical skills. Thus, future studies could explore the importance of perception related to tennis performance.

The instruments identified in this systematic review are important for analysing performance in tennis. Newell's constraints-led approach, which has been applied in performance analysis (Glazier, 2010; Newell, 1986), suggests that sports performance hinges on three sources: the task, the environment and the individual. According to Davids et al. (2004), the key role of coaches and instructors is to manipulate these constraints so that they facilitate players' discovery of functional movement patterns. Constraints can be manipulated in practice through the introduction of instruments. For example, task constraints can be changed by introducing target areas used to measure or improve ball accuracy. However, the instruments identified in this review varied in their practicality.

The interview procedures applied during actual match situations for examining decision-making skills require less experience and materials and could be easily incorporated in practice by coaches and instructors. In addition, a radar system and target areas for assessing ball velocity and ball accuracy, respectively, could be easily integrated in practice. However, the use of video-based experiments for measuring anticipatory skills and visual behaviours would be more difficult to incorporate into training, as these require more expertise and resources. Moreover, a point to consider when introducing such instruments to practically monitor and improve anticipatory skills is that implicit learning techniques may be more effective than explicit learning instructions, especially under stressful conditions (Liao & Masters, 2001; Williams et al., 2002). Players could benefit from instructions that direct their attention towards information-rich areas as opposed to specific information cues. They should be instructed to focus solely on the contact zone so that they can discern regularities between the racket and ball orientation for each type of serve (Williams et al., 2002).

For this review, two expert researchers working independently from one another assessed the methodological quality of the studies as accurately as possible using the quality assessment form developed by Law et al. (1998). It is conceivable that scores might have been slightly different if another form had been used. However, a limitation of this review was that sex and age were not considered in comparisons of performance levels. Therefore, it is difficult to draw definitive conclusions regarding which factors are important for players of different ages and sexes. Very little research has been conducted on technical and tactical skills. In addition, few studies were found that assessed these skills longitudinally or focused on young tennis players. Technical and tactical skills should be measured over time in studies of young players to deepen understanding of the development of these skills.

Thirty-six articles in which technical or tactical skills were separately measured were included in the review. These studies provided insights relating to particular skills that differentiate players with different performance levels. One advantage of conducting separate assessments of technical and tactical skills is that this leads to more knowledge about a specific skill related to the level of performance within a more controllable environment. By contrast, a significant disadvantage of measuring technical or tactical skills in isolation is that this measure is not reflective of actual match play, because a tennis stroke is always executed in a particular context and not in isolation. The tactical possibilities depend on players' technical abilities, given that technical skills both determine and limit players' tactical solutions and decisions. The reverse is also true, as players' technical skills determine tactical possibilities. The performance of a particular stroke (i.e., technical execution) that is most likely to result in winning the point is based on a tactical decision, meaning that these skills should be studied in an integrated way. Future studies should explore the relationship between technical and tactical skills and tennis performance. In addition, further studies should focus on developing a test for the integrated measurement of these skills.

Conclusions

The aim of this review was to provide an overview of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis in relation to performance levels and to provide recommendations for the analysis of these skills in tennis performance. The results of the studies that measured only technical skills revealed that performance levels were differentiated based on ball velocity. Weak evidence was found for more accurate ball placement by advanced players compared with their less skilled counterparts. The studies that assessed only tactical skills showed strong evidence that players with higher performance levels display superior decision-making and anticipatory skills, more elaborate tactical knowledge and better visual search strategies than players whose performance levels are lower. However, a significant disadvantage of the studies was that they mainly measured technical and tactical skills in isolation. This is a drawback because players' technical skills determine and limit their tactical solutions and decisions (and vice versa); therefore, these skills should be studied in an integrated manner. Future studies should explore the relationship between technical and tactical skills and tennis performance. In addition, they should focus on developing a test that enables these skills to be measured in an integrated manner and is also easy to incorporate in practice.

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CHAPTER 3

THE DUTCH TECHNICAL-TACTICAL TENNIS TEST (D4T) FOR TALENT IDENTIFICATION AND DEVELOPMENT: PSYCHOMETRIC CHARACTERISTICS

Kolman, N.S, Huijgen, B., Kramer, T., Elferink-Gemser, M., & Visscher, C. (2017). The Dutch Technical-Tactical Tennis Test (D4T) for Talent Identification and Development: Psychometric Characteristics. Journal of Human Kinetics, 55(1), 127–138. https://doi.org/10.1515/hukin-2017-0012

Abstract

This study examined the test-retest reliability, validity and feasibility of the newly developed Dutch Technical-Tactical Tennis Test (D4T). This new test is relevant for talent identification and development in tennis. Thirty-two youth male tennis players (age 13.4 ± 0.5 years) were classified as elite (n=15) or sub-elite (n=17) according to their position on the national youth ranking list under 15 years (cut-off rank 50) in the Netherlands. Games, rallies and different tactical situations (i.e. offensive, neutral and defensive) were simulated with a ball machine. Players had to return 72 balls to predetermined target areas. Stroke quality was recorded based on ball velocity and accuracy (VA-index), as well as percentage errors. Test-retest reliability was assessed by comparing differences between the first and second test-session (n=10). An intraclass-correlation coefficient of .78 for the VA-index was found ($p < .05$), indicating excellent test-retest reliability. Independent t-tests revealed that elite players outscored sub-elite players for the VA-index, ball velocity, accuracy and percentage errors ($p < .05$), supporting good validity. Furthermore, a high correlation was found between the VA-index and individual positions on the youth ranking list ($r = -.75$; $p < .001$). The assessment of feasibility indicated that the D4T was applicable for instructors and coaches. In conclusion, the D4T was shown to be a reliable, valid and feasible test to measure technical-tactical characteristics of tennis performance in youth players.

Keywords: racquet sports, field test, performance, ball velocity, accuracy, youth sports.

Introduction

In tennis especially technical and tactical characteristics are crucial for performance (MacCurdy, 2006; Meylan et al., 2010). Technique in tennis is generally characterized by stroke quality of which the key determinants are the combination of ball velocity and accuracy along with the success rate (Landlinger et al., 2012; Vergauwen et al., 2004). A clear relationship between ball velocity and the level of tennis performance exists, with international players producing higher ball velocities than national players (Landlinger et al., 2012; Martin et al., 2014). Also, a relationship between ball accuracy and the level of tennis performance has been shown, although up to now exclusively between experts and non-experts (Lyons et al., 2013) and not between international and national players, with the exception of lateral stroke accuracy (Landlinger et al., 2012). To our knowledge, only one study has measured ball velocity as well as ball accuracy in youth tennis players (Vergauwen et al., 2004). In this study, a rally test was conducted on a court with reduced dimensions (13.40 × 6.10 m) to measure groundstroke performance in youth players (age 12.7 ± 0.7 years). The results revealed that players with more experience generated a higher success rate, ball velocity and ball accuracy than their less experienced counterparts.

Technical characteristics are needed for the execution of appropriate tactics in a given situation. Consequently, when technical characteristics develop, the quality of tactical characteristics can improve as well (Wang et al., 2013). Tactical characteristics are defined as the knowledge about in-game adaptations and decision-making activity on the court (Elferink-Gemser et al., 2010). Anticipation of actions of an opponent together with making appropriate decisions are important aspects of a successful tactical performance. Players have to deal with these aspects instantly (Balser et al., 2014; Féry and Crognier, 2001). Expert players have more experience in performing sport-specific actions and anticipating their opponents' actions than novices (Williams et al., 2002). Williams et al. (2002) showed that expert players anticipated better on their opponents and made earlier decisions than novices, which is a substantial advantage for the execution of groundstrokes. Furthermore, Crognier and Féry (2005) showed that the anticipation of strokes was dependent of the tactical situation (i.e. offensive, neutral and defensive). They indicated that players' accuracy in anticipating the direction in which to move to intercept the ball was close to 80% when the players were in the offensive situation, while their accuracy was lower when they were in a defensive situation.

To measure performance characteristics in tennis, field tests have been used (Landlinger et al., 2012; Lyons et al., 2013; Vergauwen et al., 1998, 2004). An example of a test that measures technical and tactical characteristics is the Leuven Tennis Performance Test (LTPT) (Vergauwen et al., 1998). In this test, players have to direct their strokes to a target point located at the intersection of the baseline and the sideline. In the LTPT, the higher ranked players made fewer errors than their lower ranked counterparts. Furthermore, they scored higher on ball velocity and lateral stroke accuracy than lower ranked players. However, in this test the risk of the ball landing outside the court is high (Landlinger et al., 2012) and it should be noted that a higher risk resulting in more errors is detrimental for the success rate of strokes.

Previous research in youth tennis showed that on average a rally was between 2.5 and 3 strokes, with more strokes per rally on slow than on fast surfaces (Fernandez-Fernandez et al., 2009). Moreover, data recorded from 481 matches on grass revealed that the average number of rallies per game was approximately six (Magnus and Klaassen, 1999). Therefore, to be realistic with match play, a new field test should include three strokes per rally, six rallies per game and a target area that is located inside the court. At the moment, no reliable and valid test exists that includes the aforementioned aspects and measures technical as well as tactical characteristics in youth tennis players.

The overall purpose of the current study was to develop a reliable, valid and feasible technical-tactical test that could be used in talent identification and development in tennis. It was investigated whether the test was reliable and whether differences in position on the youth ranking list would be manifested in the test performance, supporting its validity. Moreover, it was analyzed whether anticipation and decision-making influenced the execution of groundstrokes differently in players with different positions on the ranking list. Finally, it was evaluated whether the test could be applicable for instructors and coaches.

Material and Methods

Participants

Thirty-two youth male players (age 13.4 ± 0.5 years; body height 167.7 ± 10.6 cm; body mass 52.3 ± 10.9 kg) were recruited via tennis organizations, clubs and coaches who all gave permission for this study. Participants were classified as elite (n=15) or sub-elite (n=17) according to their position on the Dutch national youth ranking list under 15 years at the time of testing (KNLTB). Elite players were those ranked among the top-50, while sub-elite players were classified between position 51 and 350 on the ranking list. Test-retest reliability was assessed in ten sub-elite players.

Measures

The Dutch Technical-Tactical Tennis Test (D4T) consisted of 72 strokes, grouped in four games of six rallies, in which each rally included three strokes. A ball machine (Pro Match Smartshot, Mubo, Gorinchem, Netherlands) was used to meet the criterion of standardization and to feed balls to the participants. Ball accuracy was measured using target areas to which participants were instructed to direct their strokes. A large target area (3.6 × 2.7 m) and a middle target area (2.4 × 1.8 m) were located at both corners at the intersection of the baseline and the sideline as displayed in Figure 1. A small target area (1.2 × 0.9 m) was located inside the middle target area and was positioned 0.45 m from the sideline and 0.6 m from the baseline. The colored target areas were stitched on a large carpet and a colored cap was placed in the center of the small target area as the main target point.

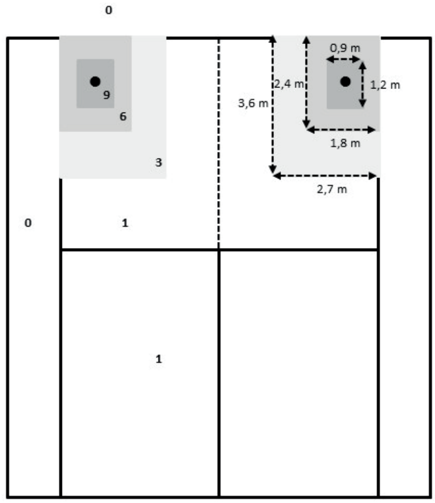

Figure 1. Representation of the half of a tennis court including the dimensions of the target areas and the number of awarded points to balls landing in the areas

Each game was divided into two offensive, two neutral and two defensive rallies, representing different tactical situations as displayed in Figure 2. Offensive rallies consisted of three ball projections just beyond the service line. Neutral rallies comprised three ball projections to the area around the middle of the court approximately one meter before the baseline, and defensive rallies included three ball projections to the sideline and beyond the service line. The velocity of the ball projections was approximately 70, 75 and 80 km/h, in the offensive, neutral and defensive rallies, respectively. The time interval between the ball projections was 2.5 s in each tactical situation.

The order of the tactical situations (i.e. offensive, neutral and defensive) in games occurred randomly. However, the order of the games during the test was the same for each participant, since the degree of difficulty was increased during successive games. In the first game, during each rally, participants had to return their strokes to the left target area (deuce side). In the second game, they had to direct the strokes to the right target area (advantage side) and finally, in the third game, participants had to aim their strokes alternately between the two target areas. For example, if a participant directed the strokes in one rally to the left/right/left target area, in the next rally they had to aim their strokes to the right/left/right target area. In the final game, the target area was determined by lights which turned red either on the left or right side of the court. The lights were positioned on tripods and placed in both corners of the singles court just behind the baseline and after the target areas. A light gate was placed before the ball machine. After a ball passed the light gate, a signal was sent by an interface and computer to the lights with an adjustable delay set at 500 ms. Following a prescribed protocol and after the signal was given, one of the two lights turned red. The lights were illustrative of the position of an (artificial) opponent. Hence, participants had to return their strokes to the opposite side of the red light. The complete test design is displayed in Figure 2.

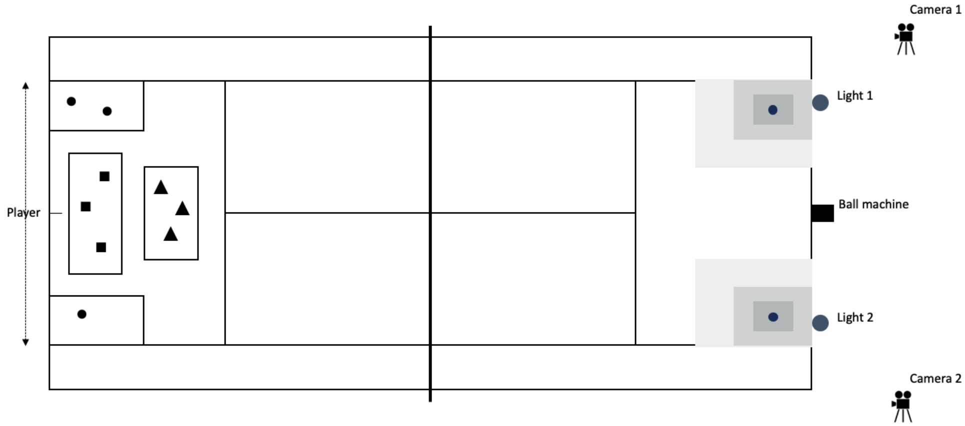

Figure 2. Representation of the (▲) offensive, (■) neutral and (●) defensive tactical situation and the complete test design. The forms represent the three ball projections in the tactical situations.

Ball velocity and accuracy

Ball velocity was measured using a radar system (Ball coach pocket radar, PR1000-BC) and was recorded after each stroke. In the current study, a high degree of reliability was found between the velocity of the radar system and the velocity calculated using captured video images. The single measure intra-class correlation coefficient (ICC) was .988 with a 95% confidence interval from .979 to .993, $F(1,49) = 162.303$, $p < .001$. Ball accuracy was determined by recording the landing position of the ball using two HD-cameras (JVC Everio GZ-GX1). A total of nine, six and three points were awarded to balls landing inside the small, middle and large target area, respectively, as displayed in Figure 1. When balls landed outside the target areas, although still in the court on the correct side (determined by a given game situation), one point was awarded. When balls landed in the wrong side of the court, outside the singles lines or in the net, zero points were awarded.

A measure of stroke quality, the velocity-accuracy-index (VA-index) was calculated by the following formula wherein velocity was expressed in km per hour (kph):

$$\text{Velocity} - \text{accuracy index} = \frac{\text{kph}^2}{100} \times \frac{(\text{sum of achieved points})}{(\text{number of strokes} \times 9}$$

Due to the nonlinear transformation of ball velocity, the higher the ball velocity, the more a given increment in ball velocity was rewarded, thus the velocity in the formula was squared (kph^2) (Vergauwen et al., 1998). The sum of achieved points was described as the amount of points given to balls landing inside the target areas, the number of strokes was defined as the number of strokes in a particular game, tactical situation or complete test.

Procedures

The study was approved by the ethical committee of the Medical Faculty of the University of Groningen (Groningen, Netherlands, November 19th, 2015) and was consistent with the ethical requirements for human experimentation in accordance with the Declaration of Helsinki.

Experimental procedures and potential risks were explained to parents/legal guardians and participants, who all signed a written informed consent form. Two observers measured the players height and sitting height to the nearest mm, and body mass to the nearest 0.1 kg. On testing days, participants performed a 10 min warm-up, including 5 min of groundstrokes. Afterwards, they were alternately tested on an indoor tennis court. In the meantime, the remaining participants conducted a training session at low intensity. During the test, participants were allowed to rest for 20 s in between the rallies and 90 s after three games, which was similar to match play (ITF Tennis). Participants were not limited to a particular stance or grip, but were requested to return balls at their own style (except the use of slice strokes) and match pace. Participants were allowed to use their own racket during the test. Before testing, they played four rallies, one of each different tactical situation (i.e. offensive, neutral and defensive) and one rally with the lights, to get accustomed to the test situation. Test-retest reliability was assessed by ten participants who performed the protocol twice within 14 days.

Statistical Analyses

IBM SPSS Statistics 23 (IBM Corp. Somers, NY) was used for the statistical analyses. Scores on the VA-index, ball velocity, accuracy and percentage errors were checked for normality by exploring normality plots and z-scores for skewness and kurtosis. If values were missing, maximum likelihood estimation was used as substitution method in the missing value analysis. In total 2.1% of the values of the velocity variable were missing. For the interrater reliability, the Cohen's kappa was used by evaluating the landing position of balls in one session by two observers. The relative and absolute reliability of the D4T were examined using an ICC and a paired t-test, respectively. ICC values were interpreted as poor if $< .40$, good if ranging between .40 and .75, and excellent if $> .75$, in accordance with the reliability level scale suggested by Fleiss (1986). Measures of agreement were determined by the standard error of measurement (SEM), smallest detectable differences (SDD) and a Bland-Altman plot (De Vet et al., 2006; Weir, 2005). The discriminant validity was evaluated by comparing the scores on the VA-index, ball velocity, accuracy and percentage errors of the elite and sub-elite players using independent t-tests. Moreover, two univariate ANOVAs were executed with the performance level as a between-subject factor and the game number (1, 2, 3, and 4) and tactical situation (offensive, neutral and defensive) as within-subject factors for the dependent variable VA-index. These ANOVAs were performed separately, as the VA-index per game number and tactical situation were distinct outcomes which were not possible to analyze together. The Bonferroni post-hoc test was performed when the main effect of the game number or tactical situation on the performance was significant. The concurrent validity was investigated by correlating the VA-index with the national ranking using the Spearman's correlation coefficient; p-values lower than 5% were considered statistically significant. Finally, the practical feasibility of the D4T was evaluated, although no fixed requirements for feasibility existed (Bowen et al., 2009). Examples of test criteria for good feasibility are such as that the duration of the test should not take too long, the test should be easy to perform by participants and the number of used materials and test leaders should be considerably small.

Results

Reliability

For the interrater reliability, the Cohen's kappa revealed an almost perfect agreement between the two observers for the evaluation of the landing position of the balls, $\varkappa = .98$ ($p < .001$). The results for the test-retest reliability of ten participants showed good relative as well as absolute reliability as presented in Table 1. Figure 3 presents the Bland-Altman plot of the test-retest reliability of the VA-index. The plot shows the difference in the VA-index between the first and the second test-session, a mean difference in the VA-index closer to 0 represents a more reliable measure.

Table 1. Reliability outcomes of the Dutch Technical-Tactical Tennis Test (D4T) in youth tennis players (n = 10)

	Mean ± SD		ICC	ICC 95% CI	Absolute reliability	Absolute reliability 95% CI	SEM	SDD
	T1	T2						
VA-index	17.92 ± 3.09	17.63 ± 4.31	.78*	.19 - .95	.29	-2.06 - 2.64	2.32	6.44
Velocity (kph)	95.91 ± 5.43	93.52 ± 5.86	.87**	.51 - .97	2.40*	.09 - 4.71	2.28	6.33
Accuracy (pts)	1.75 ± .29	1.80 ± .43	.73*	-.02 - .93	-.05	-.30 - .20	.25	.69

Note. CI: Confidence Interval; ICC: intra-class correlation coefficient (model: one-way random); SDD: smallest detectable difference; SEM: standard error of measurement; T1: measurement 1; T2: measurement 2; * p < .05; ** p < .005

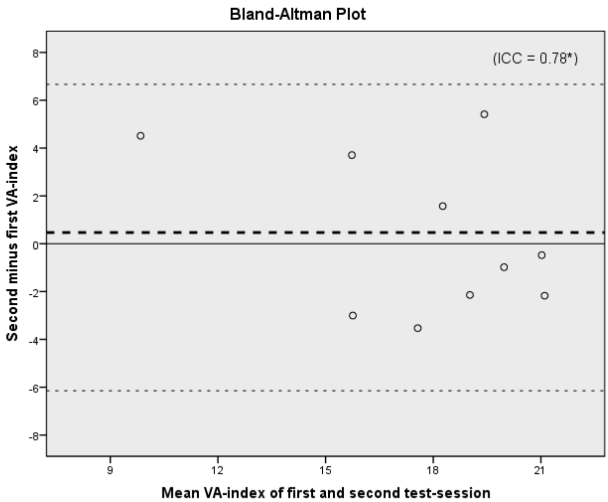

Figure 3. Bland-Altman plot for the test-retest reliability in youth tennis players (n = 10). The bold dotted line represents the difference in the mean VA-index between the first and the second test-session. The non-bold dotted lines represent the 95% limits of agreement (± 1.96 × SD). ICC: intra-class correlation coefficient (model: one-way random); * p < .05.

Discriminant validity

Tables 2 and 3 illustrate the mean scores for the VA-index, velocity, accuracy and percentage errors for the elite and sub-elite players in the D4T in total, and in the different games and tactical situations, respectively. The elite players scored significantly higher than the sub-elite ones on all variables. No differences between the games for the VA-index were found ($F(3) = .374$, $p > .05$), and also the interaction between the level of performance and the game number (Level × Game number) for the VA-index was non-significant ($p > .05$). In contrast, differences were found between tactical situations on the VA-index ($F(2) = 9.293$, $p < .001$), players in the offensive situation scored higher on the VA-index than in the defensive situation ($p < .001$), but not in the neutral situation ($p > .05$). No differences were found between the VA-index for players in the neutral and defensive situation and also the interaction between the level of performance and tactical situation (Level × Tactical) was non-significant (p > .05).

Table 2. Descriptive statistics (mean ± SD) and differences between elite and sub-elite youth tennis players in the D4T (n=32)

	Elite (n=15)	Sub-elite (n=17)	Total (n=32)	Level t-value (df)	d^b
VA-index	30.53 ± 5.44	20.86 ± 7.81	25.40 ± 8.30	4.010 (30)**	1.437
Mean velocity (kph)	106.12 ± 5.31	97.71 ± 7.48	101.65 ± 7.73	3.623 (30)**	1.297
Mean accuracy (points)	2.44 ± .40	1.92 ± .55	2.16 ± .55	3.048 (30)**	1.091
Percentage errors (%)	35.22 ± 4.06	40.78 ± 9.87	38.17 ± 8.1	-2.127 (21.822)*	.736

Note. [a]t-test (one-tailed) for all variables; [b]effect size using Cohen's d, > .2 = small, > .5 = medium, > .8 = large, > 1.3 = very large; * p < .05; ** p < .005

Concurrent validity

The validity for the relation between the VA-index and individual positions on the youth ranking list showed a highly significant Spearman's correlation coefficient of -.750 (p < .001) as displayed in Figure 4. This means that the players with a high position on the national ranking list tended to have a higher VA-index. The proportion of explained variance was .64, which means that 64% of the variance in the VA-index was explained by the ranking.

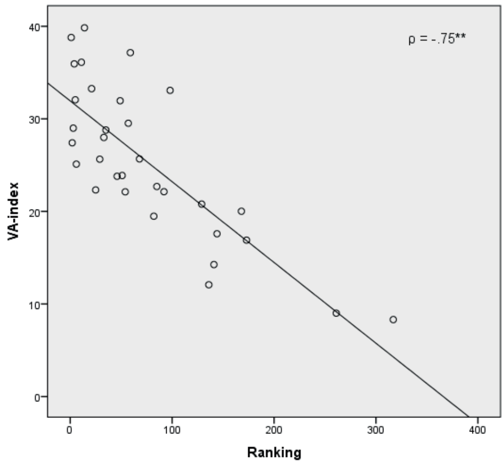

Figure 4. Representation of the relationship between the ranking and the VA-index in youth tennis players (n=32)

Table 3. Descriptive statistics (mean ± SD) and differences between elite and sub-elite youth tennis players in different games and tactical situations (n=32)

				Interaction	
	Elite (n=15)	Sub-elite (n=17)	Total (n=32)	F(df)[a]	p^b
Game situation				1.045 (3)	.375
Game 1					
VA-index	30.73 ± 7.83	22.69 ± 12.40	26.46 ± 11.12		
Mean velocity (kph)	104.66 ± 5.21	96.40 ± 8.97	100.27 ± 8.45		
Mean accuracy (points)	2.53 ± .65	2.09 ± .97	2.30 ± .85		
Percentage errors (%)	34.07 ± 9.82	36.59 ± 15.97	35.41 ± 13.30		
Game 2					
VA-index	29.38 ± 11.99	23.47 ± 10.07	26.24 ± 11.23		
Mean velocity (kph)	106.23 ± 5.30	97.65 ± 8.02	101.67 ± 8.05		
Mean accuracy (points)	2.33 ± .89	2.13 ± .67	2.22 ± .78		
Percentage errors (%)	37.78 ± 13.16	40.19 ± 13.83	39.06 ± 13.35		
Game 3					
VA-index	31.52 ± 6.31	18.17 ± 6.53	24.42 ± 9.26		
Mean velocity (kph)	107.43 ± 4.86	97.87 ± 7.39	102.35 ± 7.90		
Mean accuracy (points)	2.46 ± .47	1.71 ± .58	2.06 ± .65		
Percentage errors (%)	36.65 ± 10.45	45.09 ± 16.08	41.14 ± 14.18		
Game 4					
VA-index	30.57 ± 8.32	19.13 ± 8.04	24.49 ± 9.92		
Mean velocity (kph)	106.18 ± 6.95	98.92 ± 7.28	102.32 ± 7.92		
Mean accuracy (points)	2.44 ± .64	1.74 ± .65	2.07 ± .72		
Percentage errors (%)	32.22 ± 9.21	41.17 ± 12.60	36.98 ± 11.86		
Tactical situation				.80 (2)	.452
Offensive					
VA-index	37.88 ± 8.91	24.12 ± 10.35	29.71 ± 11.84		
Mean velocity (kph)	108.22 ± 4.40	100.88 ± 7.55	103.86 ± 7.35		
Mean accuracy (points)	2.91 ± .64	2.09 ± .71	2.42 ± .78		
Percentage errors (%)	31.42 ± 6.28	39.91 ± 10.78	36.46 ± 10.03		
Neutral					
VA-index	31.37 ± 8.36	21.99 ± 7.93	25.80 ± 9.24		
Mean velocity (kph)	106.80 ± 5.49	99.48 ± 8.37	102.45 ± 8.11		
Mean accuracy (points)	2.47 ± .61	1.95 ± .61	2.16 ± .65		
Percentage errors (%)	35.26 ± 9.43	40.35 ± 8.90	38.28 ± 9.32		
Defensive					
VA-index	26.31 ± 6.21	17.42 ± 7.21	21.03 ± 8.05		
Mean velocity (kph)	103.44 ± 6.37	95.36 ± 8.27	98.64 ± 8.46		
Mean accuracy (points)	2.21 ± .44	1.69 ± .58	1.90 ± .58		
Percentage errors (%)	38.12 ± 9.75	40.79 ± 15.25	39.71 ± 13.17		

Note. [a]ANOVA for the interaction of Level × Game number, and Level × Tactical; [b]p-value (two-tailed) < .05

Feasibility

The maximum time required to prepare the D4T was approximately 15 min and the mean time required to give clear instructions about the D4T to participants was three minutes. The instructions about the D4T were easy to comprehend. The duration of the D4T was approximately 12 min. The physical demand of the D4T was not very high. In general, the average time required to prepare and administer the D4T to a group of eight participants was three hours. The used materials in the D4T consisted of a ball machine, a radar and light system, cameras and target areas stitched on a carpet. The minimum number of test leaders required to administer the D4T was two.

Discussion

The aim of this study was to develop a reliable, valid and feasible technical-tactical test that could be used for talent identification and development in tennis. The newly developed Dutch Technical-Tactical Tennis Test (D4T) showed good test-retest reliability. Furthermore, the D4T was able to discriminate between elite and sub-elite players; moreover, a high correlation was found between individual positions on the youth ranking list and the VA-index, supporting the validity of the test. The assessment of practical feasibility indicated that the D4T was applicable for instructors and coaches.

The results for the interrater reliability showed an almost perfect agreement between two observers for the evaluation of the landing position of the balls. The target areas on the court were recorded with two cameras, thus the landing positions of the balls could be accurately noted, which is an advantage of the D4T. Furthermore, the results for the test-retest reliability indicated that the reliability of the VA-index and ball velocity were excellent, whereas the reliability of the ball accuracy was good in boys aged under 15. In the current study, test-retest reliability was assessed in the younger sub-elite players, though older elite players have a more consistent tennis performance (McPherson and Thomas, 1989; Vergauwen et al., 2004). Therefore, it is expected that even higher reliability outcomes would be obtained when test-retest reliability is assessed in older and more experienced players. Further research should examine whether the D4T is also reliable in girls and in players in other age categories.

The results revealed that elite players scored higher on the VA-index, ball velocity, accuracy and percentage errors than sub-elite players. This is in line with earlier research that found elite players making less errors and producing higher scores on ball velocity and accuracy than sub-elite players (Landlinger et al., 2012; Lyons et al., 2013; Vergauwen et al., 1998). Furthermore, a strong relationship between individual positions on the national youth ranking list and the VA-index was found. The results showed that players with a high position on the youth ranking list tended to have higher scores on the VA-index; these scores decreased gradually as players had lower positions on the youth ranking list. However, the use of the national ranking list as a measure of performance is a point of discussion. A players' position on the ranking list can be very unstable, because it is partially determined by the number of tournaments played. Since a players' position on the ranking list can be altered in a few weeks, the classification of players as elite or sub-elite can be misleading.

The occurrence of various tactical situations influenced the VA-index, which can be explained by the difference in the degree of difficulty of the projected balls. In the offensive situation, players received the easiest balls, supported by higher scores on the VA-index, compared to lower scores in the more challenging neutral and defensive situation. However, the effect of a tactical situation on performance did not differ between the levels of performance. Contrary to our expectations, the effect of a game situation on performance was non-significant. The results revealed that the performance levels did not vary significantly for the VA-index between the four games. It was expected that differences in the VA-index between performance levels would become more observable in the game with the lights considering that expert players anticipate better and make earlier decisions than novices, which is a substantial advantage for the execution of groundstrokes (Del Villar et al., 2007; McPherson and Thomas, 1989; Williams et al., 2002). However, all players included in the study had enough adequate experience in performing sport-specific actions and dealing with their opponents' actions compared to the novices measured in the aforementioned studies. An alternative explanation might be that the time delay between the ball passing the light gate and the moment of lightning of the signs was too small. In the current protocol, the delay was set at 500 ms, which was possibly sufficient for all players to make appropriate decisions and to execute groundstrokes accurately. Therefore, future research should examine whether the game with the lights is more able to discriminate between particular sports levels when varying the delay.

Concerning the design of the D4T, it was of particular interest to examine the practical feasibility of the test. In general, the average time required to prepare and administer the D4T to a group of eight participants was three hours, which is a significant advantage compared to other field tests as it can be easily incorporated in training (Rota et al., 2014; Vergauwen et al., 1998). The materials of the D4T can be reduced for practical usage by instructors and coaches. Usually, a ball machine as well as a radar system to measure ball velocity and cameras to videotape the landing points of the balls are readily available for many sports organizations, instructors and coaches. Furthermore, the carpets with the stitched target areas can be replaced by taping the dimensions of the target areas on the court. Conversely, the requirement for the light system might be more difficult to manage or replace by low-cost alternatives. As mentioned before, future research should analyze various time delays set within the light system. If it appears that the light signals with a different delay do not discriminate between different levels of performance, it should be additionally examined whether the D4T is also reliable and valid without using the light system.

Since the D4T was developed as a test for talent identification and development, it is interesting for future research to investigate whether the test is also able to discriminate between players within the top-50 in the Netherlands. Also, it should be noted that the players in the current study were classified as elite or sub-elite according to the national ranking list in the Netherlands, which cannot be considered as international elite performance level. Therefore, it would be also interesting to include international elite players in future studies using the D4T. The results of the current study revealed that the VA-index was the most distinguishing factor between performance levels, thus, future research should focus on possible differences in the VA-index between players with more homogeneous levels of performance. However, individual scores on ball velocity and accuracy are also essential to be taken into account. The speed-accuracy trade-off hypothesis states that to achieve greater accuracy, the execution time of a movement needs to increase (Fitts, 1954). Earlier research in soccer revealed that elite players were more accurate in their ball control, especially under time pressure, compared to sub-elite players (Huijgen et al., 2013). It would be interesting to further investigate whether talented players are able to maintain accuracy in their strokes when the demands (e.g. speed) of tennis are increased. Furthermore, additional research is needed to indicate if having superior scores on the VA-index during adolescence is indeed a good predictor for future performance in adulthood. However, future research should take into account that, besides technical and tactical characteristics, other factors such as anthropometry, physiology and psychology are important for championship tennis performance. Practical implications for instructors and coaches can be to implement the D4T at the beginning and at the end of a season, to monitor players' progress in a season. Differences between the second and the first test-session on the VA-index larger than the SDD of 6.44 are indicative of players' development within a season. In summary, this is the first study that developed a test to measure technical and tactical characteristics in youth tennis players. The D4T was shown to be a reliable, valid and feasible test to assess technical-tactical characteristics of youth tennis players.

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CHAPTER 4

THE VALUE OF TECHNICAL CHARACTERISTICS FOR FUTURE PERFORMANCE IN YOUTH TENNIS PLAYERS: A PROSPECTIVE STUDY

Kolman, N. S., Huijgen, B. C. H., Visscher, C., & Elferink-Gemser, M. T. (2021). The value of technical characteristics for future performance in youth tennis players: A prospective study. PLOS ONE, 16(1), e0245435.
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Abstract

The aim of this study is to examine whether technical characteristics predict current and future tennis performance of youth tennis players. Twenty-nine male youth tennis players (age 13.40 ± .51) were assessed on anthropometrical characteristics (height, weight, maturity status) and technical characteristics (ball speed, accuracy and percentage errors) using an on-court tennis test when they were under-14 (U14). Game situations were simulated, which were either fixed or variable. The variable game situations required players to consider the direction of the ball, as opposed to the fixed game situations where players needed to play every ball to the same side. Players' tennis ratings were obtained U14 ('current performance') and under-18 (U18) ('future performance'). According to their rating U18 players were classified as future elite ($n = 9$) or future competitive ($n = 20$). A multiple linear regression analysis showed that ball speed and accuracy were significant predictors of current and future performance ($p < .001$), with R2 of .595 and .463, respectively. When controlling for age, a one-way MANCOVA revealed that future elite players were more accurate than future competitive players ($p = .048$, 95% CI [.000 to .489]), especially in variable compared to fixed game situations ($p < .05$). In conclusion, the current study is the first to show that technical characteristics are crucial for current as well as future performance in youth male tennis players. Findings of this prospective study provide essential information to coaches about characteristics that require most attention in performance development in youth players.

Keywords: racket sports, predictability, technique, accuracy, speed

Introduction

Tennis performance results from the interaction of anthropometrical, physiological, psychological, tactical and technical characteristics (Elferink-Gemser et al., 2011; Elferink-Gemser et al., 2018; Kovacs, 2007). Maturation, learning and training are the driving forces for the development of these characteristics in youth players. However, the process of performance development is complex and highly varied in talented players (Gulbin et al., 2013). Assessing and monitoring youth tennis performance may help in the successful development of youth players. Knowledge of the possible predictors of current and future tennis performance will provide essential information to coaches about the characteristics that require most attention in their performance development.

Technical characteristics have been demonstrated crucial for tennis performance (for a review see Kolman et al., 2019). Ball speed and accuracy are usually considered the two most important components of technique in tennis (Landlinger et al., 2012). Professional tennis players are able to direct their strokes both forcefully and accurately to any intended location on the court. An accurate stroke that lacks a high ball speed benefits the opponent, providing this player more time to prepare. Therefore, the combination of speed and accuracy is essential for success in almost every stroke. The number of errors appears critical for tennis match outcome as well. Data analysis of professional tennis tournaments has shown that match winners make fewer unforced errors than match losers (Filipčič et al., 2005; Martínez-Gallego et al., 2013). Furthermore, research has shown that the number of errors depends on the level of performance. Higher ranked male players make fewer errors than their lower ranked counterparts (Kolman et al., 2019).

Players need to execute their technical characteristics within a tennis-specific situation. They have to adjust their stroke selection according to the tactical situation. In an offensive situation, players have more time to prepare their strokes compared to a defensive situation where they are under time pressure. In addition, technical characteristics depend on players' ability to anticipate future events. Expert players are faster and more accurate in expecting the direction of their opponents' strokes than players whose performance levels are lower (Kolman et al., 2019). Besides being in an offensive situation, outstanding anticipatory skills give players more time to prepare and position themselves. These tactical characteristics determine and limit players' technical possibilities in a given situation. The reverse is also true as players' technical characteristics control their tactical possibilities. This means that the tennis-specific situation plays an extremely important role in executing technique in tennis (Kolman et al., 2019). Still, literature on this topic is scarce.

Earlier research mainly focused on anthropometrical and physical predictors of current tennis performance, unfortunately less is known about predictors of future performance. For example, in a cross-sectional study Ulbricht and colleagues showed that national male players under-14 and under-16 were taller and heavier than their regional counterparts (Ulbricht et al., 2016). Height is an advantage in tennis, especially for the serve. Taller players can hit the ball down from a higher point, allowing them to serve at a higher speed than smaller players with the same probability of a successful serve (Fett et al., 2020; Vaverka & Cernosek, 2013). Sprint performance could also benefit from a youth players' height, because taller players are able to take longer steps (Kramer et al., 2020). Several physical characteristics, i.e. medicine ball throwing, sprint time, jump height and agility, have also been related to performance. Upper body strength and power were most closely related to tennis performance in youth players (Kramer et al., 2017; Ulbricht et al., 2016). Small to moderate correlations were found between these characteristics and ranking (r values ranging from -.17 to -.50) (Kramer et al., 2017). These results indicate that players with a stronger upper body have a better ranking. Although upper body strength explained 25% of the variance in males' performance under-13, predicting tennis performance three years later based upon this variable was not possible (Kramer et al., 2017). These results were not remarkable, because physical fitness of youth players is highly dependent on age and maturity status (Gouvea et al., 2016; Myburgh et al., 2016; Söğüt et al., 2019). Youth male tennis players advanced in maturity and age performed better in measures of upper body strength, speed and power (Myburgh et al., 2016). So, older and more mature players have a physical advantage over their relatively younger and less mature opponents. Age and maturation should therefore be taken into consideration when evaluating technical predictors of tennis performance.

The role of technical characteristics in a tennis-specific situation for performance has not been thoroughly investigated yet, especially the role of these characteristics for future performance is unknown. The aim of this prospective study is to examine whether technical characteristics in a tennis-specific situation predict tennis performance under-14 ('current performance') and under-18 ('future performance') of youth tennis players. Predicting current and future tennis performance with the use of an on-court test, while considering age and maturation, will provide crucial information about performance of youth players in a tennis-specific situation. Findings will contribute to prescribing training programs and monitoring of players' development. Evaluating crucial characteristics for future performance is necessary for the development of players, as it guides coaches to focus their youth training programs on exercises to improve these characteristics in specific game situations.

Method

Participants

Thirty-two male youth players (age 13.4 ± 0.5; body height 167.7 ± 10.6 cm; body mass 52.3 ± 10.9 kg) participated in this study. All players underwent measurements in the pre-season of 2016. Tennis ratings in April 2016 and January 2020 were obtained by using a database of the Royal Dutch Lawn Tennis Association (KNLTB) (www.mijnknltb.nl), when the players were in the age categories under-14 (U14) and under-18 (U18) respectively. In the current study tennis rating U14 is called 'current performance', while rating U18 is called 'future performance'. Three players were excluded from analyses because they stopped with competitive tennis at least one year before January 2020. These three players had similar descriptives (age, height, body mass, maturity status, starting age, tennis training, physical training, ball speed, accuracy, percentage errors and current performance) as the 29 remaining players ($P > .05$). The remaining players were classified as elite ($n = 9$) or competitive ($n = 20$), according to their rating U18. Elite players were those with a rating lower than 3 (range between 1.3 and 2.9), while competitive players were those with a rating higher than 3 (range between 3.0 and 7.8). Players with a rating of 3 or less are among the best 0.6% of all tennis players in the Netherlands. A cut-off value of 3 was chosen to ensure elite players were among the best 1.0% of all tennis players in the Netherlands. This cut-off value makes sense, because players with a rating lower than 3 often do not participate in regional tournaments, but participate in tournaments to earn ranking points in the Netherlands. Informed consent was obtained from players and their parents/legal guardians prior to the measurements after receiving oral and written descriptions of the procedures. The study was approved by the ethical committee of the Medical Faculty of the University of Groningen (Groningen, Netherlands, November 19th, 2015, reference number ECB/2015.11.11_1) and was consistent with the ethical requirements for human experimentation in accordance with the Declaration of Helsinki.

Procedures

Tennis performance

Tennis performance was indicated by players' individual rating in the Netherlands. The rating represents a player's general level of play. In the rating system, players are rated on a scale of 9 levels, ranging from 1 to 9 with 4 decimal places. A rating of 9 represents a beginner, while a 1 represents high-level players. The rating is dynamic, which means that a rating is calculated after every match. A player's current rating depends on the results he has achieved and the number of matches played. A result that is achieved in a match depends on the current singles rating of the opponent. When an opponent has a current rating that differs more than 1 point, probably the strongest player wins. If the strongest player actually wins, the result of this match does not count for the determination of the rating. Otherwise a player could receive a worse rating after a win. However, if the weakest player wins, the result does count. The dynamic rating system resembles the International Tennis Number (ITN), a rating system where players are rated on a scale of 10 levels, from ITN 1 to ITN 10.

Demographic information

Information on age, age of starting tennis and hours of practice was obtained with a short questionnaire.

4

Maturity status

Testing sessions started with the anthropometrical measurements, which included body height, body mass and sitting height. Players' body height was measured with a stadiometer and sitting height with a square stool to the nearest millimeter. Body mass was obtained with a digital balance to the nearest 0.1 kilogram. Leg length was calculated by subtracting sitting height from body height (Mirwald et al., 2002). Maturity status was calculated according to the biological age of maturity of each player as described by Mirwald and colleagues (Mirwald et al., 2002). The age at peak height velocity (APHV) is a commonly used indicator of somatic maturity representing the time of the fastest rate of growth in stature during adolescence. This means that a maturity status of -1.0 indicates the player was measured 1 year before this peak velocity; a maturity of 0 indicates that the player was measured at the time of this peak velocity; and a maturity age of +1.0 indicates that the participant was measured 1 year after this peak velocity. Although the method for determining APHV can be inaccurate for early and late maturing boys, it appears to be valid for boys who are on time in maturation and during the period of the growth spurt (Malina & Kozieł, 2013).

Dutch Technical-Tactical Tennis Test

Technical characteristics in a tennis-specific situation were assessed with the Dutch Technical-Tactical Tennis Test (D4T) (Kolman et al., 2017). The D4T simulated games, rallies and various tactical situations (offensive, neutral and defensive situations) with a ball machine (Pro Match Smartshot, Mubo, Gorinchem, the Netherlands) on an indoor tennis court (hardcourt). Before the test, players performed a warm-up of 10 minutes, including 5 minutes of hitting groundstrokes. Players were alternately tested, while the remaining players conducted a training session at low intensity. Measurements took place in the morning or afternoon (10.00 a.m. – 18.00 p.m.), depending on players' time of training. Ball speed was measured using a radar system (Ball coach pocket radar, PR1000-BC) and ball accuracy was measured using target areas as illustrated in Figure 1.

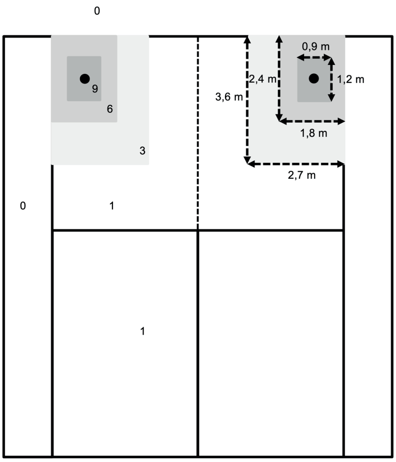

Figure 1. Dimensions of target areas to determine accuracy
This figure demonstrates the half of a tennis court including the dimensions of the target areas and the number of awarded points to balls landing in the areas (Kolman et al., 2017).

The D4T consisted of 72 strokes, grouped in four games of six rallies, in which each rally included three strokes. The various games had an increasing difficulty. In game 1 and game 2, players had to return their strokes to either the left target area (deuce side) or right target area (advantage side). In game 3 players had to alternate their strokes between the left and right target area. In game 4 players had to return their strokes to left or right target area, as indicated by a light that turned red either on the left or right side of the court (Figure 2). The lights were illustrative of the position of an (artificial) opponent. Hence, players had to return their strokes to the opposite side of the red light. The conditions in game 1 and 2 were more fixed compared to the variable conditions in game 3 and game 4 (see Box 1). During the test, players were allowed to rest for 20 seconds in between the rallies and 90 seconds after three games, which was similar to match play.

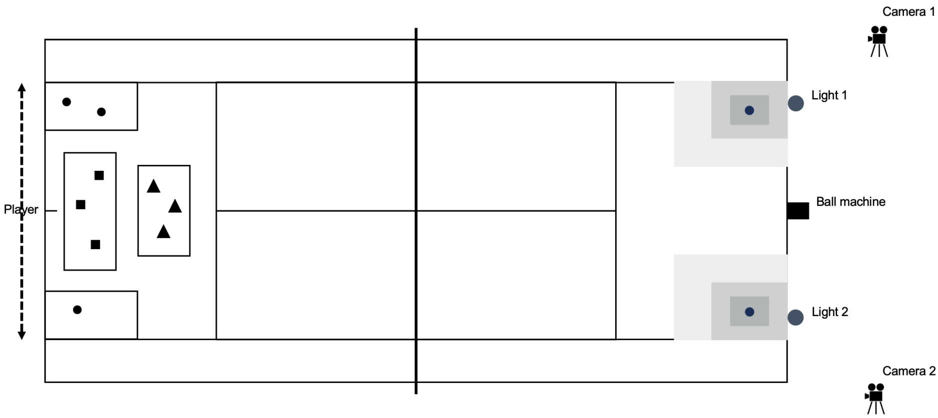

Figure 2. Illustration of the complete test design and various tactical situations
This figure demonstrates an (▲) offensive, (■) neutral and (●) defensive tactical situation. The symbols represent the three ball projections in the tactical situations (Kolman et al., 2017).

Box 1
An overview of various game situations

Game 1 (fixed)	Players have to return their strokes to the left target area (deuce side)
Game 2 (fixed)	Players have to return their strokes to the right target area (advantage side)
Game 3 (variable)	Players have to return their strokes alternately between the left and right target area
Game 4 (variable)	Players have to return their strokes to the opposite side of where the light turned red

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Outcome measures included ball speed, accuracy and percentage errors. The D4T has been revealed a reliable and valid instrument to measure technical characteristics in youth players, with an intraclass-correlation coefficient ranging from .73 to .87 and a Spearman's correlation coefficient of -.75 ($P < .001$) (Kolman et al., 2017). Detailed information on the D4T has been reported previously (Kolman et al., 2017).

Statistical analyses

SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, N.Y., USA) was used for the statistical analyses. Normality of the data was evaluated by exploring normality plots and z-scores for skewness and kurtosis. If values were missing, maximum likelihood estimation was used as substitution method in the missing value analysis. In total 2.1% of the values of the ball speed variable were missing. Relationships between rating U14, rating U18, demographic information, anthropometrical characteristics and technical characteristics were determined by a Pearson's correlation coefficient. The magnitude of correlation coefficients (r) was considered as small ($r = .10$), moderate ($r = .30$) and large ($r = .50$) (Cohen, 1988). Forward multiple regression analyses were performed using age, starting age, maturity status and technical characteristics, from which a current and future tennis performance (rating) prediction equation was derived. According to the magnitude of correlation coefficients, the magnitude of explained variance (R2) was regarded as small (R2 = .01), moderate (R2 = .09) and large (R2 = .25). Detailed analyses were performed to further unravel the importance of technical characteristics for future tennis performance. A one-way multivariate analysis of covariance (MANCOVA) was conducted with rating U18 as grouping factor (elite versus competitive) and accuracy in various games as dependent variables, whilst controlling for age which was considered a covariate. Assumptions for regression analysis and one-way MANCOVA were met. An alpha-level of .05 was used for all significance tests.

Results

Table 1 shows the descriptive statistics of youth male players at the time of measurements (U14) across future performance level (U18).

Table 1. Descriptive statistics of youth male players U14 across performance level U18 (n = 29)

	Elite (n = 9)	Competitive (n = 20)	Total (n = 29)
Age (y)	13.67 ± .45	13.27 ± .51	13.40 ± .51
Height (cm)	175.56 ± 12.28*	165.86 ± 7.53	168.87 ± 10.12
Body mass (kg)	60.90 ± 14.47**	49.74 ± 6.98	53.20 ± 10.98
Maturity status (y)	.55 ± 1.03**	-.44 ± .57	-.14 ± .86
Starting age (y)	4.67 ± 1.32*	5.90 ± 1.29	5.52 ± 1.40
Tennis training (hrs/wk)	10.67 ± 2.65	8.65 ± 3.15	9.28 ± 3.10
Physical training (hrs/wk)	3.44 ± 1.24	2.59 ± 1.19	2.85 ± 1.25
Ball speed (km/h)	104.27 ± 5.08	101.37 ± 7.54	102.27 ± 6.92
Accuracy (pt)	2.59 ± .32**	2.05 ± .52	2.22 ± .52
Percentage errors	34.17 ± 4.84	39.38 ± 9.20	37.76 ± 8.38
Rating U14	4.59 ± .54**	6.47 ± .93	5.88 ± 1.20
Rating U18	2.01 ± .61 **	4.33 ± 1.26	3.61 ± 1.54

Note. Data are expressed as mean ± standard deviation; * P < 0.05, **P < 0.01 significantly different from competitive players.

Relationship among variables

Table 2 presents the correlation coefficients between rating U14, rating U18, (starting) age, height, weight, maturity status and technical characteristics. The values for age, height, weight and technical characteristics represent the values at the initial assessment U14. Results indicated a large positive relationship between rating U14 and rating U18 (r = .91, p < .001). A lower value for rating means a better performance. An inverse relationship was found between rating U14 and other variables such as age, maturity status, ball speed and accuracy (r-values ranging between -.51 and -.65, all p < .001). There was a large positive correlation between rating U14 and percentage errors (r = .51, p < .001). No significant relationship was found between starting age and rating U14 (r = .305, p > .05). Correlations between rating U18 were identical to the variables related to rating U14. These variables were also statistically significant and in the same direction with r-values ranging between -.39 and -.59 (p < .001, p < .05).

Prediction of current and future tennis performance

A multiple linear regression analysis was calculated to predict rating U14 based on age, starting age, maturity status, ball speed, accuracy and percentage errors. A significant regression equation was found for rating U14 (F (2, 26) = 19.085, p < .001), with an R2 of .595. Only ball speed and accuracy were statistically significant, with accuracy recording a higher unstandardized beta value (B = -1.038, p = .003, 95% CI [-1.683 to -.393]) than ball speed (B = -.082, p = .002, 95% CI [-.131 to -.033]). Players' predicted rating U14 (current tennis performance) is equal to 16.575 – 1.038

(accuracy) - .082 (ball speed), where accuracy is measured in points and ball speed is measured in $km \cdot h^{-1}$.

A second multiple regression analysis was calculated to predict rating U18 based on the same predictors used for the regression analysis of rating U14. A significant regression equation was found for rating U18 ($F (2, 26) = 11.213$, $p < .001$), with an R^2 of .463. Ball speed and accuracy were again statistically significant, with accuracy recording a higher unstandardized beta value ($B = -1.095$, $p = .025$, 95% CI [-2.045 to -.145]) than ball speed ($B = -.098$, $p = .009$, 95% CI [-.170 to -.026]). Players' predicted rating U18 (future tennis performance) is equal to 16.070 – 1.095 (accuracy) - .098 (ball speed), where accuracy is measured in points and ball speed is measured in $km \cdot h^{-1}$.

Accuracy in game situations

Figure 3 shows the accuracy in every game for future elite and competitive players separately. A one-way MANCOVA was conducted to compare accuracy in various games between future elite and competitive players, whilst controlling for age. There was a statistically significant difference between players' rating U18 on the combined dependent variables after controlling for age, $F (4, 23) = 2.832$, $p = .048$; Wilk's $\Lambda = .670$, partial $\eta^2 = .330$, 95% CI [.000 to .489]. Follow-up analysis showed that future elite players were significantly more accurate than future competitive players in game 3 ($p = .038$) and game 4 ($p = .035$), but there were no differences between performance levels in game 1 ($p = .606$) and game 2 ($p = .328$) (Figure 3).

4

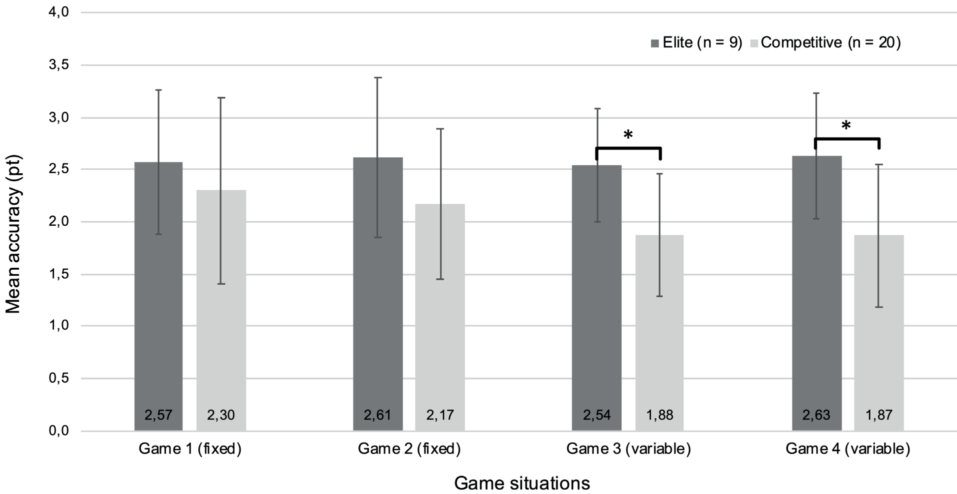

Figure 3. Accuracy in game situations for future elite and competitive players separately
This figure demonstrates the mean accuracy in fixed and variable game situations (errors bars represent standard deviations of the mean). For a detailed overview of various game situations see Box 1; * $p < 0.05$ in accuracy between future elite and competitive players.

Table 2. Correlations between rating U14, rating U18, anthropometrical characteristics (U14) and technical characteristics (U14) (n = 29)

	Rating U14	Rating U18	Age	Starting age	Height	Weight	Maturity status	Ball speed	Accuracy	Percentage Errors
Rating U14	1									
Rating U18	.905**	1								
Age	-.516**	-.388*	1							
Starting age	.305	.303	-.135	1						
Height	-.502**	-.430*	.439*	-.055	1					
Weight	-.537**	-.447*	.339	-.100	.926**	1				
Maturity status	-.629**	-.540**	.563**	-.138	.934**	.932**	1			
Ball speed	-.651**	-.589**	.345	-.078	.474**	.513**	.555**	1		
Accuracy	-.639**	-.548**	.442*	-.286	.285	.353	.414*	.401*	1	
Percentage errors	.505**	.458*	-.343	.320	-.232	-.242	-.353	-.234	-.708**	1

Note. * $P < 0.05$; ** $P < 0.01$.

Discussion

To examine whether technical characteristics predict current (U14) and future tennis performance (U18), male youth tennis players were assessed in a tennis-specific situation. A strong relationship was found between various technical characteristics (i.e. ball speed, accuracy and percentage errors) and current as well as future tennis performance. Ball speed and accuracy were found to significantly predict current performance and future performance. Together these predictors accounted for 60% of the variance in current performance and 46% in future performance. These large proportions of explained variance demonstrate that technical characteristics in a tennis-specific situation are extremely important for youth tennis performance.

Anthropometrical characteristics, maturity status and age were associated with performance level. This means that players with a superior rating were taller, heavier, more mature and older. These results deviate from those previously reported with a sample of male players under-12, where no relationship was shown between performance level (ranking) and height, weight, maturity status and age (Söğüt et al., 2019). These players were on average 2.5 years before their APHV, so physical differences between players were probably smaller and less decisive than in the current sample where players were around their APHV. Therefore, the results of the current study were not surprising, because in adolescence biological older players have a physical advantage over smaller and less mature opponents (Malina et al., 2015). This was also evident from the higher ball speed that biological older players produced in the current study. However, anthropometrical characteristics, maturity status and age were not able to significantly predict current performance nor future performance. These variables do not seem sensitive enough to predict success in tennis or other racket sports (Faber et al., 2016). Considering the significant role of maturation for youth tennis performance (Ulbricht et al., 2016), predicting future performance based upon these variables seems to be extremely difficult. Current performance may be a sound predictor of future performance, given the strong relationship between current and future performance in the current study (r = .91). However, it provides little insight into the characteristics required for an outstanding tennis performance. In addition, it gives limited information about the components that coaches should focus on to improve performance. It appears therefore crucial to unravel performance characteristics, such as technical characteristics, to prescribe training programs.

Technical characteristics, i.e. ball speed and accuracy, were found to predict current performance U14, which means that youth players who produce fast and accurate balls have a better rating. These results were not remarkable, because hard-hitting players have an advantage over their less hard-hitting opponents, given that an increased ball speed reduces the time for an opponent to return the ball successfully. Similar results have been reported in highly skilled tennis players (Landlinger et al., 2012). Professional players outperformed high-performing youth players for ball speed; however, both groups seem to be able to coordinate various body segments successively, resulting in an efficient groundstroke technique to produce high ball speeds (Landlinger et al., 2010; Landlinger et al., 2012]. In addition to a higher ball speed, players with a higher performance level demonstrated a higher accuracy in their strokes. The results are in line with earlier research in talented soccer players (Huijgen et al., 2013). To be in control during a match, the combination of ball speed and accuracy is of great importance. According to the speed-accuracy trade-off hypothesis, an increase in the execution time of a movement is required to achieve greater accuracy (Fitts, 1954). In the study on talented soccer players, elite players demonstrated greater accuracy in their ball control, especially under time pressure, compared to sub-elite players (Huijgen et al., 2013).

Technical characteristics in a tennis-specific situation also appear extremely important for future performance U18, as indicated by the strong relationship between the various technical characteristics and future tennis performance. It was found that ball speed and accuracy predict future performance of youth tennis players. These results are in line with earlier research in a range of sports, such as field hockey (Elferink-Gemser et al., 2007) soccer (Huijgen et al., 2014) and handball (Lidor et al., 2005). These studies emphasize the predictive value of technical characteristics for future sports performance. A recent systematic review also demonstrated the great capability of sport-specific technical characteristics assessments to predict future performance (Koopmann et al., 2020). Especially in an early-entry sport as tennis, sport-specific technical characteristics seem to be crucial for future performance given the specific competences to be developed from an early age. Tennis-specific technical characteristics appear to better predict future performance compared to other indicators, such as isolated physical and anthropometrical characteristics that were not found to be significant predictors of future tennis performance (Kramer et al., 2017).

Future elite players were significantly more accurate than future competitive players. In-depth analysis revealed that elite players outperformed competitive players in the variable game situations, but not in the fixed game situations. Elite players were able to maintain their accuracy throughout the game situations, while competitive players became less accurate during the variable game situations. This might be due to the tennis-specificity and increased difficulty of the variable game situations compared to the fixed game situations. The variable game situations required players to consider the direction of the ball, as opposed to the fixed game situations where players needed to play every ball to the same side. In the final (variable) game, players had to look at the other side of the net to see which side the light turned red in order to play the ball to the opposite side. To capture appropriate information, i.e. the side where the light turned red, efficient visual search behaviors were required. These behaviors have been shown crucial for elite tennis players, for example to see an opponents' actions or the direction of oncoming (Kolman et al., 2019). Executive functions might also have played a role in the current study, given the variable game situations and the information players had to remember where to play the ball (i.e. working memory was required). Elite tennis players might have superior information processing speed, which could have provided them more time to execute their technique properly with the increased demands of the game situations (Ishihara et al., 2017).

Despite the fascinating findings of this study, some limitations need to be acknowledged. First, it should be recognized that the D4T measures technical characteristics of groundstrokes in offensive, neutral and defensive rallies, but that it does not capture technique in all game situations. Tennis includes more crucial strokes for performance, like the serve, return and volley strokes. Although the technical characteristics of groundstrokes are crucial for performance, it must be considered that other game characteristics also determine match outcome. Second, it should be acknowledged that predicting future performance U18 is not indicative of becoming a future professional tennis player. Players' development occurs in a non-linear, unpredictable manner, making it increasingly difficult to predict performance in the distant future (e.g. Abbott et al., 2005;

Gulbin et al., 2013; Phillips et al., 2010). However, gaining knowledge about performance in the near future provides insight into which characteristics require attention in the development of talented players. Third, the results of this study cannot be generalized to other populations without caution. Accordingly, it remains unknown whether the same results apply for female players and other age categories. Fourth, the current study had a relatively small sample size. Although a small number of participants is common in research in high-level competitive sports, caution should be taken in generalizing the findings to professional tennis players. Final, the choice of the Dutch rating system as an indication of tennis performance makes it difficult to compare the findings with other research. However, the Dutch rating system has several advantages compared to the often-used ranking positions. In the dynamic system the rating changes after any match, regardless of whether the match has been played in a tournament or competition. This allow players to better track their progress. Furthermore, the rating system is age neutral and rates all players on the same scale. That makes it easier to compare players of different age categories.

Several practical implications for coaches may be derived from this study. The decisive role of ball speed and accuracy for future performance suggest coaches to focus their youth training programs on exercises to improve these characteristics in variable game situations. For tennis players early in childhood, it seems important to first focus on accuracy. Coordination that is required for accuracy is best developed at a young age (Hirtz & Starosta, 2002). Although coordinative abilities are also required for high ball speed, coaches should focus on this component later in adolescence, because the development of strength (which is important for ball speed) is dependent on the maturity status of players (Gouvea et al., 2016). When players have developed a sufficient degree of accuracy, coaches could focus on gradually increasing the speed of players' balls. These technical characteristics should be developed in a tennis-specific situation to simulate the context of the match. For future studies it would be interesting to examine whether accuracy in more challenging tennis-specific situations could even better predict future performance, since the distinguishing factor in future performance level is related to accuracy in variable game situations. Technical characteristics accounted for almost half of the variance in future performance; however, a proportion of the variance is still unexplained. Future research should focus on the evaluation of other crucial characteristics including longitudinal assessments to further unravel tennis performance.

In conclusion, the current study was the first to show that technical characteristics in a tennis-specific situation, i.e. ball speed and accuracy, significantly predict current performance U14 as well as future performance U18 in youth male players. Future elite players were more accurate than future competitive players, especially within variable game situations. These findings indicate the relevance of technical characteristics in a sport-specific situation for future performance. By recognizing the importance of ball speed and accuracy in youth players, researchers, coaches and practitioners become more aware of components that require attention in the development of youth tennis players. Knowledge of these predictors contribute to prescribing training programs and monitoring of players' development.

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CHAPTER 5

TECHNICAL SKILLS IN COMPLEX TENNIS SITUATIONS: DUTCH TALENTED PLAYERS U15 COMPARED TO PLAYERS U17

Kolman, N. S., Huijgen, B. C., Visscher, C., & Elferink-Gemser, M. T. Technical skills in complex tennis situations: Dutch talented players U15 compared to players U17. *Frontiers in Sports and Active Living, 5, 57.* https://doi.org/10.3389/fspor.2023.1107740

Abstract

Technical skills in complex situations appear crucial for progress towards elite tennis performance. However, it is unknown how these skills develop in different age categories in a group of talented youth players. The aim of this study is to evaluate possible differences in technical skills among Dutch talented youth tennis players U15 compared to U17. A total of 19 players (12 males, 7 females; age 14.6 ± 1.4 years) were tested on ball speed, accuracy, percentage errors and spin rate using the on-court Dutch Technical-Tactical Tennis Test. With a ball machine, four games were simulated which were either fixed (game 1 and game 2) or variable (game 3 and game 4), depending on the complexity of the task. Each game consisted of two offensive, two neutral and two defensive rallies, representing different tactical situations. A two-way ANOVA revealed a statistically significant interaction between the effects of age category and sex for ball speed ($F(1,15) = 5.472$, $p = 0.034$, $\eta2 = 0.267$), indicating that males U17 produced higher ball speed compared to males U15, whereas no differences were found between females U15 and U17. A one-way ANCOVA showed that, regardless of sex, players U17 scored significantly higher on accuracy than players U15 ($F(1,16) = 5.021$, $p = 0.040$, $\eta2 = 0.239$). No differences were found between players U15 and U17 for spin rate and percentage errors ($p > .05$), although there was a medium to large effect size for males U17 to produce higher spin rates compared to males U15. A closer examination of accuracy revealed that players U17 scored significantly higher compared to players U15 in game 4 ($F(1,17) = 6.358$, $p = .022$, $\eta2 = .272$) and in defensive situations ($F(1,17) = 9.602$, $p = .007$, $\eta2 = .361$). In conclusion, the results of the current study suggest that technical skills, especially ball speed for males and accuracy in complex situations for both males and females, continue to develop in adolescence in talented tennis players. There is an increased understanding about underlying technical skills that contribute to progress towards elite tennis performance. To effectively develop technical skills, coaches are encouraged to design specific practices where these skills are performed in complex situations under high cognitive and temporal pressure.

Keywords: technique, racket sports, expertise, cognition, precision, performance

Introduction

Many structured talent development programs have been developed for sports, including tennis (Crespo & McInerney, 2006; Ribeiro et al., 2021). National tennis associations provide specialized training programs with the aim of developing and perfecting tennis performance. Offering the best facilities, training and guidance is thus a priority for associations in order to develop talented players optimally. Unfortunately, our understanding of talent development processes is rather limited and it is difficult to provide specific recommendations for tennis associations (Till & Baker, 2020). A thorough understanding of tennis-specific skills during a player's adolescence is required to facilitate the development of talents performing at a level where details make the difference.

Outstanding technical skills are considered essential for performance in sports. Most of the studies in a recent systematic review found that technical skills discriminate between performance levels, explain past performance or predict future performance (Koopmann et al., 2020). Studies on tennis-specific technical skills underline that players at a higher performance level outscore players at a lower performance level on measures such as ball speed, percentage errors and accuracy (Kolman et al., 2019). An increased ball speed reduces the time for an opponent to return the ball successfully (González-González et al., 2018; Landlinger et al., 2012). The amount of errors seems particularly important for reaching professional level, as the error rate is lower among professional players compared to elite youth players (Kovalchik & Reid, 2017). To be in control in a match, players should also hit their strokes with sufficient accuracy as hitting the ball to a specific location on the court allows them to keep the ball far enough from their opponents to produce a winner or cause the opponent to make an error (Lyons et al., 2013). Spin rate, however, may be equally important, because the amount of spin imparted to the ball affects its ball trajectory. This is useful to overcome constraints of the game (i.e. net and court boundaries) or for a tactical advantage (Cant et al., 2020).

The relevance of technical skills for youth tennis performance was confirmed by a recent prospective study showing that ball speed and accuracy measured under 14 years (U14) were significant predictors of tennis performance at the same time and four years later (Kolman et al., 2021). Technical skills were assessed with the Dutch Technical-Tactical Tennis Test (D4T), a reliable and valid on-court test (Kolman et al., 2017). Games were simulated which were either fixed or variable. In the fixed situations, players needed to direct their strokes to predetermined target areas, whereas in the variable situations the players were required to consider the direction of their strokes (e.g. respond to an imaginary opponent). Variable situations were considered more complex compared to fixed situations, due to the presumed higher cognitive load. More in depth-analyses of this prospective study revealed that the ability to maintain accuracy in variable situations, not in fixed situations, was considered essential to reach the elite level under 18 years (U18). In other words, players who reached the elite level U18 were more accurate in variable situations in their younger years (i.e. U14) compared to lower performing players U18. However, how these technical skills develop during adolescence, especially from the age of 12 to 16 years, and what important technical changes take place during this period remains open to debate. Adolescence is regarded as a key developmental phase in the course of talented players' careers. Development occurs in combination with physical change, including puberty, the pubertal growth spurt, and accompanying maturational changes (Malina et al., 2015). By exploring the technical skills of talented players in different age categories, we may acquire a better understanding of underlying technical skills that contribute to progress towards elite tennis performance. Knowledge about the important technical changes during adolescence may be of value for the adaptation of talent development programs.

From a constraints-led perspective, technical performance emerges from the interaction between the person (e.g. anthropometry, physical skills), the environment (e.g. court surface, type of competition) and the task at hand (e.g. complexity, intensity) (Newell, 1986; Renshaw et al., 2019). Through systematically manipulating constraints it is possible to construct and mimic a tennis-specific situation. With the D4T, task constraints are manipulated by changes in the complexity of the task. From the literature it is apparent that if the complexity of the task increases, there is a decrease in technical performance in a range of sports including ice hockey, rugby and soccer (Fait et al., 2011; Gabbett & Abernethy, 2012; Huijgen et al., 2013). By means of simulating fixed and variable situations, the D4T allows tennis players to experience technical demands in situations of different complexity. Another way to adjust the complexity in the D4T is by changes in time constraints. The impact of time constraints on tennis performance is reflected by simulating offensive, neutral and defensive situations in the D4T. Players need to make quick and accurate decisions in order to perform accurately under high time pressure (García-González et al., 2014). In a defensive situation, there is less time for anticipating the direction of an opponents' stroke and keeping the accuracy of strokes high compared to an offensive situation where players are in control of the rally (Crognier & Féry, 2005). The speed-accuracy tradeoff is highlighted in a group of youth tennis players with less accuracy in defensive compared to offensive situations (Kolman et al., 2017). Given that technical skills are always executed in a particular context, we must consider the tennis-specific context when examining the technical skills in a group of talented youth players.

Technical skills in complex situations appear crucial for progress towards elite tennis performance, however, it is unknown how these skills develop in different age categories in a group of talented youth players. Therefore, our aim of this study is to evaluate possible differences in technical skills of Dutch talented youth tennis players under 15 (U15) compared to under 17 years (U17). We hypothesized that (a) players U17 have superior technical skills compared to players U15 and (b) differences between players U17 and U15 are most pronounced in complex situations (i.e. variable and defensive situations).

Method

Ethical approval

Ethical approval for this research protocol (PSY-1819-S-0262) was obtained from the Psychology Department of the University of Groningen (Groningen, Netherlands, September 19th, 2019). We obtained advanced written informed consent or assent from all players and advanced written informed consent from parents or legal guardians of all players under 16 years of age (the legal age for giving consent in the Netherlands).

Participants

Nineteen youth players between 12 and 17 years old (12 males, 7 females; age 14.6 $\pm$ 1.4 years) participated in this study. All participants were within the national high-performance program of the Royal Dutch Lawn Tennis Association (KNLTB). According to their year of birth, males were ranked between position 2 and 14 on the national ranking list of the KNLTB, while females were ranked between position 1 and 5. Table 1 shows the age, anthropometric characteristics, tennis history, tennis practice and additional physical practice for players U15 and U17 and males and females separately.

Table 1. Descriptive statistics (mean ± SD) of talented youth tennis players (n=19)

	U15			U17		
	Male (n=7)	Female (n=4)	Total (n=11)	Total (n=8)	Male (n=5)	Female (n=3)
Age (yrs)	13.7 ± 0.7	13.2 ± 0.5	13.5 ± 0.6	16.0 ± 0.5	16.1 ± 0.6	15.7 ± 0.2
Height (cm)	168.2 ± 12.9	166.5 ± 5.8	167.6 ± 10.5	176.3 ± 5.8	177.7 ± 3.5	174.1 ± 9.1
Weight (kg)	52.1 ± 11.8	51.1 ± 5.1	51.7 ± 9.6	67.4 ± 6.2	69.2 ± 5.4	64.3 ± 7.4
Maturity offset (yrs)	-0.2 ± 1.4	1.4 ± 0.6	0.4 ± 1.4	2.3 ± 0.7	2.0 ± 0.4	2.7 ± 1.0
Age starting tennis (yrs)	6.4 ± 1.8	5.5 ± 0.6	6.0 ± 1.5	4.3 ± 1.5	4.3 ± 1.7	5.7 ± 1.2
Tennis experience (yrs)	7.4 ± 1.5	7.7 ± 1.0	7.5 ± 1.3	11.8 ± 1.6	12.1 ± 1.9	11.3 ± 1.4
Tennis practice (hrs/week)	11.8 ± 2.5	10.9 ± 1.5	11.5 ± 2.2	14.5 ± 2.4	14.5 ± 2.4	14.5 ± 3.0
Physical practice (hrs/week)	3.8 ± 1.1	4.5 ± 0.5	4.0 ± 1.0	5.3 ± 1.0	5.1 ± 0.9	5.7 ± 1.2

Measures

Anthropometry

Anthropometric data were obtained, which included body height, sitting height and body mass. Players' body height and sitting height were measured with a SECA height tape instrument to the nearest 0.1 cm (SECA, model 206, Seca Instruments, Ltd., Hamburg, Germany). Players were standing with bare feet against the wall (or were sitting on a bench for sitting height) and were asked to take a deep breath and to hold it. Body mass was measured to the nearest 0.1 kg (UWE, model ATM B150, Universal Weight Enterprise Co., Ltd., Taiwan). Leg length was calculated by subtracting sitting height from body height. Maturity status was estimated by the non-invasive method of calculating the age at peak height velocity using sex-specific predictive equations (Mirwald et al., 2002).

Technical skills

Ball speed, accuracy, percentage errors and spin rate were measured with the Dutch Technical-Tactical Tennis Test (D4T), a reliable and valid instrument to measure technical skills in youth players (Kolman et al., 2017). The D4T requires players to hit 72 balls, grouped in four games of six rallies, in which each rally includes three strokes fed by a ball machine. Each game consists of two offensive, two neutral and two defensive rallies, representing different tactical situations as displayed in Figure 1. The difficulty of the ball projections was slightly increased compared to the original D4T, making it more suitable for a group of talented youth players. Offensive rallies consist of three ball projections just beyond the service line. Neutral rallies comprise of three ball projections to the area around the middle of the court a half to one meter before the baseline, and defensive rallies includes three ball projections to the sideline and beyond the service line. The different tactical situations occurred in random order in each game.

The various games have increasing complexity. In the first and second game, players have to return their strokes to the left target area (deuce side) and right target area (advantage side), respectively (Figure 1). In the third game, players have to alternate their strokes between the left and right target area. For example, if players direct their strokes to the left-right-left target area in the first rally, they should aim their strokes to the right-left-right target area in the second rally. In the fourth game, players have to return their strokes to the left or right target area, as indicated by a simulated opponent (research assistant) who moves either 1,5 meters to the left or right side of the court. Hence, players have to return their strokes to the opposite side of the side where the opponent is moving to. This is a modification from the original D4T where the target area in the fourth game was determined by lights which turned red either on the left or right side of the court. The simulated opponent was used instead of lights to increase the ecological validity of the D4T. The conditions in the first and second game were more fixed compared to the variable and complex conditions in the third and fourth game. During the test, players were allowed to rest for 15 seconds in between the rallies and 90 seconds after three games, which was similar to match play. More detailed information on the D4T has been reported previously (Kolman et al., 2017).

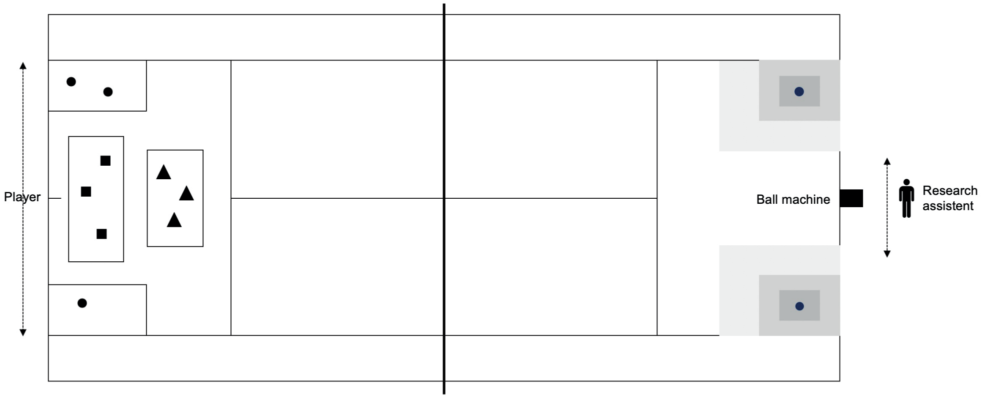

Figure 1. Illustration of the D4T with various tactical situations.
This figure shows the test situation of the D4T with various tactical situations. The symbols represent the three ball projections in an offensive (▲), neutral (■) and defensive (●) tactical situation.

Technical skills were recorded with PlaySight SmartCourt, a system for video-review and analytics and equipped with 10 on-court cameras. This system allows for the valid registration of ball speed, ball placement, spin rate and the registration of session video material (Playsight, 2015). For accuracy, a total of nine, six and three points were awarded to balls landing inside the small, middle and large target area, respectively (Figure 1). One point was awarded to balls landing outside the target areas, but still in the court on the correct side (determined by the given game situation). Balls landing in the wrong side of the court, outside the singles lines or in the net, were awarded with zero points. Percentage errors was calculated as the number of faults divided by the total number of strokes multiplied by hundred.

Procedures

All measurements took place at the National Training Center of the KNLTB in Amstelveen in the Netherlands. Measurements took place on a hard-court indoor tennis court with PlaySight SmartCourt system for video-review and analytics using 10 on-court cameras. Before the D4T, players performed a warm-up of 10 minutes, including 5 minutes of hitting groundstrokes. Players were alternately tested with the remaining players conducting a training session at low to medium intensity. Measurements took place in the morning or afternoon (10.00 a.m.– 18.00 p.m.), depending on players' time of training. Participants were fed with moderately used tennis balls (Dunlop Fort Max TP) by a manually programmed ball machine (Promatch SmartShot Xtra, Mubo, Gorinchem). Participants used their own tennis racket during the test protocol. Before the measurements, a research assistant was trained to move 1,5 meters to either the left or right side of the court just after the ball was fed by the ball machine. The research assistant moved according to a predetermined program, with half of the movement being to the left and right, respectively.

Data analysis

For the statistical analyses, we used SPSS Statistics for Mac, version 28 (IBM Corp., Armonk, N.Y.). For all significance tests, we used an α-level of .05. We screened the data to ensure variables met the assumptions necessary for the use of parametric statistics before data analysis. We performed a one-way ANCOVA with age category as grouping factor (U15 versus U17) for each technical skill separately (i.e. ball speed, accuracy, percentage errors and spin rate), whilst controlling for sex which we considered a covariate. When heterogeneity of regression slopes was found, we performed a two-way ANOVA to analyze the effect of age category and sex on the relevant technical skill. We considered an effect size of $\eta 2 = 0.01$ as small, $\eta 2 = 0.06$ as medium and $\eta 2 = 0.14$ as large (Cohen, 1988). In the case of a significant covariate and for the technical skills that were statistically different between players U15 and U17, we performed additional analyses. We conducted one-way ANOVAs to further unravel differences between age categories for the relevant technical skills in complex situations. First, we assessed differences between players U15 and U17 for the relevant technical skill in fixed and variable game situations. Second, we measured differences between players U15 and U17 for the relevant technical skill in different tactical situations.

Results

Table 2 illustrates the mean scores of technical skills for players U15 and U17 and males and females separately. A one-way ANCOVA revealed a significant interaction between age category and the covariate sex for ball speed, indicating that the assumption of homogeneity of regression slopes was violated. Therefore, a two-way ANOVA was performed to analyze the effect of age category and sex on ball speed. There was a statistically significant interaction between the effects of age category and sex ($F(1,15) = 5.472$, $p = 0.034$, $\eta 2 = 0.267$). Simple main effects analyses showed no statistically significant effect of age category on ball speed (($F(1,15) = 2.128$, $p = 0.165$, $\eta 2 = 0.124$), while there was a statistically significant effect of sex on ball speed (($F(1,15) = 8.568$, $p = 0.010$, $\eta 2 = 0.364$). Males U17 produced higher ball speed compared to males U15 ($F(1,10) = 11.017$, $p = .008$, $\eta 2 = .524$), while no differences were found between females U15 and U17 ($F(1,5) = .250$, $p = .638$, $\eta 2 = .048$).

A one-way ANCOVA revealed a significant main effect of age category on accuracy after controlling for sex ($F(1,16) = 5.021$, $p = 0.040$, $\eta 2 = 0.239$). No differences were found between players U15 and U17 for spin rate ($F(1,16) = 1.221$, $p = 0.286$, $\eta 2 = 0.071$) and percentage errors ($F(1,16) = 1.2711$, $p = 0.885$, $\eta 2 = 0.001$), although sex was found a significant covariate for spin rate ($F(1,16) = 5.861$, $p = .028$, $\eta 2 = .268$). No differences were found between females U15 and U17 ($F(1,5) = .004$, $p = .952$, $\eta 2 = .001$) and males U15 and U17 ($F(1,10) = 1.363$, $p = .270$, $\eta 2 =$

.120) for spin rate, although the medium to large effect size for males indicates that males U17 produced higher spin rates than males U15.

Table 2. Descriptive statistics of technical skills (mean ± SD) and differences between talented tennis players U15 and U17

	U15			U17		
	Male (n=7)	Female (n=4)	Total (n=11)	Total (n=8)	Male (n=5)	Female (n=3)
Ball speed (kmh)	95.7 ± 7.2*	93.8 ± 5.7	95.0 ± 6.5	101.3 ± 10.0	107.4 ± 3.6*	91.1 ± 8.8
Accuracy (pts)	2.5 ± 0.5	2.5 ± 0.5	2.5 ± 0.5*	2.9 ± 0.3*	2.9 ± 0.3	2.9 ± 0.3
Errors (%)	27.8 ± 10.0	26.4 ± 6.5	27.3 ± 8.5	26.8 ± 5.5	26.5 ± 4.1	27.3 ± 8.4
Spin rate (rpm)	840.7 ± 243.9	659.6 ± 105.9	774.8 ± 217.7	884.6 ± 287.7	1015.9 ± 273.9	665.9 ± 157.3

Note. *$p < .05$ significantly different between players U15 and U17

Accuracy in tennis-specific situations

Based on the significant difference between age categories for accuracy, we performed additional analyses for accuracy in complex situations. Figure 2 and figure 3 show the accuracy for players U15 and U17 in fixed and variable game situations and different tactical situations, respectively. A significant difference was found between players U15 and U17 on accuracy in game 4 ($F(1,17) = 6.358$, $p = .022$, $\eta 2 = .272$) and accuracy in defensive situations ($F(1,17) = 9.602$, $p = .007$, $\eta 2 = .361$).

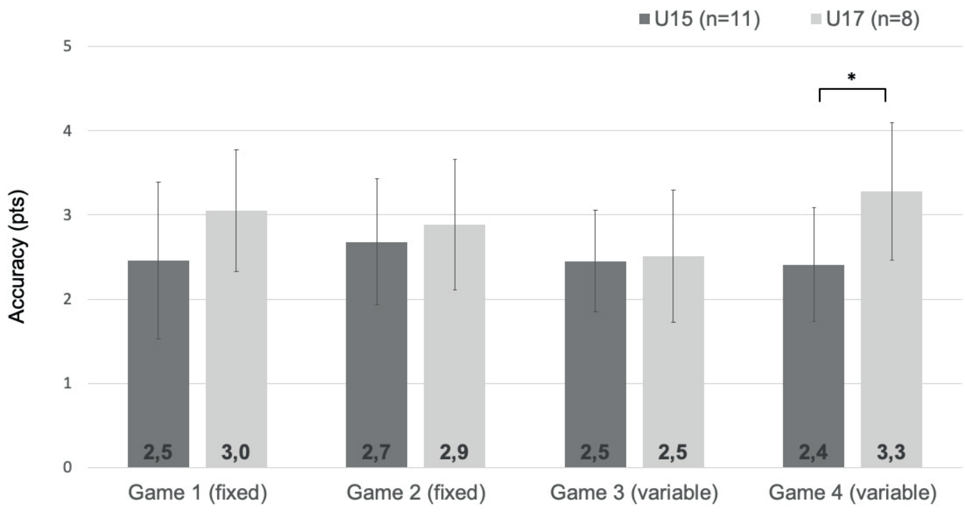

Figure 2. Accuracy in fixed and variable games for players U15 and U17.
This figure shows the mean accuracy in various game situations (errors bars represent standard deviations of the mean); * $p < 0.05$ significant difference between players U15 and U17 for accuracy.

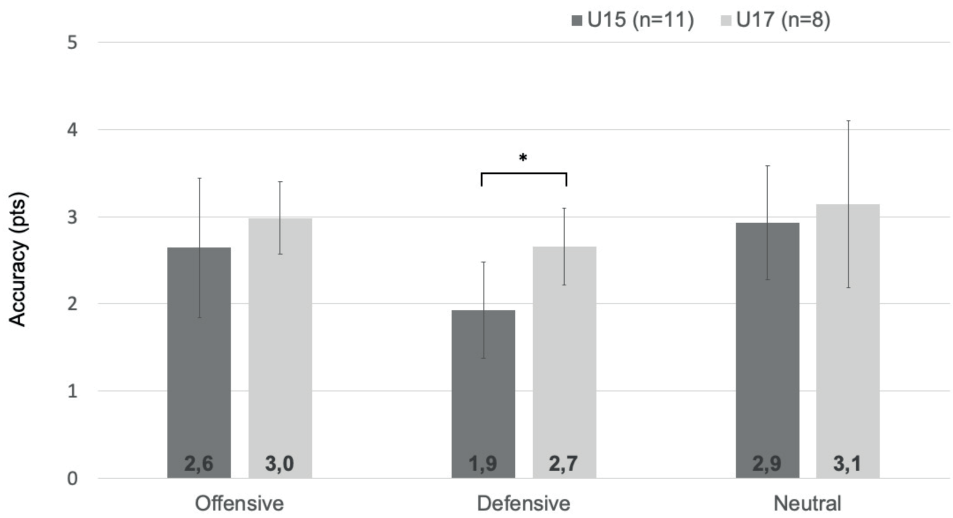

Figure 3. Accuracy in tactical situations for players U15 and U17.
This figure shows the mean accuracy in tactical situations (errors bars represent standard deviations of the mean); * $p < 0.05$ significant difference between players U15 and U17 for accuracy.

Discussion

To evaluate possible differences in technical skills among talented tennis players in different age categories, players of the Dutch national high-performance program U15 and U17 were compared on different technical skills. Males U17 produced higher ball speed compared to males U15, while no differences were found between females U15 and U17. A difference was found between age categories for accuracy for both male and female players, with players U17 being more accurate than players U15. A closer examination of accuracy demonstrates that players U17 scored higher in complex situations than players U15, given the higher accuracy in the variable game 4 and in defensive situations. These findings were in line with our hypotheses and suggest that technical skills, especially ball speed for males and accuracy in complex situations for both males and females, continue to develop in adolescence in a group of youth talented tennis players.

According to the constraints-led approach, changing task constraints requires an adaptation of the current motor behavior. By differences in task complexity, players were forced to deal with various situations in order to maintain or improve the accuracy of their strokes. In line with earlier research, our findings reveal that under increased task complexity (i.e. high temporal and cognitive pressure), the older and more experienced players were better able to maintain their accuracy than their younger and less experienced counterparts (Kal et al., 2018). Tennis players are confronted with situations in which motor and cognitive tasks have to be executed simultaneously (Amico & Schaefer, 2022; Schaefer, 2014). For example, players need to anticipate the next ball, recall strategies and play the ball with adequate speed and accuracy while being aware of their opponents' strengths and weaknesses. Usually, performance decreases under increased task complexity. Unlike the fixed situations of the D4T, the variable situations required players to consider the direction of their next ball, possibly increasing the demands on attention and working memory (Abernethy et al., 2007; Buszard et al., 2017). This is also apparent from the results of a previous study with the

D4T in which future elite players (mean age 13.7 ± 0.5 years) were able to maintain their accuracy throughout the game situations, while competitive players (mean age 13.3 ± 0.5 years) became less accurate during the variable, more complex situations (Kolman et al., 2021). Both players U15 and U17 were able to maintain their accuracy throughout the game situations, possibly due to their higher performance level compared to the competitive players in the previous study. Where players U17 were more accurate in game 4 than players U15, no differences between these age categories were found in game 3. An explanation for these findings might be related to the less pronounced task complexity in game 3 compared to game 4 where players needed to look at the other side of the net to see which side the simulated opponent moved in order to play the ball to the opposite side. The accuracy of players U17 even seemed to benefit from the increased task complexity in game 4 as indicated by the slightly higher accuracy compared to the others game situations. Due to more years of tennis experience, players U17 might have developed a higher degree of automatization, resulting in a greater resistance to skill decrement under more complex situations than players U15 (Kal et al., 2018; Schaefer & Scornaienchi, 2020). While it is uncommon for players, especially novices, to perform more accurately in variable than in fixed situations, previous research has shown increased performance in complex situations in experienced hockey players (Jackson et al., 2006). One possibility is that the diversion of attention to another task (e.g. focusing on the simulated opponent) attenuates disruptive conscious processing of movements that can occur in fixed situations.

In contrast to players U17, players U15 were unable to maintain their accuracy under high temporal demands, imposed by ball projections to the sidelines of the court in the defensive situations. The decrease in accuracy in players U15 suggests that the task complexity in the defensive situation might have been too high, causing them to play less accurately due to the greater information processing load (Poolton et al., 2006). In neutral and offensive situations, the task complexity is relatively low, remaining substantial attentional capacity for additional tasks (e.g. focusing on the next ball projection). However, as the temporal pressure increases, greater attention is required to be devoted to maintain stroke accuracy, resulting in reduced processing capacity for anticipating the next ball in the defensive situation. Another explanation for players U17 to be more accurate in defensive situations than players U15 might be related to differences in anthropometry and physical skills such as sprint speed (Kramer, Valente-Dos-Santos, et al., 2016; Kramer et al., 2021) and agility (Kramer, Huijgen, et al., 2016). During adolescence, there is an increase in height and players develop more strength and power (Malina et al., 2015). In the present study, players U17 were taller, heavier and more mature than players U15. Individual differences in growth and maturation, and associated increases in running speed and agility, could translate into an advantage for older youth players in defensive situations.

There was an interaction effect between age category and sex for ball speed, indicating that males U17 produced higher ball speed compared to males U15, while no differences were found between females U15 and U17. These findings were not surprising, given that the maturational time course of males and females is quite different (Malina et al., 2015). On average, females mature earlier than males. Several studies have shown a relationship between ball speed in groundstrokes and anthropometric factors such as height, weight and maturity status (González-González et al., 2018; Kolman et al., 2021; Landlinger et al., 2012). In the present study, females U15 have already experienced their growth spurt as opposed to males U15. During the pubertal transition from early through mid-adolescence, males become taller, heavier and stronger, increasing the differences between males U17 and males U15 on outcomes related to anthropometry and physical skills, such as ball speed. This may also apply to spin rate, given the significant main effect of sex and the medium effect size of age category. Males generated more spin than females, and the medium to large effect size for males indicates that males U17 produced higher spin rates compared to males U15. The effect of anthropometry and physical skills on spin rate merits further investigation, but earlier research studying the mechanics of spin rate also mention the impact angle and racket speed as factors affecting spin rate (Choppin et al., 2011).

There are a few strengths and weaknesses to consider. The design of the D4T provides interesting insights for tennis performance, however it is not completely representative of tennis performance demands. Players were forced to direct their strokes to a specific side of the court, depending on the fixed or variable game situation. The location of the ball projections has impacted the direction of players' stroke, which was either more cross-court or down the line. Changing the ball angle of a ball projected to the side line, by attempting to play it down the line, possibly increases the amount of lateral errors (Brody, 2006). In actual tennis competition, players are free to decide the direction of their strokes, which may result in a different amount of errors than during the D4T. Another weakness related to the lack of representativeness is the use of a ball machine, where players cannot use relevant kinematic information from the opponent (e.g. distal cues from arm and racket) to anticipate the direction of strokes (Cañal-Bruland et al., 2011; Huys et al., 2009). Returning strokes from a ball machine could result in different swing timing and movement coordination, limiting the generalization of the results (Carboch et al., 2014). However, the use of a ball machine allows for the reliable and valid comparison of technical skills between age categories due to the standardized test design. Another strength of this study was the use of a homogeneous group of talented players, with all participants playing at the highest level in their age category in the Netherlands. Understanding the underlying technical skills of this sample can help optimize talent development programs. Future studies should examine how technical skills measured with the D4T, particularly accuracy in complex situations, relate to on-court tennis performance under high temporal and cognitive pressure. The association of on-court test performance with match activities is considered a feasible approach for evaluating ecological validity (Castagna et al., 2019).

The present cross-sectional study provides insight into the technical differences between players U15 and U17, increasing the understanding of underlying technical skills that contribute to progress towards elite tennis performance. However, the actual process of technical development is unknown and it is unclear whether players U15 improve their skills, and specifically accuracy in complex situations, to the current level of players U17 in two years. Differences between these age categories may still exist due to the earlier age of starting tennis, more years of tennis experience and higher amount of training hours for players U17. In future studies, a longitudinal study design is advised to determine the actual process of technical development over time in a group of talented tennis players.

In conclusion, the results of the current study suggest that technical skills, especially ball speed for males and accuracy in complex situations for both males and females, continue to develop in adolescence from U15 to U17 in a group of youth talented tennis players. This study increases the understanding of underlying technical skills that contribute to progress towards elite tennis performance. To effectively develop technical skills, coaches are encouraged to design specific practices where these skills are performed in situations under high cognitive and temporal pressure.

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CHAPTER 6

SELF-ASSESSED TACTICAL SKILLS IN TENNIS PLAYERS: PSYCHOMETRIC EVALUATION OF THE TACTICAL SKILLS QUESTIONNAIRE IN TENNIS

Kolman, N. S., Huijgen, B. C. H., van Heuvelen, M. J. G., Visscher, C., & Elferink-Gemser, M. T. (2022). Self-assessed tactical skills in tennis players: Psychometric evaluation of the Tactical Skills Questionnaire in Tennis. Frontiers in Sports and Active Living, 4. https://doi.org/10.3389/fspor.2022.988595

Abstract

To our knowledge, no feasible, valid and reliable instrument exists to examine tactical skills over the course of multiple training and game situations in tennis yet. Therefore, the aim of this study was to develop and evaluate the psychometric properties of the Tactical Skills Questionnaire in Tennis (TSQT). The TSQT is a new instrument with closed-ended questions designed to examine tactical skills in tennis players. Participants were 233 competitive tennis players (age: 17.06 ± 4.74 years) competing on national or regional levels. With a principal component analysis (PCA) we identified four theoretically meaningful subscales for the 31-item TSQT: 'Anticipation and positioning', 'Game intelligence and adaptability', 'Decision-making' and 'Recognizing game situations' and confirmed them with a confirmatory factor analysis (CFA) ($\chi^2 = 527.02$, df = 426, p < .001, CFI = .93, RMSEA = .045, SRMR = .079). Internal consistency was good, with Cronbach's alpha of .89 for the entire scale and McDonald's omega ranging from .69-.78 for the separate subscales. A subsample of 57 players completed the TSQT twice to assess test-retest reliability. Absolute test-retest reliability of the subscales was good with no significant differences in mean scores between test and retest ($p > .05$). Relative test-retest reliability was moderate with ICC values ranging from .65 to .71. National players outperformed regional players on the subscales 'Game intelligence and adaptability', 'Decision-making' and 'Recognizing game situations' ($p < .05$), and there was a trend toward significance for 'Anticipation and positioning' ($p = .07$). This study supported the psychometric properties of the TSQT. Evaluating tactical skills with the TSQT provides players, coaches and other professionals with insight in players' self-assessed tactical skills over the course of multiple training and game situations. It creates the opportunity for players to reflect on their skills and detect personal development areas with their coach. We advise to use this information as input for tailor-made training programs.

Keywords: racket sports, tennis, Tactical Skills Questionnaire in Tennis (TSQT), principal component analysis, talent development, performance

Introduction

Outstanding tactical skills are requisite for elite performance in many sports (Elferink-Gemser et al., 2011; Elferink-Gemser et al., 2018; Lees, 2003; Smith, 2003). At the highest performance level in dynamic open-ended sports like tennis, players must often make quick and accurate tactical decisions (García-González et al., 2014). In temporally constrained situations, they must detect and use contextual and kinematic information to anticipate the opponent's intentions. Specific sources of contextual information, including shot sequence and the position of the players on the court, facilitate player anticipation (Murphy et al., 2018). Some have suggested that these contextual sources include the minimal required information needed for successful anticipation, and that the later emergence of kinematic information from the opponent's actions around ball-racket contact may be confirmatory (Murphy et al., 2019; Williams & Jackson, 2019). In other words, as postural cues from the opponent become available, the number of options for responding appropriately may decrease to permit the emergence of an option with high success likelihood. Elite tennis players have been found to be better at detecting and using contextual and kinematic information than less skilled players, resulting in their superior anticipation and decision-making skills compared to players with lower performance levels (Kolman et al., 2019). For example, they have a greater ability to put pressure on their opponents by choosing responses that are more likely to compromise the opponent's actions (e.g., force the opponent to move or play to their weaker side) (Del Villar et al., 2007). Players' positions on the court are crucial, as an optimal position enhances court coverage and enables an effective response to the opponent's most likely stroke direction. Not surprisingly, game intelligence has been considered essential for tennis performance, and it is often defined as the ability to 'read the game' and act accordingly (Lennartsson et al., 2015). As all these tactical skills (e.g., anticipation, decision-making, positioning, and game intelligence) must be well developed to meet the game's competitive demands, monitoring them is important to assist player development. This is particularly relevant for talented youth players aiming to reach the elite level. Still, no instrument is available to assess these skills over the course of multiple tennis training and game situations.

A feasible instrument to gather information on players' tactical skills is the Tactical Skills Inventory for Sports (Elferink-Gemser et al., 2004). This self-report questionnaire measures invasive game player's accumulated know-how on their tactical skills over a prolonged period of time, independent of their shape of the day or their opponent. It contains scales for declarative knowledge describing 'knowing what to do' and procedural knowledge relating to 'doing it'. Research in field hockey players revealed that elite players scored higher than amateur players on both self-assessed declarative and procedural knowledge (Elferink-Gemser et al., 2010). However, within a group of elite players the selection of an appropriate action within the context of the game, i.e. procedural knowledge, seems to differentiate more between performance levels than knowledge of the rules and goals of the game, i.e. declarative knowledge. This finding is confirmed in a study with soccer players, however, less is known regarding the game of tennis. For studying tactical skills, it is important to consider both the 'quality' and 'quantity' of players' tactical skills. Quality is inferred from the players' excellence in the demonstrated tactical skills and quantity refers to how often players display their tactical skills. Both factors may determine match outcome. For instance, the performance depends on players' ability to make the right decision about the next stroke. Thus, the *quality* of this action affects match performance. In addition, players who make the right decision about their next stroke more often will ultimately outperform players who occasionally make the right decision. This means that the outcome of a match also hinges on the *quantity* of a players' ability to make the right decision at the right time.

To our knowledge, no feasible, valid and reliable instrument exists to examine procedural knowledge (e.g. decision-making, anticipation, positioning, game intelligence) over the course of multiple training and game situations in tennis yet. Such instrument provides players, coaches and other professionals with insight in players' self-assessed tactical skills. It creates the opportunity for players to reflect on their skills and together with the coach to detect personal development areas. As such, it can provide relevant input for the content of training programs. Considering the relevance of assessing these skills in tennis, the aim of this study is to develop and evaluate the psychometric properties of the Tactical Skills Questionnaire in Tennis (TSQT) with a sample of competitive tennis players. Specifically, the purpose is to assess its content validity, construct validity, internal consistency, test-retest reliability and discriminative validity.

Materials and methods

We conducted this study in seven phases: (a) questionnaire design and construction, (b) exploration of the readability and comprehension of questionnaire items, (c) identification of components with principal component analysis (PCA), (d) verification of the component model with confirmatory factor analysis (CFA), (e) examination of internal consistency, (f) evaluation of test-retest reliability and (g) assessment of discriminative validity. We used the COSMIN Study Design Checklist for Patient-Reported Outcome Measurement Instruments for reporting on these procedures (Mokkink et al., 2019).

Ethical Considerations

We obtained ethical approval for this research protocol from the Psychology Department of the University of Groningen (Groningen, the Netherlands, September 19th, 2019), and we obtained advanced written informed consent or assent from all players and advanced written informed consent from parents or legal guardians of all players under 16 years of age (the legal age for giving consent in the Netherlands).

Participants

The study's inclusion criteria required participants to be healthy volunteers, between 10-35 years of age, who had both competitive tennis experience and sufficient proficiency in speaking, reading and writing Dutch to take this questionnaire. We recruited participants from different tennis clubs in the Netherlands and the Royal Dutch Lawn Tennis Association (KNLTB). Our total participant sample included 233 competitive tennis players (160 males, 73 females; *M* age = 17.06, *SD* = 4.74 years). The average number of training hours per week (including both tennis training and strength and conditioning training) ranged between 0-3 hours per week for 26.7% of the sample. For 18.1% of the sample, the average training per week was at least 3 hours. For 19,4%, 17.2% and 18.5% of the sample, the average training per week was at least 6, 9 and 12 hours, respectively.

Development of the Tactical Skills Questionnaire in Tennis (TSQT)

The aim of the first two phases of this research was to ensure acceptable content validity of the TSQT. In other words, we first sought to confirm that the questionnaire adequately covered all relevant tactical skills to be measured (Trakman et al., 2017). Following advice from Artino et al. (2014), we began with a literature review that helped to operationalize the construct of tactical skills and determined whether other similar measures of tactical skills in tennis already existed (Artino et al., 2014). Finding no evidence of any similar instrument we designed the TSQT by using the TACSIS as an example model, reformulating various TACSIS items to be tennis-specific. For example, we changed an item of the TACSIS '*My positioning during a match is generally*' into '*My position on the court is*'. We adapted another item from the TACSIS '*My anticipation (thinking about proceeding actions) is*' to '*In looking ahead (thinking about my next stroke), I am*'. Next, we relied on a group of four scientists with extensive experience in research on tactical skills in sports to formulate new items for the domains of anticipation, positioning, decision-making and game intelligence. A distinction was made between the quality and quantity of these skills. The quality of tactical skills was inferred from the players' self-assessed excellence in the demonstrated tactical skills and the quantity of tactical skills was inferred from the players' self-assessed frequency of displaying the tactical skills.

In the next step we discussed the new items with an expert panel consisting of an embedded scientist, a performance manager and two highly experienced international tennis coaches of the Royal Dutch Lawn Tennis Association (KNLTB). The expert panel offered suggestions for improving the questionnaire, including adding items to assess the ability to read game situations before acting and performing. We then formulated or reformulated items to meet this need (e.g., '*I quickly see when my opponent changes the direction of the ball*'). The expert panel also indicated a need to distinguish between tactical skills when a player has a lot of response time (offensive situation), enough time (neutral situation) or not enough time (defensive situation). Again, we formulated and reformulated items to address this domain in different situations (e.g., '*In making the right decisions when my opponent is under pressure, I am:*' was developed for a situation in which players have a lot of time, the item '*In a cross rally I choose the right moment to open down the line*' was developed for a neutral situation in which players have enough time, and '*My position when I am under pressure from my opponent is:*' was developed for a defensive situation in which players do not have enough time).

In the second phase we examined the readability and comprehension of each item. We piloted a preliminary version of the questionnaire for 13 youth tennis players aged 12-14 years to check the understanding of items within the youngest age groups who would be completing the questionnaire. Players completed the questionnaire individually during tennis practice and were allowed to give comments and suggestions. We confirmed that these young participants understood all items, except two, and we reformulated these two items. Thus, the first and second phase of test development resulted in an initial 38-item TSQT, with content validity supported by the results of the literature review, expert item evaluation and pilot testing. We developed the questionnaire in Dutch and then translated it into English according to the back-translation procedure whereby one researcher with a proficiency in both languages translated the items from Dutch to English and these English items were translated back to Dutch by another bilingual translator. We compared the new translations with the original items and made several minor linguistic modifications to maintain the intended item meanings. The final questionnaire can be found in Supplementary File 1.

TSQT Structure

The TSQT consisted of 38 items on a 5-point Likert scale. We chose an uneven-point scale with a neutral middle option to avoid forcing respondents to answer positively or negatively. To minimize response bias, we placed negative options on the left side of the scale and positive options on the right side of the scale (DeCastellarnau, 2018). As such, the questionnaire provided two semi-negative choices: ‘almost never’ and ‘sometimes’ relating to questions about the quantity of skills and ‘very mediocre’ and ‘mediocre’ relating to questions about the quality of skills. There was one neutral option (‘regularly’ or ‘reasonable’) and two semi-positive choices (‘often’ and ‘almost always’ or ‘good’ and ‘very good’). To improve the reliability, we labelled all options (DeCastellarnau, 2018). The questionnaire ended with some demographic questions about the respondent’s age, gender, tennis level and training hours.

Procedures

We administered the questionnaire to our 233 participants at different tennis clubs and the Royal Dutch Lawn Tennis Association (KNLTB) in the Netherlands. Participants completed the questionnaire individually with a researcher present. A subsample (n = 57) completed the questionnaire twice within two to four weeks. The time interval between test and retest was considered long enough to reduce the chance of participants recalling their first answers, and short enough to reduce the chance for a true change of the construct to occur (Paiva et al., 2014).

Statistical Analysis

For most statistical analyses, we used the Statistical Package for the Social Sciences for Windows (SPSS, version 26; IBM Corp., Armonk, N.Y., USA). For the confirmatory factor analysis (CFA), we used LISREL for Windows, version 8.80 (Jöreskog K, Sörbon D. 2006; Scientific Software International). For all significance tests, we used an α-level of .05. We checked normality of the data distribution for items by exploring normality plots and z-scores for skewness and kurtosis. The percentage of missing values across the 38 items varied between 0 and 2.6%. We imputed missing values with regression estimates obtained by predicting missing values with a regression of observed scores on other items. After stratification on age, gender and tennis level, we randomly allocated subjects to the group for PCA (n = 117) and CFA (n = 116).

Principal Component Analysis

In the third phase, we assessed the adequacy of sampling by Kaiser Meyer Olkin (KMO). We interpreted the KMO using the guidelines of Hutcheson and Sofroniou (1999) (.40 = minimum; .50-.70 = mediocre; .70-.80 = good; .80-.90 = great; >.90 superb). To determine if correlations between items were sufficiently large to perform a PCA, we used Bartlett's Test of Sphericity. We performed a PCA to examine the component structure of the 38-item questionnaire (i.e. the construct validity). Construct validity refers to whether the items of a questionnaire represent the underlying conceptual structure (Rattray & Jones, 2007). Due to conceptual considerations, we extracted four components in the analysis. We used an oblique rotation, because all items were intended to measure the same concept and components were assumed to correlate. We deleted items with low communalities (<.30) and/or items with low component loadings on each component (<.30). A low communality suggests that the item has little in common with the other items and a low component loading means that the component has a weak association with the principal component score.

Confirmatory Factor Analysis

In the fourth phase, we used a CFA to verify the four-component model identified by the PCA. We estimated the relationships between the four components and between each item and the corresponding component. We also estimated the explained variance and error variance for each item. We judged the adequacy of model fit by the following fit statistics: comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root-mean square residual (SRMR). For the CFI, we considered values of ≥.90 as acceptable and values of ≥.95 as good (Bentler, 1990; Hu & Bentler, 1999). For the RMSEA, we interpreted values of ≤.06 as good (Hu & Bentler, 1999). For the SRMR, we considered values of ≤.08 as acceptable and values of ≤.06 as good (Bentler, 1995; Browne & Cudeck, 1992; Hu & Bentler, 1999). We also examined the chi-square value; however, the statistic is highly sensitive to sample size (Boateng et al., 2018). We used modification indices and theoretical arguments to to improve the model fit.

Internal consistency

In the fifth phase, we calculated mean item scores for each subscale of the TSQT. To assess the internal consistency of the TSQT, we determined the average inter-item correlation and McDonald's omega for each subscale and Cronbach's alpha for the total scale. In contrast to the commonly reported Cronbach's alpha, McDonald's omega makes fewer and more realistic assumptions and problems associated with inflation and attenuation of internal consistency estimations are far less likely (Dunn et al., 2014). We considered an average inter-item correlation between .15-.50 as good (Clark & Watson, 2016). In agreement with the guidelines of Nunnally (1978) for Cronbach's alpha, we considered McDonald's omega of ≥ 0.7 as acceptable (Nunnally). To determine the relationships between subscales, we calculated Pearson's correlation coefficients based on mean item scores. We interpreted the strength of the relationship as weak (.10-.30), moderate (.30-.50) or strong (>.50) (Statistics, 2020).

Test-retest reliability

In the sixth phase, we assessed test-retest reliability with a subsample of 57 tennis players (34 males, 23 females; age: 18.78 ± 4.60 years). The size of the subsample corresponds with the recommended sample size of at least 50 participants for test-retest reliability (Atkinson & Nevill, 2000; Hopkins, 2000). We determined the absolute and relative reliability of the TSQT. Absolute reliability refers to the degree to which repeated measurements vary for individuals. Relative reliability refers to the ability of individuals to maintain their rank in a sample with repeated measurements (Bruton et al., 2000). To estimate the absolute test-retest reliability of the TSQT, we calculated mean differences between test and retest, with 95% confidence intervals. We assessed the relative test-retest reliability by intraclass correlation coefficients (ICC) with 95% confidence intervals based on single ratings, consistency and two-way mixed-effects model. We interpreted the ICC values using the guidelines of Koo and Li (2016) (<0.5 = poor; 0.5-0.75 = moderate; 0.75-0.90 = good; >0.90 = excellent) (Koo & Li, 2016).

Discriminative validity

In the last phase, we evaluated discriminative validity within a sample of 218 players since the competitive level of 15 players was unknown. Players were classified as national or regional according to their competitive level of performance. National players competed nationally (usually throughout the Netherlands) or internationally (usually in other countries), while regional players usually competed in their own region in the Netherlands. The sample consisted of 88 national players (54 males, 34 females; age: 15.61 ± 4.35 years) and 130 regional players (97 males, 33 females; age: 18.07 ± 4.70 years). We assessed the discriminative validity by a one-way multivariate analysis of covariance (MANCOVA) with performance level as between-subjects factor (national versus regional) and four subscales as dependent variables, whilst controlling for age and sex as covariates. We hypothesized that national players would outperform regional tennis players on the different subscales of the TSQT.

Results

Principal Component Analysis

The KMO measure of sampling adequacy was .82, which was considered great, and Bartlett's test of sphericity was significant ($\chi2$ (703) = 1790.28, p < .001) indicating that there was a certain redundancy between the items that could be summarized with a few components. The initial PCA yielded a four-component model that explained 42.1% of the variance. Six items with communalities of less than .30 and one item with a pattern coefficient of less than .30 were removed from the questionnaire for subsequent analysis. A second PCA was performed on the retained 31 items. Items and pattern loadings are presented in Table 1. In total, the four components accounted for 47.0% of the variance (27.6%, 7.4%, 6.5 and 5.5%, respectively, before rotation). The components were labelled 'Anticipation and positioning' (Component 1, 10 items), 'Game intelligence and adaptability' (Component 2, 6 items), 'Decision-making' (Component 3, 8 items) and 'Recognizing game situations' (Component 4, 7 items).

Confirmatory Factor Analysis

The initial CFA indicated acceptable model fit for the 31-item, four-component model identified by EFA (χ^2 = 569.94, df = 428, p < .001, CFI = .91, RMSEA = .054, SRMR = .083). Modification indices suggested to add a path from the item 'My game intelligence is..' to 'Game intelligence and adaptability' to improve model fit. The item corresponds with the content of the component; therefore, this path was added. After that, the non-significant loading of the item to 'Anticipation and positioning' was deleted. Furthermore, modification indices suggested to add covariances between error terms. Therefore, the covariance between three pairs of error terms was added. The final CFA resulted in an acceptable to good model fit (χ^2 = 527.02, df = 426, p < .001, CFI = .93, RMSEA = .045, SRMR = .079).

Table 1. Items and pattern loadings of the TSQT

	1	2	3	4
Quantity of tactical skills (1 = almost never and 5 = almost always)				
1. I use the weak spot of my opponent		**.542**		.325
2. I quickly see where my opponent is serving to	**.692**			
3. When I am under pressure from my opponent, I make the right decisions		.359	**.614**	
4. In a cross rally I choose the right moment to open down the line			**.613**	
5. Before my opponent hits the ball, I move towards the right spot	**.622**			
6. I choose the right moment to change the direction of the ball			**.309**	.405
7. When my opponent serves, I quickly move to the right spot	**.449**			.306
8. When I want to disrupt my opponent, I change the (top) spin of my balls		**.507**	.421	
9. I quickly see where my opponent is standing with my service				**.755**
10. I incorporate the experiences of earlier points in my decisions		**.400**		.468
11. When I want to disrupt my opponent, I change the height of my balls		**.744**		
12. Before my opponent hits a drop shot, I move forward	**.656**			
13. When I notice that my tactical plan is not working, I quickly adjust my game		**.316**	.344	
14. I quickly see when my opponent changes the direction of the ball	.420			**.423**
15. When I am in an attacking position, I see where the open space is				**.738**
16. When I'm at the net, I quickly see where my opponent is hitting the ball				**.398**
Quality of tactical skills (1 = very mediocre and 5 = very good)				
17. The decisions I make about my next stroke are generally:			**.652**	
18. In moving to the spot where my opponent serves, I am:	**.350**			
19. In making the right decisions at the right time, I am:			**.680**	
20. My choice from various options to score a point is generally:			**.568**	
21. In varying my strokes at the right time, I am:			**.654**	
22. In being at the right spot at the right time, I am:	**.720**			
23. My game intelligence is:	**.421**		.327	
24. In making the right decisions when my opponent is under pressure, I am:				**.407**
25. My position on the court is:	**.516**			
26. In determining the depth of an incoming ball, I am:	**.597**			
27. My position when I am under pressure from my opponent is:	**.499**			
28. In recognizing game situations, I am:	.382	**.407**		
29. In quickly recognizing my opponent's weak spot, I am:		.467		**.547**
30. My position when I put pressure on my opponent is:				**.613**
31. In responding to a defensive ball of my opponent, I am:			**.592**	

Note. Extraction method: Principal component analysis; Rotation Method: Oblimin with Kaiser Normalization.
Pattern loadings less than .30 are not displayed, pattern loadings on the allocated component for the CFA are presented in bold.
Component 1 (Anticipation and positioning) = items 2, 5, 7, 12, 18, 22, 23, 25, 26, 27
Component 2 (Game intelligence and adaptability) = items 1, 8, 10, 11, 13, 28
Component 3 (Decision-making) = items 3, 4, 6, 17, 19, 20, 21, 31
Component 4 (Recognizing game situations) = items 9, 14, 15, 16, 24, 29, 30

Internal Consistency

Descriptive statistics and internal consistency of the four subscales are displayed in Table 2. Overall, the TSQT was found to be highly reliable (α = .89).

Table 2. Descriptive statistics, McDonald's omega and average inter-item correlation coefficients of subscales of the TSQT (n = 233)

	M	SD	McDonald's omega	Inter-item correlation
Anticipation and positioning (9 items)	3.47	.54	.78	.29
Game intelligence and adaptability (7 items)	3.55	.57	.69	.25
Decision-making (8 items)	3.46	.51	.77	.30
Recognizing game situations (7 items)	3.68	.55	.73	.29

The relationship between subscales is shown in Table 3. The largest positive correlation was found between the subscales 'Decision-making and 'Recognizing game situations (r = .62).

Table 3. Pearson correlations between subscales of the TSQT

	Anticipation and positioning	Game intelligence and adaptability	Decision-making	Recognizing game situations
Anticipation and positioning	1			
Game intelligence and adaptability	.51*	1		
Decision-making	.48*	.51*	1	
Recognizing game situations	.55*	.50*	.62*	1

Note. *p < .01

Test-Retest Reliability

Descriptive statistics of the absolute and relative reliability of the TSQT are shown in Table 4. A value of 0 was within the 95% confidence interval of the mean differences between test (T1) and retest (T2), supporting the absolute reliability of the TSQT. Moderate relative reliability was observed for the subscales 'Anticipation and positioning' (ICC = .66), 'Game intelligence and adaptability' (ICC = .65), 'Decision-making' (ICC = .71) and 'Recognizing game situations (ICC = .69).

Table 4. Test-retest reliability for each subscale of the TSQT (n = 57)

	M ± SD T1	M ± SD T2	M ± SD T1 – T2	SE T1 – T2	95% CI T1 – T2	ICC	95% CI ICC
Anticipation and positioning	3.42 ± .52	3.49 ± .51	-.06 ± .43	.06	-.180-.050	.658	.483-.783
Game intelligence and adaptability	3.52 ± .54	3.51 ± .58	.02 ± .48	.06	-.112-.143	.652	.473-.780
Decision-making	3.33 ± .48	3.38 ± .49	-.09 ± .37	.05	-.185-.012	.703	.544-.814
Recognizing game situations	3.60 ± .60	3.51 ± .60	.11 ± .47	.06	-.014-.238	.685	.519-.802

Note. M ± SD of T1 – T2 = mean difference between the score for the first and second measurement; SE of T1 – T2 = standard error of the mean difference; 95% CI T1 – T2 = 95% confidence interval for the mean difference; ICC = intraclass correlation coefficient; 95% CI for ICC = 95% confidence interval for intraclass correlation coefficient.

Discriminative Validity

Table 5 shows descriptive statistics of national and regional players for each subscale. One-way MANCOVA showed a difference between national and regional players on the combined dependent variables after controlling for age and sex, F (4, 211) = 5.245, $p < .001$; Wilk's $\Lambda = .910$, partial $\eta^2 = .090$. Follow-up analyses showed that national players scored higher than regional players on the subscales 'Game intelligence and adaptability' ($p < .001$), 'Decision-making' (p <

.001) and 'Recognizing game situations' ($p < .01$), and there was a trend toward significance for 'Anticipation and positioning' ($p = .07$).

Table 5. Descriptive statistics of national and regional players for each subscale of the TSQT (n = 218)

	National (n = 88)		Regional (n = 130)					
	M	SD	M	SD	F	df	p	ηp2
Anticipation and positioning	3.53	.57	3.42	.53	3.309	1, 214	.070	.015
Game intelligence and adaptability	3.69	.56	3.42	.57	13.155	1, 214	<.001	.058
Decision-making	3.64	.51	3.32	.48	16.139	1, 214	<.001	.070
Recognizing game situations	3.83	.53	3.56	.54	9.975	1, 214	.002	.045

Discussion

Our aim in the present study was to develop and evaluate the psychometric properties of the TSQT with a sample of competitive tennis players. Findings of this study supported its content validity, construct validity, internal consistency, test-retest reliability and discriminative validity.

We affirmed content validity by the results of the literature review and item evaluation by the expert panel. Previous studies have shown the relevance of tactical skills for elite tennis players (Kolman et al., 2019; McPherson & Kernodle, 2007; Murphy et al., 2018). In the common categorization of tactical skills based on declarative or procedural knowledge, it appeared that procedural knowledge discriminated best between the more and the less successful field hockey and soccer players (Elferink-Gemser et al., 2010; Kannekens et al., 2011). To avoid a ceiling effect in the answers for tennis players at the highest level, we specifically developed items about procedural knowledge, i.e., 'doing it' in tennis. We adapted numerous items for procedural knowledge from the TACSIS and applied them to tennis. We formulated novel items around the construct of tactical skills. All items were checked by the expert panel and four authors of this study who confirmed that they represent tactical skills in tennis.

With the PCA and CFA, we omitted seven items from the original 38-item questionnaire because they made insufficient contribution to the component (i.e. the pattern loading was too low) or they loaded on the non-hypothesized component. For example, we deleted the item '*My choice to lob or pass when my opponent is at the net is:*' due to a low pattern loading. The item touches on more than one issue (i.e. choice to lob and choice to pass), but leaves room for only one response. Respondents might have understood this double-barreled item differently, resulting in a weak influence on the component. Final analyses resulted in a 31-item TSQT, composed of four subscales: 'Anticipation and positioning' (10 items), 'Game intelligence and adaptability' (6 items), 'Decision-making' (8 items) and 'Recognizing game situations' (7 items). The four subscales of the TSQT are considered to represent important domains of tactical skills in tennis, supporting the construct validity of the TSQT. Nevertheless, the four-component model structure explained merely 47% of variance in the instrument, suggesting that tactical skills may be affected by a broader range of factors than are assessed within this scale.

We confirmed the internal consistency of the TSQT by average inter-items correlations from .25 to .30, Cronbach's α of .89 and McDonald's ω ranging between .69 and .78 for the separate subscales. These coefficients were similar to those reported for the TACSIS (Elferink-Gemser et al., 2004). The high internal consistency found in the present study clearly demonstrates that the items of the TSQT measure the same concept. This is supported by the positive correlations between the subscales. Moreover, the subscales of the TSQT were absolutely and relatively stable over time, indicating that the TSQT is a reliable questionnaire for examining these skills in competitive tennis players. The time interval of 2 to 4 weeks between test and retest was considered long enough to make the players forget their answers from the first test, and short enough for players to improve their tactical skills. The ICC values for the subscales were between .65 and .71, indicating that the PTSST meets moderate to acceptable levels of reliability for application in a group of competitive tennis players (Koo & Li, 2016). The ICC values were similar to those reported in youth hockey players for the subscales of the TACSIS (ICC .60-.88) (Elferink-Gemser et al., 2004).

We largely confirmed the discriminative validity of the TSQT by differences between national and regional players on the TSQT and the subscales 'Game intelligence and adaptability', 'Decision-making' and 'Recognizing game situations'. These results are in line with the results of a systematic review showing that players with higher performance levels display superior tactical skills than players whose performance levels are lower (Kolman et al., 2019). However, national players did not outperform regional players on the subscale 'Anticipation and positioning', although this finding almost reached statistical significance (p = .07), but the effect size was small at .015, measured by partial-eta squared. One possible explanation for the non-significant finding could be that differences in performance level between the national and regional youth players might have been too small to discriminate performance levels for all subscales. An alternative explanation might be that the items underlying the subscale 'Anticipation and positioning' were not precise enough to detect differences at the group level.

There are several practical applications of the TSQT. Evaluating self-assessed tactical skills in tennis players provides players, coaches and other professionals with insight in players' tactical skills. They can use the TSQT to reflect on player's self-assessed strengths and weaknesses. This can open the discussion about the content of the training programs and designing tailor-made exercises to optimize performance development. With the TSQT, one can specifically target areas for development such as working on, for example, ´choosing the right moment to open down the line in a cross rally´. If it becomes clear that a player assesses him- or herself low on this item from the subscale ´Decision-making´, the coach can create a training environment in which the player is challenged in this situation specifically. Focusing on a player's strengths is crucial as well, so that players can learn to use their strengths in order to win matches. The TSQT can also assist in making players aware of their development areas and stimulate their self-regulated learning. By having them self-assess their tactical skills, they are stimulated to share and take responsibility for their own developmental process. Various studies among talented athletes have shown the value of well-developed self-regulatory skills, such as reflection, for performance and performance development (Jonker et al., 2010; Post et al., 2022; Toering et al., 2012). It is essential to realize that due to the characteristics of the TSQT, being a self-report measure, it is not suitable for selection purposes. Players may give socially desirable answers if they feel that reporting less-developed domains of tactical skills may have adverse effects for them, such as decreasing their chances for selection. This makes the comparison between individual players based on their responses on the TSQT questionable.

The advantage of a self-report measure such as the TSQT lies not only in its value for creating moments of reflection of players. The questionnaire also opens up the opportunity to assess large groups in a relatively easy way and derive rich contextual information. In addition, since it taps into the accumulated know-how of players and covers multiple training and game situations, it is less influenced by a player's shape of the day or opponent compared to so called 'objective' measures of tactical skills. Objective methods of assessing tactical skills include measures that directly assess observed performance in one or more tactical domains. These methods may use a variety of metrics, such as number of eye fixations and correct responses for anticipating groundstroke type and direction (see for a review Kolman et al., 2019). Although no gold standard for objective tactical skills assessment has emerged, popular measures include temporal occlusion paradigms, stick-figure stimulations and observational instruments (Cocks et al., 2016; García-González et al., 2014; Huys et al., 2008). Despite it can be argued that objective measures have the advantage for obtaining unbiased, reliable data, these measures merely focus on one or a limited number of aspects of tactical performance which are observed during a limited number of training sessions or games. This may be one of the reasons why in a study on soccer players no statistically significant relationship between self-assessed tactical skills as measured by the TACSIS and objective tactical performance during small sided games has been found (Nortje et al., 2014). In addition, not seldom, objective measures of tactical skills are expensive and time-consuming. This makes them less suitable if one aims to assess tactical skills over the course of multiple training and game situations in large groups.

Several strengths and weaknesses of this study are acknowledged. One strength of the current study was that it focused on both the quantity and quality of tactical skills. By gaining insight in both factors, an appropriate picture can be obtained from player's tactical skills. The importance of both factors seems to be confirmed by the fact that the ratio of the remaining items in terms of quantity and quality is similar after the PCA and CFA as in the initial 38-items questionnaire. A weakness of the study was related to the relatively small sample size for PCA and CFA. The literature about factor analysis provides a wide range of rough guidelines regarding an adequate sample size. Most of these guidelines consistently advocate for an absolute minimum sample size to obtain decent factor solutions, ranging from an ideal sample size of at least 50 to 1000 participants (Aleamoni, 1976; Barrett & Kline, 1981; Mundfrom et al., 2005). Other studies recommend a minimum sample size from 3 to 20 times the number of items (Mundfrom et al., 2005). The sample size of this study is within these recommended ranges, but near the required minimum. However, for most of these recommendations there is little empirical evidence. In addition, the adequacy of sampling was supported with the KMO above .8. Moreover, Barlett's test of sphericity was significant ($p < 0.001$), indicating that it was reasonable to proceed with PCA even considering the small sample size. The application of the TSQT in other countries, cultures, performance groups, age categories and racquet sports require the verification of the conclusions in the current sample, consisting of competitive tennis players from the Netherlands. To improve feasibility, it should be examined if the psychometric properties of the TSQT are maintained if the scale consists of fewer items measuring the same construct. Future research should focus on assessing tactical skills with the TSQT longitudinally to detect any improvements in tactical skills over time due to a training program. Moreover, it would be interesting for further studies to assess tactical skills in large groups to define benchmarks per age category and males and females separately.

In conclusion, findings from this study provide coaches and other professionals with a valid and reliable questionnaire for assessing tactical skills in competitive tennis players. Evaluating tactical skills with the TSQT provides players, coaches and other professionals with insight in players' self-assessed tactical skills over the course of multiple training and game situations. It creates the opportunity for players to reflect on their tactical skills and detect personal development areas with their coach. It is advised to use this information as input for tailor-made training programs.

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Supplementary File 1

Tactical Skills Questionnaire in Tennis (TSQT)

This questionnaire is about your tactical skills. The first 16 questions are about how **often** you make certain decisions, how **often** you recognize situations or how **often** you are in the right place. You can choose from 5 answers options. Choose the answer that best **fits** each description provided. There are **no** right or wrong answers.

You can choose from the following answers:

- **Almost never** = if you **almost never** do this, or if this statement does **not apply** to you
- **Sometimes** = if you **sometimes** do this, or if this statement does **a little apply** to you
- **Regularly** = if you **regularly** do this, or if this statement does **regularly apply** to you
- **Often** = if you **often** do this, or if this statement does **often apply** to you
- **Almost always** = if you **almost always** do this, or if this statement does **almost always apply** to you.

Example:

	Answer options				
	Almost never	**Sometimes**	**Regularly**	**Often**	**Almost always**
I quickly see where my opponent is serving to	O	●	O	O	O

	Answer options				
	Almost never	**Soms**	**Regularly**	**Often**	**Almost always**
1. I use the weak spot of my opponent	O	O	O	O	O
2. I quickly see where my opponent is serving to	O	O	O	O	O
3. When I am under pressure from my opponent, I make the right decisions	O	O	O	O	O
4. In a cross rally I choose the right moment to open down the line	O	O	O	O	O
5. Before my opponent hits the ball, I move towards the right spot	O	O	O	O	O
6. I choose the right moment to change the direction of the ball	O	O	O	O	O
7. When my opponent serves, I quickly move to the right spot	O	O	O	O	O
8. When I want to disrupt my opponent, I change the (top) spin of my balls	O	O	O	O	O
9. I quickly see where my opponent is standing with my service	O	O	O	O	O
10. I incorporate the experiences of earlier points in my decisions	O	O	O	O	O
11. When I want to disrupt my opponent, I change the height of my balls	O	O	O	O	O
12. Before my opponent hits a drop shot, I move forward	O	O	O	O	O
13. When I notice that my tactical plan is not working, I quickly adjust my game	O	O	O	O	O
14. I quickly see when my opponent changes the direction of the ball	O	O	O	O	O
15. When I am in an attacking position, I see where the open space is	O	O	O	O	O
16. When I'm at the net, I quickly see where my opponent is hitting the ball	O	O	O	O	O

The next 15 questions are about how **good** you make certain decisions, how **good** you recognize situations or how **good** your position is. You can choose from 5 answers options. Choose the answer that best **fits** each description provided. There are **no** right or wrong answers.

You can choose from the following answers:

- **Very mediocre** = if you do this **very mediocrely**, or if this statement does **not apply** to you
- **Mediocre** = if you do this **mediocrely**, or if this statement does **a little apply** to you
- **Reasonable** = if you do this **reasonably**, or if this statement does **apply reasonably** to you
- **Good** = if you do this **well**, or if this statement does **apply well** to you
- **Very good** = if you do this **well**, or if this statement does **apply completely** to you

Example:

	Answer options				
	Very mediocre	**Mediocre**	**Reasonable**	**Good**	**Very good**
In determining the depth of an incoming ball, I am:	O	●	O	O	O

	Answer options				
	Very mediocre	**Mediocre**	**Reasonable**	**Good**	**Very good**
17. The decisions I make about my next stroke are generally:	O	O	O	O	O
18. In moving to the spot where my opponent serves, I am:	O	O	O	O	O
19. In making the right decisions at the right time, I am:	O	O	O	O	O
20. My choice from various options to score a point is generally:	O	O	O	O	O
21. In varying my strokes at the right time, I am:	O	O	O	O	O
22. In being at the right spot at the right time, I am:	O	O	O	O	O
23. My game intelligence is:	O	O	O	O	O
24. In making the right decisions when my opponent is under pressure, I am:	O	O	O	O	O
25. My position on the court is:	O	O	O	O	O
26. In determining the depth of an incoming ball, I am:	O	O	O	O	O
27. My position when I am under pressure from my opponent is:	O	O	O	O	O
28. In recognizing game situations, I am:	O	O	O	O	O
29. In quickly recognizing my opponent's weak spot, I am:	O	O	O	O	O
30. My position when I put pressure on my opponent is:	O	O	O	O	O
31. In responding to a defensive ball of my opponent, I am:	O	O	O	O	O

Vragenlijst tactische vaardigheden in tennis (TSQT)

Deze vragenlijst gaat over jouw tactische vaardigheden. De eerste 16 vragen gaan over hoe **vaak** je bepaalde beslissingen neemt, hoe **vaak** je situaties herkent of hoe **vaak** je op de juiste plek staat. Je kunt uit 5 antwoorden kiezen. Maak het antwoord zwart dat **het beste bij je past.** Er zijn **geen** goede of foute antwoorden mogelijk.

Je kunt kiezen uit de volgende antwoorden:

- **Bijna nooit** = als je dit **bijna nooit** doet, of als deze uitspraak **niet** bij je past
- **Soms** = als je dit **soms** doet, of als deze uitspraak **een beetje** bij je past
- **Regelmatig** = als je dit **regelmatig** doet, of als deze uitspraak **redelijk** bij je past
- **Vaak** = als je dit **vaak** doet, of als deze uitspraak **goed** bij je past
- **Bijna altijd** = als je dit **bijna altijd** doet, of als deze uitspraak **helemaal** bij je past.

Voorbeeld:

	Antwoordopties				
	Bijna nooit	**Soms**	**Regelmatig**	**Vaak**	**Bijna altijd**
Ik zie snel waar mijn tegenstander heen serveert	O	●	O	O	O

		Antwoordopties				
		Bijna nooit	**Soms**	**Regelmatig**	**Vaak**	**Bijna altijd**
1.	Ik maak gebruik van de zwakke plek van mijn tegenstander	O	O	O	O	O
2.	Ik zie snel waar mijn tegenstander heen serveert	O	O	O	O	O
3.	Wanneer ik onder druk sta van mijn tegenstander, neem ik de juiste beslissingen	O	O	O	O	O
4.	In een crossrally kies ik het juiste moment om rechtdoor te openen	O	O	O	O	O
5.	Voordat mijn tegenstander de bal slaat, beweeg ik richting de juiste plek	O	O	O	O	O
6.	Ik kies het juiste moment om de bal van richting te veranderen	O	O	O	O	O
7.	Als mijn tegenstander serveert, beweeg ik snel naar de juiste plek	O	O	O	O	O
8.	Als ik mijn tegenstander wil ontregelen, wissel ik de (top)spin van mijn ballen	O	O	O	O	O
9.	Ik zie snel waar mijn tegenstander gaat staan bij mijn service	O	O	O	O	O
10.	De ervaringen van eerdere punten neem ik mee in mijn beslissingen	O	O	O	O	O
11.	Als ik mijn tegenstander wil ontregelen, verander ik de hoogte van mijn ballen	O	O	O	O	O
12.	Voordat mijn tegenstander een dropshot slaat, beweeg ik naar voren	O	O	O	O	O
13.	Als ik merk dat mijn tactisch plan niet werkt, pas ik mijn spel snel aan	O	O	O	O	O
14.	Ik zie snel wanneer mijn tegenstander de bal van richting verandert	O	O	O	O	O
15.	Wanneer ik in een aanvallende positie ben, zie ik waar de ruimte ligt	O	O	O	O	O
16.	Als ik aan het net sta, zie ik snel waar mijn tegenstander de bal heen slaat	O	O	O	O	O

De volgende 15 vragen gaan over hoe **goed** je bepaalde beslissingen neemt, hoe **goed** je situaties herkent of hoe **goed** jouw positie is. Je kunt uit 5 antwoorden kiezen. Maak het antwoord zwart dat **het beste bij je past.** Er zijn **geen** goede of foute antwoorden mogelijk.

Je kunt kiezen uit de volgende antwoorden:

- **Zeer matig** = als je dit **slecht** doet, of als deze uitspraak **niet** bij je past
- **Matig** = als je dit **matig** doet, of als deze uitspraak **een beetje** bij je past
- **Redelijk** = als je dit **redelijk** doet, of als deze uitspraak **redelijk** bij je past
- **Goed** = als je dit **goed** doet, of als deze uitspraak **goed** bij je past
- **Zeer goed** = als je dit **zeer goed** doet, of als deze uitspraak **helemaal** bij je past.

Voorbeeld:

	Antwoordopties				
	Zeer matig	**Matig**	**Redelijk**	**Goed**	**Zeer goed**
In het bepalen van de diepte van een aankomende bal ben ik:	O	●	O	O	O

	Antwoordopties				
	Zeer matig	**Matig**	**Redelijk**	**Goed**	**Zeer goed**
17. De beslissingen die ik neem over mijn volgende slag zijn over het algemeen:	O	O	O	O	O
18. In het bewegen naar de plek waar mijn tegenstander heen serveert, ben ik:	O	O	O	O	O
19. In het nemen van de juiste beslissingen op het juiste moment ben ik:	O	O	O	O	O
20. Mijn keuze uit verschillende mogelijkheden om een punt te scoren is over het algemeen:	O	O	O	O	O
21. In het variëren van mijn slagen op het juiste moment, ben ik:	O	O	O	O	O
22. In het op het juiste moment op de juiste plek staan, ben ik:	O	O	O	O	O
23. Mijn spelinzicht is:	O	O	O	O	O
24. In het nemen van de juiste beslissingen wanneer mijn tegenstander onder druk staat, ben ik:	O	O	O	O	O
25. Mijn positie op de baan is:	O	O	O	O	O
26. In het bepalen van de diepte van een aankomende bal ben ik:	O	O	O	O	O
27. Mijn positie wanneer ik onder druk sta van mijn tegenstander, is:	O	O	O	O	O
28. In het herkennen van spelsituaties ben ik:	O	O	O	O	O
29. In het snel herkennen van de zwakke plek van mijn tegenstander, ben ik:	O	O	O	O	O
30. Mijn positie wanneer ik druk zet op mijn tegenstander, is:	O	O	O	O	O
31. In het reageren op een verdedigende bal van mijn tegenstander, ben ik:	O	O	O	O	O

CHAPTER 7

GENERAL DISCUSSION

The aim of this thesis was to create reliable, valid and feasible tools for monitoring technical and tactical skills in youth tennis players and to gain more insight into the importance of these skills for youth tennis performance. The results of the studies included in this thesis inhabit one small piece of the puzzle of unravelling tennis performance. Tools with sufficient psychometric properties were created to monitor technical and tactical skills in a tennis-specific context. With the use of these tools, more knowledge was gained about underlying technical skills that contribute to progress towards elite tennis performance. The first section of this general discussion focuses on creating tools for monitoring technical and tactical skills. The second section emphasizes the importance of underlying skills to progress towards elite tennis performance. The third section describes some considerations to take into account. In the fourth section, directions for future research are highlighted followed by practical implications. The last section of the general discussion ends with concluding remarks.

Creating tools for technical and tactical skills

To gain more insight into existing outcome measures and tools for assessing technical and tactical skills in tennis related to performance level, an overview of the literature was provided in chapter 2. The results of this systematic review indicated strong evidence for players with higher performance levels to score higher on technical skills (ball speed and to a lesser extent accuracy) and tactical skills (decision making, anticipation, tactical knowledge and visual search strategies) compared to their lower performing counterparts. Most of the tools identified were measured in laboratory settings or measured skills in isolation from the performance context (Balser et al., 2014; Cocks et al., 2016). These tools provided interesting insights for tennis performance; however, the designs were not always representative of tennis performance demands. The performance of a particular stroke (i.e., technical execution) that is most likely to result in winning the point is, for example, based on a tactical decision on-court, meaning that technical skills should be studied in a tennis-specific context.

This line of reasoning fits within the constraints-led approach, suggesting that performance emerges from the interaction between the person, task and environment (Newell, 1986; Renshaw et al., 2019). With the development of the Dutch Technical-Tactical Tennis Test (D4T) in chapter 3, a first step has been taken to measure technical skills in a tennis-specific context. Ball speed, accuracy and percentage errors were outcome measures in different games and tactical situations (i.e. task constraints). The interaction of these task constraints with personal constraints (e.g. physical and technical skills) and environmental constraints (e.g. court surface) impact the outcome measures of the D4T. Changing task constraints, even without changing personal and environmental constraints, requires an adaptation of the current motor behavior. By means of simulating fixed (game 1 and 2) and variable (game 3 and 4) situations, the D4T allows tennis players to experience technical demands in situations of different complexity. Due to the simulation of offensive, neutral and defensive situations, changes in time constraints (i.e. less time in defensive compared to offensive situations) also impact the complexity in the D4T. Differences in task complexity force players to deal with various situations in order to hit their strokes with sufficient technique. Psychometric evaluation found the D4T to be a reliable, valid and feasible tool for measuring technical skills in youth tennis players. Measurement properties are key for scientific relevance, making the D4T valuable for theory development and increasing our understanding of underlying technical skills to progress towards elite tennis performance (chapter 4 and 5). The D4T also offers relevant data for practical purposes, for example information about players' relative strengths and weaknesses in different tactical situations.

Up to now, there was no reliable, valid and feasible tool to examine tactical skills over the course of multiple training and game situations yet. Therefore, a new tool with closed-ended questions was designed to examine tactical skills in tennis players. The development and psychometric evaluation of the Tactical Skills Questionnaire in Tennis (TSQT) was described in chapter 6. Four theoretically meaningful subscales were identified: 'Anticipation and positioning', 'Game intelligence and adaptability', 'Decision-making' and 'Recognizing game situations'. Evaluating self-assessed tactical skills with the TSQT provides players, coaches and other professionals with insight in players' tactical skills. The TSQT creates the opportunity to reflect on players' self-assessed strengths and weaknesses, opening the discussion about the content of the training programs and the design of tailor-made exercises to optimize performance development.

To develop tactical skills in a talent development program, there should be a shared understanding and perception of all stakeholders involved in the progression towards elite tennis performance (Pankhurst et al., 2013). Coaches are considered significant stakeholders in the process of talent development and play a prominent role in the development of skills and sports performance (Wolfenden & Holt, 2005). A shared mental model between players' perceptions, and those of coaches, can optimize performance development (Giske et al., 2015). Shared mental models or 'being on the same page' help coaches to work more efficiently with players on the development of sport-specific skills, such as tactical skills, which in turn may enhance the chances of players' success (Taylor et al., 2021). A lack of shared consensus drives a gap and mismatch in training, coaching and development processes among stakeholders operating at different parts in the talent development program (Collins et al., 2019). When players share an understanding with their coach of which tactical skill (e.g. decision-making, anticipation and positioning) to improve on court, players can focus on that specific component in practice without questioning the coaches' approach. In addition, players and coaches who have shared knowledge and understanding are more likely to communicate effectively and appropriately (Jowett & Cockerill, 2003). In contrast, when players and coaches have their own mental model of the appearance of optimal tactical skills, the effort and motivation in practice and susceptibility of players for feedback may be different.

Since tactical skills play a key role in the progression towards elite tennis performance (McPherson & Kernodle, 2007; Triolet et al., 2013; Williams & Jackson, 2019), it is interesting to understand to what extent players' self-assessed tactical skills align with the perceptions of their coaches. Therefore, future research should compare tactical skills, as measured by the TSQT, with the perceptions of coaches. In the absence of a shared understanding of tactical skills, there is a need to gain more knowledge about how these differences in perception arise.

Underlying technical skills to progress towards elite tennis performance

The importance of underlying technical skills to progress towards elite tennis performance was studied in chapter 4 and 5. There was a strong relationship between underlying technical skills (i.e. ball speed, accuracy and percentage errors) and performance level of youth male players U14 (chapter 4). The combination of ball speed and accuracy of players U14 explained 60% and 46% of the variance of performance level U14 and U18 (i.e. four years after assessing technical skills), respectively. Players who were classified as elite ones U18 were more accurate in their younger years, especially in complex situations, than their lower performing counterparts U18. Technical skills were considered essential to perform well later in adolescence, but seem not yet fully developed at this age in a group of talented tennis players (chapter 5). Accuracy in complex situations for both males and females seems to continue to develop in adolescence, although a longitudinal study design is needed to determine the actual process of technical development over time. Males U17 produced higher ball speed compared to males U15, while no differences were found between females U15 and U17. These findings were not surprising, given that females mature earlier than males (Malina et al., 2015).

In line with earlier research, the findings of chapter 4 and 5 reveal that under increased task complexity (i.e. high temporal and cognitive pressure), the older and more experienced players were better able to maintain their accuracy than their younger and less experienced counterparts (Kal et al., 2018). Usually technical performance decreases with increased task complexity, although the timing depends on players' expertise (Fait et al., 2011; Gabbett & Abernethy, 2012; Huijgen et al., 2013). Elite players were able to maintain their accuracy throughout the games, while competitive players became less accurate in complex situations (chapter 4). In chapter 5, players U15 and U17 were both able to maintain their accuracy throughout the game situations, possibly due to their higher performance level compared to the competitive players in chapter 4. The accuracy of players U17 even seemed to benefit from the increased task complexity, as indicated by the slightly higher accuracy in game 4 compared to the others game situations. Due to more years of tennis experience, players U17 might have developed a higher degree of automatization, resulting in a greater resistance to skill decrement in more complex situations than players U15 (Kal et al., 2018; Schaefer & Scornaienchi, 2020). While it is uncommon for players, especially novices, to perform more accurately in variable than in fixed situations, previous research has shown increased performance in complex situations in experienced hockey players (Jackson et al., 2006). One possibility is that the diversion of attention to another task (e.g. focusing on the simulated opponent) attenuates disruptive conscious processing of movements that can occur in fixed situations.

In contrast to players U17, players U15 were unable to maintain their accuracy under high temporal demands, imposed by ball projections to the sidelines of the court in the defensive situations. The decrease in accuracy in players U15 suggests that the task complexity in the defensive situation might have been too high, causing them to play less accurately due to the greater information processing load (Poolton et al., 2006). In neutral and offensive situations, the task complexity is relatively low, remaining substantial attentional capacity for additional tasks (e.g. focusing on the next ball projection). However, as the temporal pressure increases, greater attention is required to be devoted to maintain stroke accuracy, resulting in reduced processing capacity for anticipating the next ball in the defensive situation. Another explanation for players U17 to be more accurate in defensive situations than players U15 might be related to differences in anthropometry and physical skills such as sprint speed (Kramer, Valente-Dos-Santos, et al., 2016; Kramer et al., 2021) and agility (Kramer, Huijgen, et al., 2016). During adolescence, there is an increase in height and players develop more strength and power (Malina et al., 2015). The players U17 were taller, heavier and more mature than players U15 (chapter 5). Individual differences in growth and maturation, and associated increases in running speed and agility, could translate into an advantage for older youth players in defensive situations. In chapter 4, future elite players were biologically more mature at a younger age compared to their future competitive counterparts. Their physical advantage over smaller and less mature opponents may have increased their chances for selection and retention within talent development programs. Early maturing players are more likely to be encouraged and rewarded for their participation, obtain more practice time and receive greater access to specialized coaching and training resources (Cumming et al., 2017). Therefore, the influence of maturation to progress towards elite tennis performance should be considered.

Considerations

There are some considerations that need to be taken into account. Increasing our understanding about technical and tactical skills inhabit one small piece of the puzzle of unravelling tennis performance; however, the interaction of these skills with anthropometrical, physiological and psychological requirements should not be neglected (Elferink-Gemser et al., 2018; Kovacs, 2007). In the development of the D4T and the TSQT, a balance was made between the advantages and disadvantages of the design and methodology. In addition to a focus on 'outcome-related' methods (e.g. accuracy of groundstrokes), other methodologies such as 'technique-related' methods (e.g. biomechanical movement analysis) and 'competition' methods (e.g. competition performance data) can be worthwhile to consider as to increase our understanding (Koopmann et al., 2020). Focusing on 'outcome-related' methods, either in isolation or as part of multidisciplinary assessment protocol, has been the topic of debate the past years (Piggott et al., 2019; Pinder et al., 2013; Vilar et al., 2012). The discussion appears to focus primarily on (a) the representative design of currently used monitoring tools and (b) the ideal level of specificity and detail included in such assessments (Robertson et al., 2014). In the development of the D4T and TSQT, the decision to utilize either approach may have contrasting advantages in relation to reliability, validity and feasibility as well as for the generalization of the results.

The D4T measures technical skills of groundstrokes in offensive, neutral and defensive rallies, but it does not capture technique in all situations. Tennis includes more crucial strokes like the serve, return and volley (Cui et al., 2018; Gillet et al., 2009; Hizan et al., 2011; Reid et al., 2010). The first and second serve capability (direction, ball speed and success), net point success and breakpoint opportunity are important predictors of success in tennis. The use of a ball machine allows for the reliable and valid assessment of groundstrokes and comparison between age categories due to the standardized test design on the one hand. On the other hand, players cannot use relevant kinematic information from the opponent (e.g. distal cues from arm and racket) to anticipate the direction of strokes (Cañal-Bruland et al., 2011; Huys et al., 2009). Returning strokes from a ball machine could result in different swing timing and movement coordination, limiting the generalization of the results (Carboch et al., 2014). In the absence of a gold standard to assess sport-specific skills, capturing the dynamic and changing conditions in tennis, while retrieving reliable and valid outcomes, remains a challenge.

Future perspectives

The findings of the studies in this thesis provide new insights and recommendations for further research. Concerning the value of the D4T and TSQT for measuring technical and tactical skills, it is interesting to understand which skills at an earlier time-point may contribute toward successful future tennis performance in both youth and adult players. Therefore, both prospective and longitudinal research designs are recommended. However, it is acknowledged that the skills correlating with performance at young ages may not necessarily be the same factors explaining adult performance (Baker et al., 2019). A shared mental model between the perception of players and coaches can optimize performance development (Giske et al., 2015); therefore, future research should compare players' self-assessed tactical skills, as measured by the TSQT, with the perceptions of coaches.

Findings of the cross-sectional study in chapter 5 provide insights into the technical differences between players U15 and U17, but a longitudinal study design (4+ years) is needed to determine the actual process of technical development over time in adolescence. As development occurs in combination with maturational and physical changes, future studies should consider growth and maturation in their study designs (Malina et al., 2015). Future studies should also examine how technical skills measured with the D4T, particularly accuracy in complex situations, relate to on-court tennis performance under high temporal and cognitive pressure. The association of on-court test performance with match activities is considered a feasible approach for evaluating ecological validity (Castagna et al., 2019). In addition, intervention studies could explore the effect of specific practices for accuracy in complex situations.

Finally, future research should evaluate the influence of personal, environmental and other task constraints on tennis performance. The interaction of personal constraints (e.g. fatigue and confidence), task constraints (e.g. complexity, intensity) and environmental constraints (e.g. wind, the presence of a noisy crowd) may impact players' performance differently. As tennis is characterized by an environment of constant uncertainty, where players are forced to adapt continuously and respond to different stimuli (Fonseca-Morales & Martínez-Gallego, 2021), it may be possible that (future) elite players adapt easier to constraint manipulation than players whose performance levels are lower.

Practical implications

The present thesis has several practical implications. Two main concepts have been associated with the application of evidence, namely 'evidence-based practice' and 'evidence-informed practice'. The commonly accepted definition of evidence-based practice is adapted from the definition of evidence-based medicine, which is the conscientious, explicit and judicious use of the best evidence in making decisions about the care of the individual patient (Sackett et al., 1996). An alternative to a fully evidence-based practice is an evidence-informed practice where research evidence is integrated with practical experience, patients' values, preferences and circumstances (Wackerhage & Schoenfeld, 2021). In sports, evidence-informed practice can be described as the integration of relevant research evidence, coaching expertise and athlete values into the decision-making process in, for example, talent development programs (Coutts, 2017). The International Olympic Committee (IOC) consensus statement on youth athletic development suggests that evidence-informed practices should be emphasized to ensure an enjoyable, safe, healthy and sustainable experience for all players, along performance development (Bergeron et al., 2015). In line with these recommendations, it should be investigated whether modifications in the design of the D4T result in a more feasible assessment of technical skills. Considering the importance of underlying technical skills in complex situations to progress towards elite tennis performance (chapter 4 and 5), the fixed situations (i.e. game 1 and 2) may be redundant. Omitting games 1 and 2 cuts the time of the D4T in half, meaning the test would take approximately 10 minutes instead of 20 minutes per player. Moreover, the use of a mobile app, such as SwingVision, may be a simple alternative to cameras or the system of Playsight to assess ball speed, accuracy and percentage errors (Mangolytics, Inc., 2022; Playsight, 2015). This would allow for a country-wide assessment of technical skills in large groups of tennis players.

With the current design of the D4T and TSQT, coaches and other professionals can assess and monitor technical and tactical skills over time. The D4T offers relevant data about technical skills (i.e. ball speed, spin rate, accuracy and percentage errors) in offensive, neutral and defensive situations. Moreover, it creates the opportunity for players to reflect on their skills and detect personal development areas together with their coaches. As such, it can provide relevant input for the content of training programs. For example, if a player makes numerous mistakes in an offensive situation, specific exercises for improving the finishing shot and its error rate can be useful. As the development of players is non-linear and high levels of variation exists between players (Baker et al., 2019; Gulbin et al., 2013), technical and tactical skills should be assessed repeatedly throughout the player's talent development program (e.g. at least twice a year). There is a need to focus on the individual and intra-individual comparisons (i.e. increase of decrease in score compared to the last measurement) to reflect on players' strengths and weaknesses. As already mentioned, it is important to understand to what extent players' self-assessed tactical skills align with the perceptions of their coaches. Therefore, the TSQT should be completed by coaches of the players involved. In the absence of a shared understanding of tactical skills, there is a need to discuss differences in perception. Both the D4T and TSQT can open up the conversation and stimulates players' self-regulated learning. By having them self-assess their tactical skills with the TSQT, players are stimulated to share and take responsibility for their own developmental process. At the same time, coaches are encouraged to design specific practices to target players' development areas. For instance, as accuracy under high cognitive and temporal pressure seems essential to progress towards elite tennis performance (chapter 4 and 5), exercises to improve accuracy in complex situations should be developed.

Concluding remarks

Tools with good to excellent psychometric characteristics were created for monitoring technical and tactical skills in youth tennis players. With these tools, more insight was gained into the importance of these skills for youth tennis performance. Based on the studies described in this thesis it can be concluded that:

- Tennis performance emerges from the interaction between the person, task and environment, indicating that technical and tactical skills should be studied in a tennis-specific context (**chapter 2**).
- There is strong evidence for both youth and adult players with higher performance levels to score higher on technical skills (ball speed and accuracy) and tactical skills (decision making, anticipation, tactical knowledge and visual search strategies) compared to their lower performing counterparts (**chapter 2**).
- The D4T and TSQT are reliable and valid tools, contributing to scientific purposes (**chapter 3 and 6**). Both tools are valuable for theory development and increasing our knowledge about underlying technical and tactical skills. In addition, they are relevant for

prospective and longitudinal research designs to understand which skills at an earlier time-point may contribute toward successful future tennis performance.

- Outstanding technical skills, especially accuracy in complex situations, are considered essential to progress towards elite tennis performance (**chapter 4**). Accuracy in complex situations, and for males also ball speed, seems to continue to develop in adolescence (**chapter 5**). As development occurs in combination with maturational and physical changes, the influence of maturation to progress towards elite tennis performance should be considered.
- The D4T and TSQT are feasible tools, contributing to practical purposes (**chapter 3 and 6**). In addition to monitoring the progress of players, both tools can assist in identifying relative strengths and weaknesses of players, create the opportunity for players to reflect on their skills and detect personal development areas together with their coaches. As such, they can provide relevant input for the content of training programs.

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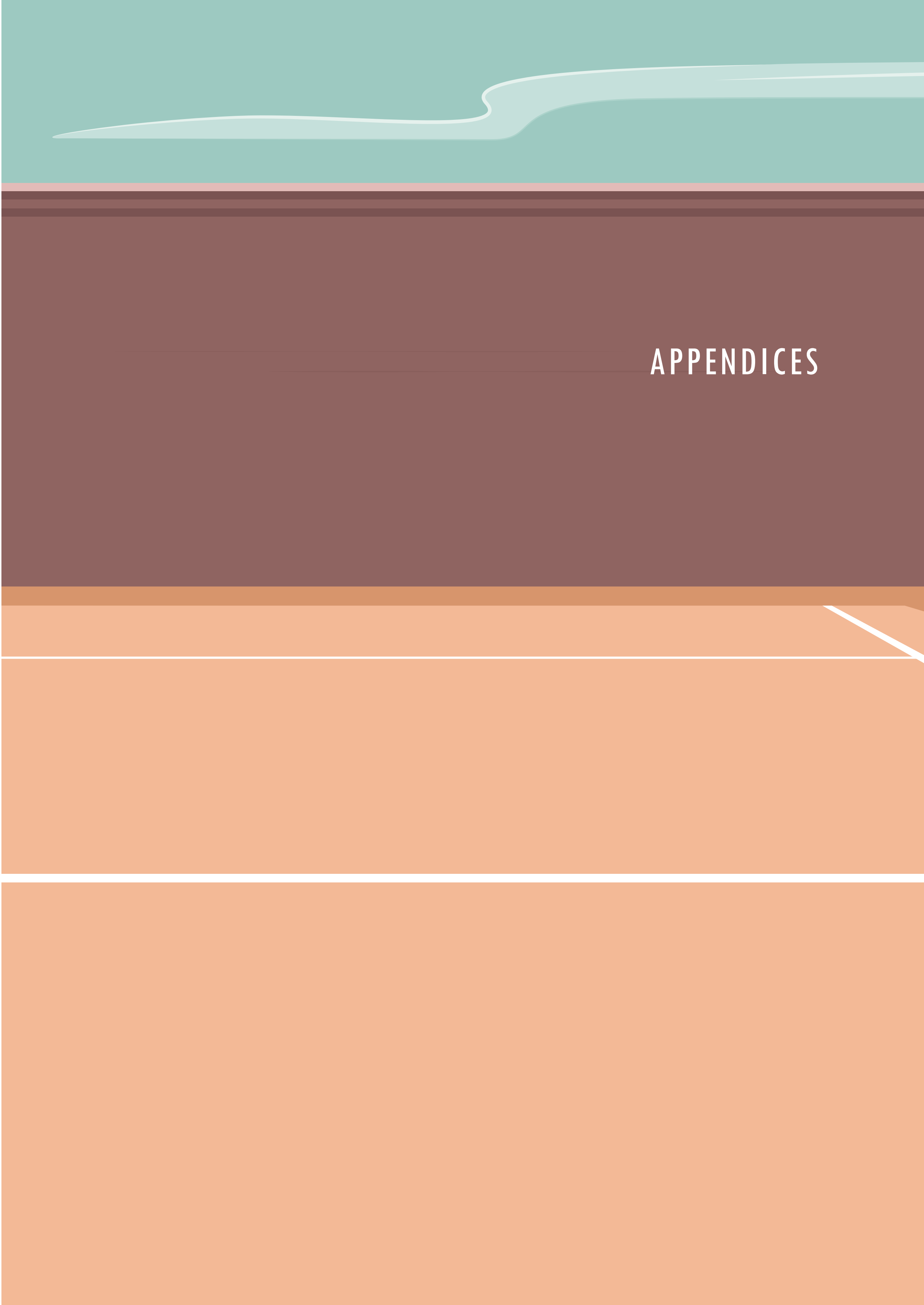
APPENDICES



Summary

The combination of outstanding technical and tactical skills is suggested to be the key to progress towards elite tennis performance. To assist talent development processes, the studies in the present thesis created monitoring tools for technical and tactical skills and increased our understanding of the importance of these skills for youth tennis performance. **Chapter 1** introduces the rationale and aims of this thesis.

Chapter 2 provides an overview of outcome measures and tools identified in the literature for examining technical and tactical skills in tennis related to performance levels. Forty studies were included in a systematic review, showing strong evidence for players with higher performance levels to score higher on technical skills (ball speed and to a lesser extent accuracy) and tactical skills (decision making, anticipation, tactical knowledge and visual search strategies) compared to their lower performing counterparts. Most of the tools identified were in laboratory settings or measuring skills in isolation from the tennis performance context. Although these tools provide interesting insights for tennis performance, the designs are not always representative of tennis performance demands. Tennis performance emerges from the interaction between the person, task and environment, suggesting that technical and tactical skills should be studied in their specific context.

In **chapter 3** we describe the psychometric properties of an on-court technical and tactical tennis test, the Dutch Technical-Tactical Tennis Test (D4T). Thirty-two male youth tennis players (age 13.4 ± 0.5 years) were measured and classified as elite (n=15) or sub-elite (n=17) based on their position on the youth national ranking list. Games, rallies and different tactical situations (i.e. offensive, neutral and defensive) were simulated with a ball machine. Technical skills were recorded based on accuracy (target areas), ball speed (radar system) and percentage errors. In total, players needed to return 72 balls to the target areas on the court. The D4T was shown a reliable, valid and feasible tool to assess technical skills in youth tennis players.

Next, in **chapter 4**, it is examined whether the technical skills of the youth players measured in **chapter 3** were able to predict their current and future performance level based on tennis rating. Players' tennis ratings were obtained under-14 ('current performance') and under-18 (U18) ('future performance'). According to their rating U18, players were classified as future elite (n=9) or future competitive (n=20). Games in the D4T were defined as either fixed or variable. The variable games required players to consider the direction of the ball, as opposed to the fixed game situations where players needed to play every ball to the same side. Both ball speed and accuracy were found significant predictors of current and future tennis performance. Future elite players were more accurate than future competitive players, especially in variable compared to fixed game situations. To our knowledge, the study of **chapter 4** is the first to show that technical skills are crucial for current as well as future performance in youth male tennis players.

Although the findings of **chapter 4** show that technical skills in complex situations appear crucial to progress towards elite tennis performance, it was unknown how these skills develop in different age categories among talented youth players. Therefore, in **chapter 5** possible differences in technical skills of Dutch talented youth tennis players under-15 (U15) compared to under-17 (U17) are evaluated. A difference was found between age categories on accuracy for both males and

females, with players U17 being more accurate than players U15. A closer examination of accuracy demonstrates that players U17 scored higher in complex situations than players U15, given the higher accuracy in the variable game 4 and in defensive situations. Males U17 produced higher ball speed compared to males U15, while no differences were found between females U15 and U17. These findings suggest that technical skills, especially accuracy in complex situations for both males and females and ball speed for males, continue to develop in adolescence in a group of youth talented tennis players.

In **chapter 6** the psychometric properties of the Tactical Skills Questionnaire in Tennis (TSQT) are evaluated, a new instrument with closed-ended questions designed to examine tactical skills in tennis players. Participants were 233 competitive tennis players (age 17.06 ± 4.74 years) competing on national or regional levels. Four theoretically meaningful subscales for the 31-item TSQT were identified 'Anticipation and positioning', 'Game intelligence and adaptability', 'Decision-making' and 'Recognizing game situations'. Findings of this study support the psychometric properties of the TSQT. Evaluating tactical skills with the TSQT provides players, coaches and other professionals with insight in players' self-assessed tactical skills over the course of multiple training and game situations. It creates the opportunity for players to reflect on their skills and detect personal development areas with their coach. Practitioners can use this information as input for tailor-made training programs.

Chapter 7 summarizes and discusses the main findings from the preceding chapters and provides future perspectives and implications for practice. Tools with good to excellent psychometric characteristics were created for monitoring technical and tactical skills in youth tennis players. With these tools, more insight was gained into the importance of these skills for youth tennis performance.

Samenvatting

Technische en tactische vaardigheden zijn essentieel in de route naar de top. Dit proefschrift beschrijft de ontwikkeling van meetinstrumenten voor technische en tactische vaardigheden en geeft inzicht in het belang van deze vaardigheden voor de jeugdtennisprestatie. De meetinstrumenten en opgedane kennis kunnen bijdragen aan de ontwikkeling van talentvolle tennissers. **Hoofdstuk 1** beschrijft het belang en het doel van dit proefschrift.

Hoofdstuk 2 geeft een overzicht van bestaande uitkomstmaten en meetinstrumenten voor technische en tactische vaardigheden. In een systematische review zijn veertig studies geïncludeerd. Hieruit bleek dat spelers van hoger niveau betere technische vaardigheden (balsnelheid en in mindere mate nauwkeurigheid) en tactische vaardigeden (beslissingen nemen, anticiperen, tactische kennis en kijkgedrag) hebben dan spelers van lager niveau. De meeste meetinstrumenten waren geschikt voor gebruik in een labsetting of het meten van technische of tactische vaardigheden los van de specifieke tennisprestatiecontext. Hoewel deze meetinstrumenten inzicht geven in de tennisprestatie, zijn ze niet altijd representatief voor de daadwerkelijke tennisprestatie. Een tennisprestatie komt tot stand door de interactie tussen de persoon, de taak en de omgeving. Dit impliceert dat technische vaardigheden in een tennis-specifieke context bestudeerd moeten worden.

In **hoofdstuk 3** proberen we deze kloof te dichten door het ontwikkelen en evalueren van de psychometrische kenmerken van de Dutch Technical-Tactical Tennis Test (D4T). Tweeëndertig jongens (leeftijd 13.4 ± 0.5 jaar) hebben de test uitgevoerd en zijn geclassificeerd als elite (n=15) of sub-elite (n=17) op basis van hun positie op de jeugdranglijst. Verschillende games, rally's en tactische situaties (aanvallend, neutraal en verdedigend) zijn gesimuleerd met een ballenmachine. Technische vaardigheden zijn in kaart gebracht door de nauwkeurigheid (mikpunten), de balsnelheid (snelheidsradar) en het percentage fouten te meten. In totaal moesten de spelers 72 ballen terugslaan naar mikpunten op de baan. De D4T blijkt een betrouwbare, valide en praktisch toepasbare test voor het meten van technische vaardigheden van jeugdtennissers.

In **hoofdstuk 4** onderzoeken we vervolgens in hoeverre de technische vaardigheden van jeugdspelers (**hoofdstuk 3)** voorspellend zijn voor de huidige en toekomstige tennisprestatie. De tennisprestatie werd bepaald op basis van de tennisrating van spelers onder-14 ('huidige tennisprestatie') en onder-18 (O18) ('toekomstige tennisprestatie'). Op basis van de rating O18 werden spelers geclassificeerd als toekomstige elite (n=9) of toekomstige competitieve spelers (n=20). Games van de D4T werden gedefinieerd als standaard of variabel. In de standaard games moesten spelers iedere bal naar dezelfde kant spelen. In de variabele games moesten spelers nadenken over de richting waar ze de bal heen moesten spelen. Zowel balsnelheid als nauwkeurigheid bleken significante voorspellers van de huidige en toekomstige tennisprestatie. De toekomstige elite spelers bleken bovendien nauwkeuriger dan de toekomstige competitieve spelers. Dit gold echter alleen voor nauwkeurigheid in de variabele games en niet in de standaard games. Voor zover we weten is de studie van **hoofdstuk 4** de eerste die aantoont dat technische vaardigheden cruciaal zijn voor zowel de huidige als toekomstige tennisprestaties van mannelijke jeugdtennissers.

Hoewel uit **hoofdstuk 4** blijkt dat technische vaardigheden in complexe situaties van belang zijn voor spelers in de route naar de top, was het onbekend in hoeverre deze vaardigheden zich ontwikkelen in verschillende leeftijdscategorieën bij getalenteerde jeugdspelers. In **hoofdstuk 5** vergelijken we daarom de technische vaardigheden van Nederlandse getalenteerde jeugdspelers onder-15 (O15) met die van onder-17 (O17). Er was een verschil in nauwkeurigheid tussen beide leeftijdscategorieën, waarbij zowel jongens als meisjes O17 nauwkeuriger waren dan jongens en meisjes O15. Aanvullende analyses lieten zien dat spelers O17 nauwkeuriger waren in complexe situaties dan spelers O15, gezien de hogere nauwkeurigheid in de variabele game 4 en in verdedigende situaties. Jongens O17 produceerden bovendien een hogere balsnelheid dan jongens O15, terwijl er geen verschillen werden gevonden tussen meisjes O15 en meisjes O17. Deze bevindingen suggereren dat getalenteerde spelers bepaalde technische vaardigheden blijven ontwikkelen tijdens de adolescentie. Dit geldt vooral voor nauwkeurigheid in complexe situaties voor zowel jongens als meisjes en balsnelheid voor jongens.

In **hoofdstuk 6** evalueren we de psychometrische kenmerken van de Tactical Skills Questionnaire in Tennis (TSQT). Dit is een nieuw instrument met gesloten vragen om tactische vaardigheden van tennissers in kaart te brengen. In totaal deden 233 competitieve tennissers (leeftijd 17.06 ± 4.74 jaar) van nationaal en regionaal niveau mee aan het onderzoek. Vier theoretisch betekenisvolle subschalen kwamen uit de analyses naar voren: 'Anticiperen en positioneren', 'Spelintelligentie en aanpassingsvermogen', 'Beslissingen nemen' en 'Herkennen van spelsituaties'. De bevindingen van deze studie ondersteunen de psychometrische kenmerken van de TSQT. Het gebruik van de TSQT om tactische vaardigheden te beoordelen, geeft spelers, coaches en andere professionals inzicht in de zelf-beoordeelde tactische vaardigheden van spelers gedurende meerdere trainingen en spelsituaties. Hierdoor kunnen spelers reflecteren op hun eigen vaardigheden en -samen met hun coach- ontwikkelgebieden blootleggen. Coaches en andere professionals uit de praktijk kunnen deze informatie gebruiken om trainingsprogramma's op maat aan te passen.

In **hoofdstuk 7** schetsen en bespreken we de belangrijkste bevindingen uit de voorgaande hoofdstukken. Ook staan er aanbevelingen in voor vervolgonderzoek en toepassingen voor de praktijk. In deze thesis zijn meetinstrumenten met goede tot uitstekende psychometrische kenmerken ontwikkeld voor het monitoren van technische en tactische vaardigheden in jeugdspelers. Hierdoor hebben we meer inzicht kunnen krijgen in het belang van deze vaardigheden voor de jeugdtennisprestatie.

About the author

Nikki Susanne Kolman was born on February 1 1992 in Sauwerd, The Netherlands. In secondary school she was already interested in the magic behind talent in sports, given the title of her final school project 'Sport, learning and performance'. After obtaining her VWO diploma at the Rölingcollege Belcampo in Groningen in 2010, she studied Human Movement Sciences at the University of Groningen from 2010 to 2013. In 2014 she continued her education with a master's degree in Sports Sciences at the University of Groningen. In 2016 she graduated cum laude with her graduation research about the development and psychometric evaluation of the 'Dutch Technical-Tactical Tennis Test'. After graduating, Nikki worked for a year and a half as a researcher/advisor at a research agency in the healthcare and welfare sector. In 2018, she started at Topsport Topics, a collaboration between the Knowledge Center of Sports & Physical Activity, NOC*NSF, VU Amsterdam and the University of Groningen. In 2019 she continued her graduation research with the start of a PhD trajectory. In her research she focused on creating tools for monitoring technical and tactical skills in youth tennis players and gaining more insight into the importance of these skills for youth tennis performance. During her PhD research, Nikki continued to work at Topsport Topics, where she still aims to enhance elite sports by making new scientific information available for practice as quickly as possible. She also provides scientifically based answers to questions from the national elite sports programs.

List of publications

International publications

Kolman, N. S., Kramer, T., Elferink-Gemser, M. T., Huijgen, B. C. H., & Visscher, C. (2018). Technical and tactical skills related to performance levels in tennis: A systematic review. *Journal of Sports Sciences, 37*(1), 108–121. https://doi.org/10.1080/02640414.2018.1483699

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Conference contributions

Kolman, N. S., Huijgen, B. C., Visscher, C., & Elferink-Gemser, M. T. (2022). The relationship between technical skills, perceived tactical skills and self-regulatory skills in youth elite tennis players. The 27th Annual Congress of the European College of Sport Science, Sevilla, Spain.

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Dankwoord

Alleen het dankwoord nog. Uitserveren op 6-2 5-1. In theorie een makkie, maar door de veelgehoorde zin "Mensen lezen toch alleen maar het dankwoord" voel ik de druk. Gelukkig zijn er ontzettend veel mensen om te bedanken en kan ik maar beter beginnen met serveren (of schrijven). En cliché, maar waar: zonder jullie zou dit proefschrift er nooit liggen!

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