Load monitoring in high performance youth tennis players: Preparation for competition readiness.

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School of Human Movement Studies, Charles Sturt University

Bathurst, Australia
I

Alistair Philip Murphy

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Preface

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To the abovementioned mates and countless more, it’s been fun.

Cheers.
Publications Resulting from this Thesis

The following publications result from chapters in this thesis:


## Abbreviations

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<td>AFL</td>
<td>Australian Football League</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of Variation</td>
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<td>ATP</td>
<td>Association of Tennis Professionals</td>
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<tr>
<td>au</td>
<td>Arbitrary Unit</td>
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<tr>
<td>bpm</td>
<td>Beats per Minute</td>
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<td>CI</td>
<td>Confidence Intervals</td>
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<td>CK</td>
<td>Creatine Kinase</td>
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<tr>
<td>CMJ</td>
<td>Countermovement Jump</td>
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<tr>
<td>CMJ-DL</td>
<td>Countermovement Jump Double Leg</td>
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<td>CMJ-DOM</td>
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<tr>
<td>CMJ-NON</td>
<td>Countermovement Jump Non-Dominant Single-Leg</td>
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<tr>
<td>COD</td>
<td>Change of Direction</td>
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<td>CR</td>
<td>Category Ratio</td>
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<td>CR10</td>
<td>Category Ratio 0-10</td>
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<tr>
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<td>Category Ratio 0-100</td>
</tr>
<tr>
<td>CR6-20</td>
<td>Category Ratio 6-20</td>
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<tr>
<td>CSAI-2R</td>
<td>Revised Competitive State Anxiety Inventory - 2</td>
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<tr>
<td>CV</td>
<td>Coefficient of Variation</td>
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<tr>
<td>drill-RPE</td>
<td>Drill Rating of Perceived Exertion</td>
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<td>drill-TL</td>
<td>Drill Training Load</td>
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<td>EMG</td>
<td>Electromyography</td>
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<td>GAS</td>
<td>General Adaptation Syndrome</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>HIT</td>
<td>High-intensity Interval Training</td>
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<td>HR</td>
<td>Heart Rate</td>
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<td>Heart Rate Exercise</td>
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<td>Heart Rate Variability</td>
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<td>Hz</td>
<td>Hertz</td>
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<td>ICC</td>
<td>Interclass Correlation Coefficient</td>
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<td>ITF</td>
<td>International Tennis Federation</td>
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<td>iTRIMP</td>
<td>Individualised Training Impulse</td>
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<td>LT</td>
<td>Lactate Threshold</td>
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<td>LTAD</td>
<td>Long Term Athlete Development</td>
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<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>m-TRIMP</td>
<td>Modified Training Impulse</td>
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<td>MAP</td>
<td>Maximal Aerobic Power Test</td>
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<td>MVC</td>
<td>Maximal Voluntary Contraction</td>
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<td>OBLA</td>
<td>Onset of Blood Lactate Accumulation</td>
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<td>OTS</td>
<td>Over Training Syndrome</td>
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<td>RM</td>
<td>Repetition Maximum</td>
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<td>RPE</td>
<td>Rating of Perceived Exertion</td>
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<td>RSA</td>
<td>Repeated Sprint Ability Test</td>
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<tr>
<td>s-RPE</td>
<td>Session Rating of Perceived Exertion</td>
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<td>s-TL</td>
<td>Session Training Load</td>
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<td>S&amp;C</td>
<td>Strength and Conditioning</td>
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<td>SD</td>
<td>Standard Deviation</td>
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<td>SLJ</td>
<td>Standing Long Jump</td>
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<td>s-TL</td>
<td>Session Training Load</td>
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<tr>
<td>strokes.min-1</td>
<td>Strokes Per Minute</td>
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<tr>
<td>strokes.sec-1</td>
<td>Strokes Per Second</td>
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<tr>
<td>SWC</td>
<td>Smallest Worthwhile Change</td>
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<td>TE</td>
<td>Technical Error</td>
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<td>TRIMP</td>
<td>Training Impulse</td>
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<td>VO2</td>
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<td>Maximum Oxygen Uptake</td>
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<td>VO2peak</td>
<td>Peak Oxygen Uptake</td>
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<tr>
<td>WTA</td>
<td>Women’s Tennis Association</td>
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<tr>
<td>Yo Yo IR1</td>
<td>Yo Yo Intermittent Recovery Test Level 1</td>
</tr>
<tr>
<td>Yo Yo IR2</td>
<td>Yo Yo Intermittent Recovery Test Level 2</td>
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Symbols and Subunits

± Plus or minus
< Less Than
> Greater Than
~ Approximately
°C Degrees Celsius
% Percentage
cm Centimetre
d wk⁻¹ Days per Week
h Hour
Hz Hertz
Kg Kilogram
km Kilometre
m Meter
min Minute
mL Millilitre
mL·Kg⁻¹·min⁻¹ Millimetres per Kilogram per Minute
m s⁻¹ Minutes per Second
min wk⁻¹ Minutes per Week
ms Millisecond
s Seconds
W Watt
y Year
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Abstract

This thesis examined training load monitoring within high-performance tennis environments for the preparation of domestic and international tournaments. In doing so, the thesis reports on the use, meaning and efficacy of load monitoring tools during training, simulated match play, and on-tour (both domestically and internationally) in high performance junior tennis players. The initial study assessed the level of agreement between coach and athlete perceptions of internal training load and notational analysis in junior high-performance tennis environments. The second study monitored external and internal training loads associated with junior high-performance tennis players to describe common training loads. The third study compared the external load demands and internal responses associated with training drills, simulated match play, and tournament matches of junior high-performance tennis players. The fourth study investigated changes in physical capacities of high-performance junior tennis players following a 4-week overseas tour, while also examining whether observed changes were related to match and prescribed training loads on-tour. Finally, in the same cohort, the fifth study assessed the relationship between observed changes in physical capacity and the training loads completed 4-weeks prior to tour departure and whilst on-tour.

Key findings from the current thesis include:

- While coach perception of individual drill-RPE did not differ from athletes (within the same session), coaches seem to misinterpret accumulated training load accumulation from a sequence of prescribed drills within a session.
• Open natured and recovery focused drills induced the greatest rate of perceived exertion (RPE), heart rate (HR) and stroke-rates, whilst target-hitting and defensive drills placed high-performance junior tennis players under highest mental pressure. Technical and defensive drills also provoke the greatest error-rates.

• When compared within the same group of junior high-performance tennis players, session duration and RPE, groundstroke and serve count/rate of training and simulated match play were lower than those that characterize actual tournament competition.

• Only 5-, 10-, and 20-m sprint times were observed to decline across the 4-week overseas competitive tour. Yet, closer analysis revealed that players completing the greatest amount of total and tennis training load on tour returned with the greatest decline in speed and aerobic capacities.

• A greater concentration of on-tour, total and on-court load is related to poorer 20-m sprint and multistage test performance post-tour. Heavy match schedules therefore do not provide sufficient exposure to maximal effort linear speed or aerobic training.

These findings inform tennis coaches of current drill and match demands in high-performance junior players, inherently assisting future evidence-based training prescription. Training prescription can in turn be tailored to target specific on-court preparation based on the physiological, psychological and technical needs of this cohort. The knowledge of differences in athlete and coach perceptions of load, alongside descriptions of training and match loads and changes during overseas tours assists with the prevention of “over-training”, “under-training” and “under-performance”. Therein, assisting short- and long-term athlete development, whilst avoiding the consequences of poor training prescription.
CHAPTER ONE

Introduction
Chapter 1: Introduction

1.1: BACKGROUND

1.1.1: Demands and Athlete Development in Tennis

Elite-level tennis players captivate worldwide audiences with ever increasing speed, explosiveness, agility, power, and aerobic capacity - in addition to technical and tactical finesse.\textsuperscript{1-5} Competitive tennis match play is characterized by high-intensity, intermittent efforts interspersed with active and passive recovery periods across undetermined durations - which in some cases (best of 5-set matches) are as long as 5-6 h.\textsuperscript{1,6-8} Besides the extensive physical requirements, elevated psychological stress is also present during matches, involving fluctuations in anxiety, motivation, concentration, and confidence.\textsuperscript{9-11} Such is the multi-disciplinary physical and psychological nature of tennis that successful performances cannot be distinguished by one single athletic component.\textsuperscript{1-5,9-11} Moreover, with the observed increase in the mean age of modern-day professional tennis players,\textsuperscript{12} a plan to address all facets of an athlete’s long-term athletic development (LTAD) becomes critical.\textsuperscript{1,13-16}

Similar to many other sports, professional tennis players devote countless hours of training (i.e., 15-20 h technical training per week), across many years of development, to reach their physical, mental and performance summits.\textsuperscript{16-18} Further, tennis increasingly appears to be a sport that favours early specialization. As evidence, competition exposure of children starts as young as under 8 y, before approximating the schedules of professional players by the age of 17 y (i.e., 18 - 22 tournaments annually).\textsuperscript{3,19} At the professional level, both the male and female schedules are designed for competition in upwards of 26 tournaments (up to 100 singles matches) every calendar year.\textsuperscript{20,21} The amount of high-performance tournaments that junior athletes play is comparable, and in extreme cases, where short-term success is
vigorously pursued, even greater than that of professionals.\textsuperscript{20,21} Consequently, the ability to plan the long-term development of physical and mental skills across weekly, annual and career schedules - balancing both short and long term outcomes (i.e., training vs. competition) - becomes a necessity. In turn, the monitoring of the training volume and quality (i.e., training load monitoring) of emerging tennis athletes plays a critical role in ensuring the appropriate type, volume and regularity of training stimuli are provided to assist athlete development. As such, the use of training load monitoring is proposed to assist in quantifying the athlete response to those varied loads, ensuring appropriate training prescription.\textsuperscript{22}

1.1.2: Why Measure Training Load

Accurate quantification of training load and ensuing recovery allows coaches and athletes to make informed decisions about subsequent training - dependent on current and anticipated states of fatigue or recovery.\textsuperscript{23-26} Accordingly, the concept of training load monitoring involves the quantification of both singular and accumulated training stimuli to determine whether session prescription has been as intended. As alluded to earlier, physical training forms the foundation of the development of physical capacities.\textsuperscript{27-29} However, without an understanding of the athletes’ response to various demands, training exposures cannot be balanced with sufficient recovery periods - ultimately putting athletes at risk of over or under-training.\textsuperscript{25,26,30,31} As a result, poorly or sporadically planned training may lead to injury, illness and/or reduced performance capacity.\textsuperscript{30,32-36} Thus, within most sports, and inclusive of tennis, it is suggested that training load monitoring strategies be developed to assist, if not optimize, the training prescription process.\textsuperscript{22,32}
With greater acceptance and use of training load monitoring practices in high performance sport, an increasing amount of literature has investigated the validation of various measures to monitor specific training modes (i.e., strength, power, endurance, and sport-specific exercise). Furthermore, given the subtleties of the varying physical demands of different sports, the validation of sport-specific load monitoring tools that help to optimize the training process presents as an ongoing challenge. The various definitions and interpretations of what constitutes “training load” partially clouds the debate, though delineating the training exposure into the work completed (i.e., external load) as well as the psycho-physiological response (i.e., internal load), provides some structure to this debate. Even though a working classification of training load is of assistance, the measures used are often confounded by their validity and sensitivity, logistical applicability and relevance to training in high-performance tennis settings.

1.1.3: How to Monitor Training Load; Issues and Complications

External Load
External load can be defined as the work executed by athletes (in both training and competition), independent of the psycho-physiological responses that are elicited. External load is commonly associated with measures of movement or action. Such external load variables are specifically measured and programmed using distance, time, speed and resistance. In general, athletes, coaches and other practitioners prescribe training programs using a measure of external load. It is also regularly used interchangeably with the description of the training stimuli (e.g., 6 x 400 m). In practical terms, external load prescription is the most common method of measurement, recording and prescription of training, likely owing – at least in part – to the simplicity of its implementation. When used accurately, measures of external
load can enable coaches to assess the degree of success of a training stimulus compared to what was planned.\textsuperscript{23,26,48,49}

Beyond physically marking out set distances or intervals for athletes to complete (i.e., 40m sprint), a variety of other external load tools exist. The most common measures of external load include global positioning systems (GPS), accelerometry (generally extracted from GPS unit data), motion tracking software, and notational analysis.\textsuperscript{50-57} While this will be discussed in much greater detail throughout the review of literature (Chapter 2), each of these tools provides practitioners with quantitative data describing movement patterns, velocities, distance, work-rest ratios, and/or joint and limb trajectories.\textsuperscript{50-55} Specifically, GPS devices provide the conventional measures of external load for most field-based team sports (i.e., Australian Football [AFL], cricket, hockey, soccer, rugby league and union),\textsuperscript{50-55,58-61} while video replay can inform specific movement occurrences that GPS may not pick up (i.e., limb movements, kicks, and passes). Computer vision techniques, cinematographic analyses and/or notational analysis are variously used to help quantify motor performance in a host of sports.\textsuperscript{62-65} Further, these forms of analysis may also supplement or instigate remedial work to address technical deficiencies.\textsuperscript{64-66} However, to date (outside of notational analysis) there is a dearth of appropriate external load monitoring tools available to tennis practitioners. Albeit limited availability of valid tools, external load measurements may facilitate the understanding of performance in the context of the training imposed; however, it is the relative physiological stress experienced by an athlete (i.e., internal load) that determines if the training stimulus causes a positive or negative training adaptation.
**Internal Load**

Despite the popularity of the external load monitoring tools, their use as a sole marker of training load overlooks an integral element of the dose-response relationship; that being the actual athlete’s response to the load.\(^6^7\) Accordingly, internal load markers are reported to be a key component in accurately establishing and quantifying the relative response to prescribed sessions.\(^2^3^,2^6^,3^3^,6^8^-7^1\) Effective periodisation and prescription of training to induce positive adaptation, and benefit both performance and injury prevention, requires an appreciation of both external *and* internal load.\(^2^3^,2^6^,3^3^,4^8^,4^9^,6^8^-7^1\)

Due to the highly individualized and relative nature of internal load monitoring, the type of data collected is typically psycho-physiological; which refers to the physiological and mental responses to the imposed physical stress.\(^9^,1^0^,7^2^,7^3\) Internal load assessments often involve a variety of measures including: a) perceptual measurements using arbitrary scales (i.e., RPE, mental exertion, and wellness questionnaires), b) descriptive recording of physiological function (i.e., HR, maximal oxygen consumption and ventilation), and c) changes in biochemical parameters (i.e., blood lactate, blood damage markers).\(^8^,7^4^-8^0\) Once more, the review of literature (Chapter 2) will cover these measures in more detail, however it is important to note that numerous laboratory and ecologically valid markers of internal load exist.

One of the most common and valid (due to its non-invasive nature) measures of internal load is RPE, which refers to the relative rating of perceived exertion interpreted by an individual during or following physical movement.\(^2^3^,2^5^,2^6^,3^7^,8^1\) RPE and its derivative, session-training load ([TL]; post-session RPE multiplied with the duration of the training session), is used throughout most high-performance sports
environments. Session-TL is proposed to help detect successful and unsuccessful training adaptations, specifically targeting the identification of athletes whom are not coping with training/life demands and monitoring athletes during rehabilitation. Research on the ecological validity of RPE (and session-TL) has been pursued in many sports including, but not limited to swimming, AFL, professional cycling, soccer, and rugby league. For the purposes of the introduction, a very high proportion of investigations into the validation of RPE, report RPE, session-RPE and session-TL as valid methods of quantifying internal loads in high-intensity competitive sports. Another tool commonly employed for internal load analysis is HR monitoring. Indeed, it remains one of the most important and widely used methods of load monitoring in sport. In high performance sports, longitudinal HR monitoring has been reported to assist coaching staff maintain a balance between overreaching and physiological compensation. In soccer, for example, some coaches reportedly monitor HR during an athlete’s response to certain physical stimulus in a set load, to better understand the player’s current training status. In summary, internal load monitoring tools assist reduce the chance of injury and over-training syndrome in athletes. However, unfortunately for the current course of studies, ecologically valid investigations of such tools are lacking for tennis.
1.1.4: Monitoring Competition and Training Load in Tennis - What Exists

With the ongoing advances in technology, athletes, coaches and other practitioners are taking an increasingly scientific approach to both training prescription and monitoring.\(^{32}\) However, despite sophisticated monitoring strategies reported within sports such as AFL,\(^{57,83,86}\) and soccer,\(^{53,87-90}\) presently there are limited tools available to tennis coaches that accurately describe the internal and external training loads.\(^{3,46,91,92}\) That said, one measure which has been used within tennis studies to report the external load demands of tournament play is notational analysis.\(^{1,7,14,93-96}\)

Therein describing tennis matches (3 sets) to comprise of 300-500 high intensity efforts and between 2.5-4.7 shots/rally, dependent on gender and surface,\(^{1,7,14,93,95}\) over 1.5-4 h.\(^{1,94}\) Internal load measures used in the literature (despite varying levels of scientific evidence) include HR and RPE. Mean HR’s can range between 130-170 bpm with peak HR reaching 190-200 bpm,\(^{1,96,97}\) while RPE has been reported to range from 5-7 arbitrary units (au) (category ratio; CR-10),\(^{22,98}\) and 10-16 (Borg 20-point),\(^{7,93,99}\) but with service games played at higher intensities.\(^{93,99}\) Although this provides the sport’s stakeholders some sense of the external and internal loads that characterize acute match play, substantially less is known about the loads of tennis training,\(^{3,46,92}\) or how those loads relate to tournament play.\(^{2,100}\)

Of the limited tennis training data reported, Reid et al.,\(^3\) and later Duffield et al.,\(^{101}\) have quantified the physiological and performance characteristics of tennis training, albeit only consisting of four discrete, hand-fed, tennis drills (i.e., *Star, Box, Suicide* and *Big X*). Reid et al.\(^3\) reported external loads through stroke count (0.7-2.3strokes.min\(^{-1}\)) and velocity (113-123m/s) as well as distance covered (76-114m) by virtue of GPS. Internal responses were measured via HR (178-182bpm), lactate (6.7-10.6mmol/L) and RPE (5.0-7.6au).\(^3\) Whilst this study represents a comprehensive
description of four drills, this is too narrow to translate to year round periodised training and the wide diversity of training drills used.\textsuperscript{3,91} Greater information of the external and internal loads associated with other drills, potentially arriving at general classifications of homogenous drills, would better inform and guide the coach-led prescription of session loads. Furthermore, the development and improvement of load monitoring systems for tennis, with subsequent focus on the validity of markers, alongside evidence of logistical appropriateness, would help the game's stakeholders to systematically plan and adjust the training process.

1.1.5: Complications of Monitoring Load in Tennis

Despite the range of systems used to monitor training load in elite sport, tennis remains lacking in informed, evidence-based processes. Partly, this scenario exists due to the logistical constraints of elite tennis, where methods are either inappropriate or yet to be validated in these settings.\textsuperscript{50,95,97,99} For example, GPS is reportedly of poor reliability for court sports, including tennis, due to insufficient frequency of satellite signalling to measure repeated change-of-direction movements.\textsuperscript{50,55} Multi-camera positional tracking software (i.e., Hawkeye) is both expensive to utilize (reportedly up to $100,000 per court), and impractical for training, especially with the volume of travel involved.\textsuperscript{2,102-104} Similarly, internal load measures that involve invasive biological intervention (i.e., lactate, creatine kinase [CK], testosterone), are difficult to obtain owing to their intrusion, expense, portability, and player consent.\textsuperscript{32,101}

Further, the nature of life as a tennis player is not conducive to controlled monitoring practices.\textsuperscript{15,105,107} Tennis players are often required to travel (alone) to various locations around the world for short periods of time, with variable access to resources, facilities or telecommunications.\textsuperscript{15,105,107} Consequently, perceptual scales, like RPE,
that are low cost and can be implemented without direct coaching contact seem intuitively appealing. In this sense, RPE has been extensively demonstrated as a valid and reliable load-monitoring tool in the endurance, team-sport and resistance exercise literature.\textsuperscript{26,42,105} Until recently, load monitoring in tennis relied on the intuition of the coach, which even in spite of the logistical challenges – was inadequate to cope with the complexity of dose-response relationships. While improvements in the utilization of load monitoring strategies is apparent, limited ecological validity of current tools underlines the need for a more scientific approach to training prescription, as well as athlete and coach education of the implementation and interpretation of load monitoring while isolated from professional assistance.\textsuperscript{16,21,106}

1.1.6: Issues with Training Load Prescription in Tennis

Practitioners working with tennis athletes not only face the challenge of limited access to valid and reliable load monitoring tools, but also need to negotiate the logistical and operational challenge of the sport itself when prescribing training. That is, the nature of tennis is such that athletes and coaches encounter problems associated with constant travel and time zone changes, match congestion, and limited training periods.\textsuperscript{16,21,107} Prolonged competition periods are also often scheduled owing to the importance of gaining ranking points and improvements thought to come from varied match exposure.\textsuperscript{21,108} As a result of this extended tournament play, training and development blocks – and more specifically, physical development - almost inevitably become compromised.\textsuperscript{37,38}

Within each tournament period, the weekly schedules can be characterized by heavy match congestion (obviously only during a string of winning performances). It then follows that the uncertain number, duration, and quality of matches exacerbates the
Chapter 1: Introduction

The challenge of scheduling and completing physical training within a tournament week (i.e., athletes do not know when to be at peak fitness).\textsuperscript{21,106,108} Subsequently, with a premium placed upon skill maintenance and recovery from match demands, strength and conditioning (S&C) during tournament blocks is commonly overlooked i.e., athletes do not prioritize the time to train their fitness.\textsuperscript{37,39,41} This complexity, coupled with a general lack of systematic training load information i.e., lack of valid monitoring tools, reinforces the need for appropriate external and internal load monitoring systems to feature in contemporary tennis player development.

1.1.7: Statement of the Problem

Training load monitoring has been observed to be a way of successfully balancing catabolic training stimuli with the recovery process.\textsuperscript{32,72,85,109} However, in tennis, tournament and travel demands, alongside limited preparation time and restricted access to facilities and coaching assistance, limits the available load monitoring options.\textsuperscript{15,105,107} Consequently, this means that coaching methods are often impromptu and rarely quantified. Literature highlighting the delicate training equilibrium between functional and non-functional over-training would suggest that current training prescription practices in tennis might be putting athletes at risk of injury or illness.\textsuperscript{10,32,72,85,109,110} With the limited means of monitoring training load in tennis, practitioners cannot definitively claim to have a consistent and accurate understanding of their athlete’s response to the imposed training stimuli i.e., do their perceptions match their athletes? Additional quantifiable training drill data (i.e., recorded drill databases) within the literature,\textsuperscript{3} will likely assist coaches in evidence-based choices when prescribing training drills and scheduling training loads.
While recent studies have described the responses of tennis athletes to competition demands, no investigations have compared the within-individual responses of tennis athletes to training, simulated matches and tournament play. Moreover, no research has investigated the effect of match schedule and outcomes, whilst on an international tour, on ensuing fitness capacities. As a result, the loads associated with international tours, and their relationship with fitness remains unknown. Consequently, despite the importance attached to physical fitness for professional tennis success, the best method of training load monitoring and prescription in preparation for tours as well as on-tour remains ad hoc.
Chapter 1

1.2: RESEARCH AIMS AND HYPOTHESES

Chapter 3, Study 1: Comparison of athlete-coach perceptions of internal and external load markers for elite junior tennis training.

Aims:

1. To determine the magnitude of discrepancy between coach and athlete perceptions of internal, (i.e., RPE and mental exertion) and external load (i.e., stroke count) during on-court training.
2. Compare coach and athlete perceptions of external load to objective notational analysis to assess the precision of their ratings.

Hypothesis: Coaches underestimate measures of athlete internal load, while demonstrating a greater understanding of stroke and error rates than athletes.
Chapter 4, Study 2: A descriptive analysis of internal and external loads for elite-level tennis drills.

Aims:

1. To describe external and internal loads for a range of common on-court drills within 8 homogenous drill categories.
2. To determine the relationship of session-RPE and session-TL to other internal and external load monitoring tools in tennis.

Hypotheses:

1. Physiological and perceptual demands of drills increase with increased external load, due to more intensive running efforts.
2. Session-RPE and session-TL are strongly and positively associated with other load measures including mental-exertion, mean-HR, stroke rate, and error rate.
Chapter 5, Study 3: A comparison of the perceptual and technical demands of tennis training, simulated match play, and tournament match play.

Aims:

1. To determine the technical and perceptual demands of drill-based training sessions in comparison to simulated and tournament match play.
2. To compare the technical and perceptual responses within tournament matches won and lost, as well as against seeded and non-seeded opponents.

Hypotheses:

1. Training session’s present lower training loads than simulated match play, which is, in turn lower than tournament matches.
2. As compared to matches won and played against non-seeded opponents, tournament load demands are elevated in matches lost and against seeded opponents.
Chapter 6, Study 4: The relationship of training load to physical capacity changes during international tours in high performance junior tennis players.

Aims:

1. To examine the magnitude of changes in physical capacity, from pre to post-tour, in the context of training and match load while on tour.
2. To further critique changes in physical capacity, accounting for the athletes demonstrating the most positive and negative fitness changes, whilst negating a possible regression of change data towards the mean.

Hypotheses:

1. Physical capacities will decline post-tour; with declines positively related to lower strength and conditioning training loads on tour.
2. Higher match loads on tour will negatively relate to a reduction in physical capacities from pre to post tour.
Chapter 7, Study 5: The effect of pre-departure training loads on post-tour physical capacities in high-performance junior tennis players.

**Aim:**

1. To examine the differences between loads performed prior to and on-tour, and their subsequent relationships with the observed changes in fitness characteristics.
2. To determine the effect of S&C coach presence on training load type and volume whilst on-tour.

**Hypotheses:**

1. TL completed prior to leaving for tour is greater than on-tour, while greater pre-tour TL is more strongly related to changes in physical capacity, from pre to post tour, than on-tour training and match load.
2. Greater TL is completed on-tour in the presence of S&C support.
1.3: LIMITATIONS

- The cohort of junior (14-18y) high-performance tennis athletes (both male and female) used here may restrict results being extrapolated to other populations. However, in another light, the similar high performance training programs performed by all athletes (male and female) highlight a homogenous sample.

- Data collection was conducted in field-based settings and involved high-performance but non-professional, developmental athletes. This setting prevents total control of all external variables and may restrict some (laboratory-validated) measures from being utilized.

- In addition to the above point, the high-performance nature of the tennis environment investigated, limited the subject cohort of each study to tennis athletes and a lack of control group.

- Due to the field-based and coach-determined nature of each ecologically validated study, only hard court surfaces were investigated throughout the thesis. As such, this may constrain interpretation of study results across other surfaces (i.e., clay and grass courts).

- Assessment of external load in Studies 1, 2 and 3 was limited to notational analysis due to a lack of other reliable and valid measures. A count and rate of strokes and errors may not fully describe the extent of objective physical demands (external load) during training and tournaments.

- Due to the integrated method of data collection within a high-performance tennis setting, invasive measures of internal load were limited throughout all studies. Specifically, during training sessions internal load measures were constrained to RPE, mental exertion and HR (peak and mean). However, due to the perceived restrictive properties of HR monitor bands, HR was not collected during matches.
Due to an inability to perform maximal testing on athletes during Studies 1, 2, and 3, estimated %HRmax was compared between drill categories using the formula 211 - 0.64·age (standard error, ± 10 bpm). This estimation of HRmax may present some error.

Within all studies, athletes were encouraged to standardize nutritional habits in preparation for and during both training and competition. However, the addition of S&C sessions to tennis (data collection) sessions, and the varying session intensity and duration meant energy intake could not be regulated. Similarly, owing to the field-based settings, characterized by uncertain match start and finish times, travel demands and the variable selection and timing of meal/hydration options, nutritional practices could not be standardized.

Whilst conditions across Studies 1, 2, and 3 were typically dry and relatively warm (Australian summer), these were unable to be standardized across all training sessions and matches. Similarly, during international tours (Studies 4 and 5) tennis sessions, completed in a range of climates, were not able to be controlled and present a limitation in interpretation of the results.

Throughout Studies 4 and 5, on-tour loads were highly reliant on match outcome; therefore each tour may impose a different training response. This setting prevents total control on the training schedule and therefore the amount of training and matches completed.

Field-based fitness testing within Studies 4 and 5 was punctuated by a lack of flexibility in the testing protocols. These protocols were prescribed by Tennis Australia, meaning that only certain tests were able to be completed, which did not include strength testing owing to its associated high eccentric loads.
1.4: DELIMITATIONS

- Athletes and coaches were familiarized with all training and match load monitoring practices prior to the data collection in all studies. This ensured athlete knowledge of all testing procedures, measures, and equipment;
- An assigned coach for each athlete was present during all testing procedures;
- Athletes and coaches were asked to report RPE, mental exertion, as well as stroke and error counts in isolation of peers and coaches;
- All data collection was conducted within ecologically valid circumstances and in accordance with the approval of coaching staff;
- Sampling of athletes was consistent between all studies, with Australian junior, high-performance National Academy athletes recruited.
CHAPTER TWO

Literature Review
2.1: Overview

A growing number of high-performance sporting environments have embraced the advantages of recording and monitoring responses to training through the quantification of training load. Despite the global prominence of tennis as a modern-day sport, the academic literature concerning training and competition load monitoring has been historically lax. Recently an increased adoption of load monitoring methods, as used in other sports, has been observed in tennis environments;\(^9,^{22,99}\) though the scientific literature investigating such methods in tennis-specific contexts still remains relatively sparse.\(^2,^{111}\)

As an overview, the current literature review will describe the reported physical demands of tennis matches (both singular and tournament derived), highlighting the methods adopted and monitoring systems used to quantify load. Subsequently, the review will address both the theoretical benefits of load monitoring strategies for optimal performance preparation, as well as the potential repercussions of the absence of load monitoring for high-performance athletes. The chapter will then examine the origins of load monitoring, exploring its rationale and how different theories have led to the development of load monitoring strategies. Finally, the chapter will review why limitations arise for the monitoring of load in tennis, and where possible, provide specific examples of the complications of load monitoring for tennis.
2.2: INTRODUCTION

The physical demands of tennis dictate a complex training prescription to adequately accommodate diverse physical and technical attributes. Further, competitive (professional) tennis necessitates extensive travel, resulting in truncated preparation time, restricted access to facilities and coaching assistance. Consequently, the demanding competition and training needs, interfaced with the often nomadic nature of competition-related travel, can restrict the opportunity for options for monitoring the training stimuli. Moreover, owing to an apparent divorce in the understanding of and actual training prescription by tennis coaches, improvement in the understanding of load monitoring tools is a possible key to overcoming the above scenario. To this end, without effective methods to quantify training and match loads, tennis coaches risk inadvertently exposing their athletes to the complications associated with over- or under-training, respectively i.e., under-performance, injury or illness.

With the delicate training equilibrium between functional and non-functional over-training in mind, this literature review will highlight the current research literature of training load demands in tennis. Furthermore, outside of purely reviewing match load quantification, readers are advised to consider the particular methods of load quantification, and resulting efficacy of use, within daily tennis training environments. Accordingly, this review will intentionally highlight the scarcity of quantifiable training drill data. Further, despite numerous investigations describing the responses to competition demands, there is a dearth of research comparing responses between training, simulated matches and tournament play within the same individual cohort. Hence, owing to a dearth in didactic literature allowing
specific training prescription based on individual athlete needs, the review will provide a historical overview of the evolution of load monitoring, to hopefully stimulate further research in tennis.

Finally, the review will highlight a lack of investigation into the effect of prolonged international tennis tours as are often evident in professional and junior athletes. Consequently, despite the importance of optimal physical levels for tournament success,\textsuperscript{1-5} the most effective load monitoring protocol on-tour, and hence optimal pre- and on-tour training load prescription, is uncertain. Figure 2.1 provides a conceptual overview of the topics to be presented in a subsequent section of this review of literature.
Chapter 2: Literature Review

2.3: Physical Demands of Tennis Matches

2.3.1: Acute Competition Demands
- Match Duration
- Match Temporal Structure
- Movement Characteristics
- Stroke Characteristics
- Critical Match Variables
- Physiological Responses
  - VO₂, HR, Biological Markers
- Neuromuscular Changes
  - EMG, MVC, Force Production
- Perceptual Responses to Match Play
  - RPE (CR 6-20, CR10), Muscle Soreness

2.3.2: Tournament and Consecutive Match Demands
- Tennis Tournament Frequency
- Accumulation of Load During Tournaments

2.4: Importance of Load Monitoring for Elite Sport

2.4.1: Potential Benefits of a Successful Load Monitoring System
- Tapers
- LTAD Models

2.4.2: Potential Issues Arising from Lack of a Tennis Load Monitoring System
- Fatigue Continuum
- Stages of Over-Training

2.5: Theory Behind Load Monitoring - Historical Overview

2.5.1: Path to Modern-Day Load Monitoring Systems
- History of Training
- Adaptation

2.5.2: Athletic System Models
- Impulse-Response Model
- Holistic Load Monitoring

2.6: Practical Implementation of Athletic System Models

2.6.1: External Load Monitoring
- Performance Testing
- Time-Motion Analysis

2.6.1: Internal Load Monitoring
- Biological Measures
- Heart Rate
- RPE Measures

2.7: Complications of Load Monitoring in Tennis - Key Limitations

2.8: State of the Literature

Figure 2.1: A schematic representation of the review of literature
2.3: PHYSICAL DEMANDS OF TENNIS MATCHES

“Nothing can substitute for just plain hard work. I had to put in the time to get back. And it was a grind. It meant training and sweating every day. But I was completely committed to working out to prove to myself that I still could do it”.

Andre Agassi

2.3.1: Acute Competition Demands

The theory of training practice is to develop the necessary physical, technical and tactical attributes to be sufficiently prepared for competitive demands. From a physical preparation standpoint, it is therefore necessary to understand the extent of external and internal competitive loads encountered to then ensure physical training loads are adequate. Tennis requires a dynamic and complex interaction of physical attributes, whereby athletes are required to repeat explosive movements to the ball, produce strategically determined force throughout a stroke, and recovery to a new court position after contact. From a competition perspective, Gomes et al. highlight an almost innumerable amount of match play opportunities for young tennis players; providing the example of ‘Future Tournaments’, which can consist of up to 400 events available to entry-level players in a single year. As such, this section will examine key areas within the literature describing the loads associated with acute and accumulated tennis matches (i.e., tournaments). Within this context, the load monitoring tools used and interpretation of their use will be presented where possible. To elaborate, the thesis foci are on the cohort of junior high-performance players, although there is very limited information specifically describing junior athletes competing within junior competitions. Thus, where possible the thesis will draw upon these limited studies, though the predominant body of literature relates to senior, mid to lower ranked players.
**Match Duration**

Typically, competitive tennis matches are comprised of a best of 3-set format.\(^6,121\) In junior and women’s tennis, this is consistent for all tournament types; although, Men’s Grand Slam and Davis Cup events require best of 5-set matches.\(^2,100\) Until recently, descriptive literature had focused on the match demands of 3-set matches, with studies observing matches lasting up to 3 h, with a typical average of 1.5 h.\(^8,51,93,95,122,123\) More recently, studies have made reference to the possibility of matches lasting >5 h in best of 5-set matches.\(^6,8,98,123-125\) As highlighted by Barnett\(^126\) and Reid and Duffield\(^2\), matches such as the 2012 Australian Open men’s final (5h 53 min), and 2010 men’s Wimbledon Championship match between John Isner and Nicholas Mahut (11 h 5 min), there remains a high unpredictability of professional tennis matches. These events have stimulated further investigation into the physical demands within best of 5-set matches, with Gomes et al.,\(^98\) reporting demands in a case study of a 3.5 h, (4-set [3-1]) match between 2 Davis Cup athletes.

More recently, Gescheit et al.,\(^100\) has applied these extended match durations within a descriptive analysis of the effects of 4 h matches, across 4 consecutive days, in a bid to replicate a Grand Slam or Davis Cup ‘worst case scenario’. Whilst acknowledging these possible match durations is important, in general training is prescribed through an accumulation of load, rather than for example, the prescription of 5 h simulated match play. Moreover, within junior high-performance competition, all matches are limited to best of 3 set format, with Fernandez-Fernandez et al.,\(^14\) reporting match durations of junior female athletes ranging between 53 and 111 min total duration. Yet, whilst these extreme match durations (> 5 h), and 5 set match formats, are of little influence to the immediate training plan of junior (male) athletes, within a long-term transition into the senior ranks, the significance of these figures increases.
Match Temporal Structure

Just as total match duration has been noted to vary significantly,\textsuperscript{6,121} effective playing time within matches is also highly variable, owing to a collection of factors, including; age, gender, playing surface, playing style, environmental conditions, match outcome, strategy and motivation.\textsuperscript{6} These factors have been described in numerous descriptive studies, each highlighting highly variable point, rally, and set durations.\textsuperscript{6,96,116,117} Before elaborating on previously reported effective playing time demands and variables, it is important to acknowledge that while playing time is highly unpredictable, recovery periods between sets (120 s), changeovers (90 s), and points (20 s) are, to a greater extent, controlled by International Tennis Federation rules. Thus despite playing time being variable, recovery time is non-negotiable, creating a set recovery time to a variable work duration.\textsuperscript{127}

Reid and Duffield\textsuperscript{2} report that the finalists of the 2012 Australian Open competed in 369 points during the match, and later Gescheit et al.,\textsuperscript{100} report between 301 ± 40 and 340 ± 35 points over a standardized 4 h period. Whilst, few investigations have critiqued match data of junior populations,\textsuperscript{14,93} extensive literature exists for point duration or rally time in senior populations, with Kovacs\textsuperscript{6} and later Fernandez-Fernandez et al.,\textsuperscript{125} providing extensive synopses of the within-match temporal variations of tennis from as early as 1985.\textsuperscript{128} From data available from a junior population, Fernandez-Fernandez et al.,\textsuperscript{14} report rally durations ranging from 5.1 - 7.5 s. Whilst from an elite perspective, rally durations are reported to have been as short as 2.52 s on a grass-court surface,\textsuperscript{129} and up to 10.4 s on clay.\textsuperscript{120} Since 2008, further information has become available, reporting rally durations over a 3-4 h match period.\textsuperscript{100,130} Specifically, Girard et al.,\textsuperscript{130} simulated 3 h match conditions, observing rally durations of 7.5 ± 0.8 s. Later, Gescheit et al.,\textsuperscript{100} reported rally durations across
4 consecutive days of 4 h matches ranging from 9.3 ± 1.0 s (day 2) to 10.1 ± 0.1 s (day 1). In terms of game duration, a recent analysis by Martinez-Gallego et al.,\textsuperscript{116} reports median game lengths of 174.2 s, although still as brief as 50 s in professional male tennis players. In terms of effective playing time within elite and junior competition, matches are reported to contain just 20 - 30\% actual play within total match time,\textsuperscript{8,117,123,130} equating to typical work-to-rest ratios of ~ 1:3.\textsuperscript{14,93,117,131-134} In light of these data, Kovacs\textsuperscript{6} suggests that tennis points rarely last for greater than 10 s, with the majority residing ~ 6-8 s; thus, training and testing for tennis should engage with these likely scenarios.

**Movement Characteristics**

A key marker of external load relates to the distances and speeds of the movement demands; although in tennis this is often complicated by the discreet, fine movement patterns that are difficult to measure.\textsuperscript{51,135} Movement data reported by Reid and Duffield on the 2012 Australian Open men’s final describes the in-point distances traversed by both players as measured from Hawkeye image recognition technology.\textsuperscript{2} Court displacements of both players were greater than 6 km in the (then) number 1 and 2 ranked players in the world over a 5 set match lasting 5 h 53 min.\textsuperscript{2} Whilst this example case study is of interest, other literature has reported various total match displacements, ranging from ~3.3 km during a 90 min simulated match for junior male athletes, to ~3.6 km during a 60 min simulated match for internationally ranked male adults.\textsuperscript{15,51} Previous tennis literature has classified movement demands during a match, based on displacement from ready position (recovery stance after stroke is played). As such, it has been reported through computer system analysis (SAGIT), that up to 80\% of total strokes played during an professional male match reside within 2.5 m of the ready position, leaving ~ 10 \% between 2.5 - 4.5 m, and fewer
than 5% of strokes played outside 4.5 m, equating to 8 - 12 m each point, and ~ 63 m per game.\textsuperscript{116,136,137}

The movement velocities of matches have also been assessed within both junior and elite competitive tennis players, mainly through the use of GPS technology, albeit generally during simulated competition. Through GPS analysis of junior male tennis players, Hoppe et al.,\textsuperscript{51} report peak and mean velocities of 4.4 ± 0.8 m·s\(^{-1}\), and 0.7 ± 0.1 m·s\(^{-1}\), respectively. These movement velocities are below those of elite-level adults reported by Reid and Duffield,\textsuperscript{2} whereby maximum speeds in excess of 5.6 m·s\(^{-1}\), emphasizing the athleticism of modern elite tennis athletes given the small movement spaces within court confines. Hoppe et al.,\textsuperscript{51} further reported movement within specific velocity bands, observing that 34.3% of movements were performed at 0 to < 1 m·s\(^{-1}\); 55.7 % at 1 to < 2 m·s\(^{-1}\); 7.7 % at 2 to < 3 m·s\(^{-1}\); 1.9 % 3 to < 4 m·s\(^{-1}\); 0.4 % at ≥ 4 m·s\(^{-1}\). Moreover, using automated computer software, Fernandez-Fernandez et al.,\textsuperscript{15} report peak velocities of veteran (≥ 40 y) male tennis players of up to 4.4 m·s\(^{-1}\), and up to 80 % of total time spent at walking pace. These data highlight the distinct differences in movement velocity between junior, advanced veteran, and elite level tennis players. Junior high-performance academies can thus utilise such data within the prescription of speed training sessions and on-court movement drills to ensure appropriate movement patterns are performed at appropriate standards.

**Stroke Characteristics**

Outside of (whole-body) movement parameters outlined above, notational analysis of specific stroke characteristics provides a tennis-specific marker of external load. Using the case study of the 2012 Australian Open final (hard court) as somewhat of a benchmark, Reid and Duffield\textsuperscript{2} report that the players hit over 1100 groundstrokes
with 40% of points involving > 8 strokes. These data clearly out-weigh those previously reported in a Davis Cup match (4 sets, hard court) case study by Gomes et al.,\textsuperscript{98} in which 60% of points in the third and fourth set lasted less than 2 strokes. Although both are specific case studies, the latter of these data sets aligns with earlier descriptive studies reporting between 2.5 and 6 strokes per rally within both junior and lower level professional tennis matches.\textsuperscript{8,93,101,117,136} Specifically in junior matches, number of strokes per rally have been reported to amount 5.45 ± 0.22, and 5.93 ± 0.12 strokes for male and female athletes, respectively. Thus, it can be established that outside of overtly aggressive style players,\textsuperscript{8} standard or ranking, such data likely reflects the consistency of stroke play within rallies (i.e., reduced error rates in elite matches).\textsuperscript{117}

In addition to the sheer volume of strokes played during competitive matches, the quality and outcomes of stroke play is critical for performance.\textsuperscript{6} In terms of other quantifiable tennis-specific markers of external load, research has additionally investigated the effect of acute ‘match-like’ fatigue on velocity and/or accuracy of groundstrokes and serves. Previous tennis reviews refer to research conducted using volitional fatigue inducing protocols (i.e., Loughborough Intermittent Shuttle test) to support the notion that acute fatigue during matches corresponds to a decline in stroke accuracy.\textsuperscript{7,121} However, data from actual competitive situations of any tennis population is clearly lacking.\textsuperscript{2}

Closer examination of the original papers on acute fatigue and tennis stroke play suggests that interpretations of the role of fatigue in tennis should be taken with caution.\textsuperscript{119,138-140} For example, Davey et al.,\textsuperscript{119,138} and Vergauwen et al.,\textsuperscript{139} purport declines in stroke performance (velocity and/or accuracy) with “fatigue”. Notably,
each of these papers included high-intensity tennis performance tests, rather than actual match play, or even simulated competitive matches, and reported only subtle performance decrement.\textsuperscript{119,138,139} Ferrauti et al.,\textsuperscript{141} also reported that intermittent training drills resulted in declines to both the accuracy and velocity of player serve and groundstrokes. Additionally, Davey et al.,\textsuperscript{119} reported that despite reductions of up to 81\% in hitting accuracy at the point of volitional fatigue during the simulated match-play, re-testing of serve accuracy prior to the commencement of the subsequent endurance capacity test, saw performance return to pre-test levels. To the authors knowledge, only Mitchell et al.,\textsuperscript{142}, who investigated the effect of a carbohydrate beverage on tennis play (3 h continuous play), has reported a significant stroke detriment during match play. Yet, of all variables tested (including serve velocity, serve and groundstroke accuracy), only a small decline in serve velocity (non-significant; p > 0.05), and in fact a significant improvement in first serve \% was observed.\textsuperscript{142} Together, these inconsistencies highlight the need for further investigation into the changes in performance outcome in response to “live” matches, with ranking points on offer, to infer changes in fatigue-related performance variables. This is particularly the case within junior populations where developmental tennis drills frequently involve volitional fatigue and where data from competitive scenarios is sparse.\textsuperscript{2}

As suggested in a review by Hornery et al.,\textsuperscript{111} technical skill performance (i.e., stroke play characteristics), will decline at the point of volitional exhaustion; however, the actual occurrence of volitional exhaustion in tennis is rare, likely owing to the standardized temporal structure of a match, as based on ITF rules. A recent study by Gescheit et al.,\textsuperscript{100} investigated the effect of 4 consecutive days of tennis match-play, reporting no evidence of a decline in serve velocity or accuracy following the 4 h
match on day 1. In line of these findings, Kovacs\textsuperscript{121} previously suggested that suitable work-to-rest ratios should be utilized within training to produce the optimal training outcome. As an example, technical sessions will likely require greater recovery than an on-court conditioning drill designed to stress energy system demand. Thus an example is provided of how the quantification of match demands can guide the prescription of training drills within developmental (i.e., junior high-performance) environments. As intuitively useful as such propositions are, currently they remain without evidence-based support from training or competitive environments, particularly in elite or high-performance junior populations. In order to highlight this suggestion, Table 2.1 presents a summary of a range of studies reporting a variety of external load measures to tennis match play.
Table 2.1: Summary of studies implementing external load measures to determine match demands.

<table>
<thead>
<tr>
<th>Authors (y)</th>
<th>Cohort (n)</th>
<th>Match Format</th>
<th>Surface</th>
<th>External Load Measures</th>
<th>Key Findings</th>
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<tbody>
<tr>
<td>Duffield et al., 204</td>
<td>Professional Male (8)</td>
<td>2 x Simulated 90 min Match (with and without recovery protocols)</td>
<td>Hard x 2</td>
<td>Performance Testing (Pre - Post)</td>
<td>Stroke rate ↔ between conditions</td>
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<td></td>
<td>CMJ</td>
<td>Effective playing time ↑ after recovery</td>
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<td>Accelerometry (100 Hz)</td>
<td>3D load ↔ between conditions</td>
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<td>Total 3D load</td>
<td>CMJ ↑ before match, after recovery</td>
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<td>Notational Analysis</td>
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<td>Total duration</td>
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<td>Effective playing time</td>
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<td>Number of strokes</td>
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<td>Stroke rate</td>
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<td>Number of errors</td>
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<td>Fernandez-Fernandez et al., 95</td>
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<td>23% rallies lasted between 0-3 s</td>
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<td>Game and rally duration</td>
<td>28% rallies lasted between 3-6 s</td>
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<td>Time between games, points, and serves</td>
<td>24.1% time spent resting 9-12 s</td>
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<td>Effective playing time</td>
<td>24.2% time spent resting 12-15 s</td>
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<td>Strokes per rally</td>
<td>57.7% rallies lasted between 1-3 strokes</td>
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<td>27.7% rallies lasted between 3-4 strokes</td>
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<td>Gescheit et al., 200</td>
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<td>Effective playing time ↓ days 3-4, compared to day 1</td>
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<td>20-m sprint</td>
<td>Post-match 20-m sprint ↓ days 2-4, compared to day 1</td>
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<td>CMJ</td>
<td>Pre-match CMJ ↓ days 2-4, compared to day 1</td>
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<td>Shoulder MVC</td>
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<td>3D load in each vector</td>
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<td>Notational Analysis</td>
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<td>Error, winner counts</td>
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<td>Effective playing time</td>
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<td>1st serve %</td>
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<tr>
<td>Gomes et al., 98</td>
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<td>Timing details</td>
<td>Set durations 60, 48, 45, 44 min respectively</td>
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<td>Strokes per rally</td>
<td>Rally length ↓ as match progressed</td>
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<tr>
<td>Authors (y)</td>
<td>Cohort (n)</td>
<td>Match Format</td>
<td>Surface</td>
<td>External Load Measures</td>
<td>Key Findings</td>
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<td>Gomes et al.,115</td>
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<td>- All tests ↔ 24 h post-match to baseline</td>
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<td>Hoppe et al.,90</td>
<td>Junior (13-14 y) High-Performance Male (20)</td>
<td>Simulated Match (10 games)</td>
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<td>GPS (10 Hz)</td>
<td>- Acceleration and deceleration ↑ frequent than high velocity movements</td>
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<td>- Total match time</td>
<td>- Movement velocity ↔ throughout duration</td>
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<td>- Movement velocity ↔ winners and losers</td>
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<td>Hornery et al.,95</td>
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<td>Hard x 2 Clay x 1</td>
<td>Notational Analysis</td>
<td>- Recovery time between points ↑ hard court matches</td>
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<td>- 1st and 2nd serve velocity</td>
<td>- All other notational measures ↔ between surfaces</td>
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<td>- 1st serve accuracy</td>
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<td>- Match duration</td>
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<td>- Rally length, strokes per rally</td>
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<td>- Time between games, points, and serves</td>
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<tr>
<td>Johnson et al.,118</td>
<td>Professional Male (22)</td>
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<td>Hard (US Open) Clay (French Open) Grass (Wimbledon)</td>
<td>Notational analysis</td>
<td>- French Open ↑ strokes than Wimbledon</td>
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<td>- Score (sets, games, points)</td>
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<td>- Service/Return stroke count</td>
<td>- Serve predominant stroke (45%) French Open, (60%) Wimbledon</td>
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<td>- Stroke count per game</td>
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<td>- Stroke type</td>
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</tbody>
</table>
### Authors (y) | Cohort (n) | Match Format | Surface | External Load Measures | Key Findings |
--- | --- | --- | --- | --- | --- |
Martin et al.,96 | Professional Male (4) and Female (2) | Simulated Match (16 games) | Hard Clay | Performance Testing - FH and BH running speed test | Mean point duration ↑ clay court - Effective playing time ↑ clay court - Running times ↔ between surfaces and throughout match |
Martínez-Gallego et al.,116 | Professional Male (11) | ATP Tournament 500 Valencia | Indoor Hard | Automated Tracking Software (SAGIT) - Total play time - Effective play time - Distance covered - Movement velocity - Match outcome - Time in offensive/defensive zones | Losers ↓ distance - Losers ↑ movement velocity - Losers ↑ time in defensive zones |
Mendez-Villanueva et al., | Professional Male (8) | Simulated Match (best of 3 sets) | Clay | Notational analysis - Rally duration - Rest time - Effective playing time - Strokes per rally | 56% rallies lasted between 1-6 s - ≈82% rest intervals lasted between 9-21 s - Effective playing time 13.8-28.6 % - Mean strokes per rally 2.7 ± 2.2 |
Mitchell et al.,142 | Amateur to Professional Male (10) and Female (2) | 2 x Simulated 3 h Match (with and without CHO ingestion) | Hard | Performance Testing (Pre - Post) - Serve speed and accuracy - 10 ball shuttle run test Notational Analysis - Error counts - 1st and 2nd serve % | 1st serve % ↓ hour 2, compared to hour 1 in both conditions - 1st serve % ↓ hour 3, compared to hour 1 in CHO ingestion condition - Shuttle run test ↑ post match in both conditions
<table>
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<tr>
<th>Authors (y)</th>
<th>Cohort (α)</th>
<th>Match Format</th>
<th>Surface</th>
<th>External Load Measures</th>
<th>Key Findings</th>
</tr>
</thead>
<tbody>
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<td>Murias et al.,144</td>
<td>National-level Male (4)</td>
<td>6 x Simulated Match (90 min)</td>
<td>Hard x 3</td>
<td>Notational analysis: - Total and rally duration - Time between games, and change of ends - Work to rest ratio - Distance covered (visual grid system)</td>
<td>- Total duration ↑ on clay than hard - Rally 22% ↑ on clay than hard - Rest time ↔ between surfaces - Mean distance ran in match (21%) and per point (25%) ↑ on clay than hard</td>
</tr>
<tr>
<td>O'Donoghue and Ingrani50</td>
<td>Professional Male and Female (252 matches)</td>
<td>Grand Slam Singles</td>
<td>Hard (Aus Open) (US Open) Clay (French Open) Grass (Wimbledon)</td>
<td>Notational analysis: - Score (sets, games, points) - Service success - Timing details - Stroke count - Point type - Point outcome</td>
<td>- French Open ↑ rally length - Wimbledon ↓ rally length - French Open ↑ baseline rallies - Women ↑ baseline rallies than Men</td>
</tr>
<tr>
<td>Smekal et al.,97</td>
<td>National-level Male (20)</td>
<td>Simulated Match (50 min)</td>
<td>Indoor Clay</td>
<td>Notational analysis: - Game and rally duration - Time between games, points, and serves - Effective playing time - Strokes frequency - Offensive/defensive players</td>
<td>- Rally duration 6.4 ± 4.1 s - Effective playing time 29.3 ± 12.1 % - Stroke frequency 42.6 ± 9.6 per min - Regression analysis reveals rally duration as most promising variable to determine VO₂ during match</td>
</tr>
<tr>
<td>Torres-Luque et al.,113</td>
<td>Junior (15-16 y) High-Performance Male (8), Female (8)</td>
<td>Regional Singles Tournament (semifinal and final)</td>
<td>Hard</td>
<td>Notational analysis: - Total play time - Effective play time - Point duration - Strokes per rally - Number of points</td>
<td>- Total, effective and rest time ↔ male and female - Work to Rest ratio, 1.2.7 - Stroke count ↔ as elite, but ↓ mean duration</td>
</tr>
</tbody>
</table>

 faucet increased; ↓ = decreased; ↔ = no change; FH= forehand; BH= backhand; RM= repetition maximum; CMJ= countermovement jump; Hz= Hertz; %= percentage; CHO= carbohydrate; VO₂= oxygen consumption.

Chapter 2: Literature Review
Chapter 2: Literature Review

Additional Critical Match Variables

Whist it would seem useful to compare movement demands between players as evidence of acute fatigue and/or explain match performance outcomes, such simple comparisons should be made with caution. It is important to acknowledge numerous other important match variables that can influence the external load stimulus. Such variables include playing style, court surface, and gender. The following section will examine and acknowledge the impact these variables can have in descriptive observations between acute matches.

A recent study by Martinez-Gallego et al.,\textsuperscript{116} compared the movement characteristics of winners and losers at a professional tennis tournament. It was observed that winners covered greater distances, but move at slower velocities than losers. This, along with an observed increase in time spent in defensive positions by losers, indicated that match winners tended to be positioned in more dominating positions to dictate the development of the point i.e., making the losing player run further.\textsuperscript{116} The authors suggest that total match displacement is likely irrelevant, and proceeded to inspect the differences in movement at the rally level.\textsuperscript{116} As such, winners of individual games were observed to cover greater distance in offensive zones, or positions of tactical dominance, than losers, whilst conversely, losers covered greater distance in defensive zones.\textsuperscript{116} These results suggested that game winners tended to force game losers to exhibit behaviours typically associated with a defensive strategy. While, defensive and offensive strategies are not well defined within the literature, it seems reasonable that game style (i.e., baseline player vs. serve and volley player) may impact the advantage within certain match situations, and thus affect match movement characteristics.
Typically defensive players are defined as players who are more comfortable to play a match towards or behind the baseline, whereas offensive players are players who prefer serve-volley play, while whole-court players have no obvious preference. As previously reported, playing style has a large impact on the duration of points, and usually the match. Furthermore, significant differences were observed between all three types of players depending on which player was in control of the point. When an offensive player was in control of a match, the mean rally length was < 5 s with an effective playing time of ~ 21 %, while whole-court players (6 - 11 s, and ~29 %), and defensive players (> 15 s, and 38.5 %) displayed greater rally durations when in control. Smekal et al. have reported that games where both players were defensive players resulted in greater effective playing time and rally length, though reduced stroke rates compared to games including at least 1 offensive player. As such, Smekal et al. advised that conditioning prescription should be tailored to also consider the type of playing style.

In highlighting that certain training conditions may suit different players game styles, various literature further suggests that court surface will also influence load demands. Court speeds are classified by the ITF (slow, medium and fast) according to the coefficient of friction and restitution between the ball and the court. Greater coefficients are typical on clay courts resulting in a high and relative gentle bounce, providing greater time to hit the ball than on faster surfaces. This may lead to less difficulty to play shots and therefore, longer rallies from the baseline. On the other hand, faster hard court surfaces limit the time available to hit the ball hence advantaging offensive players.
O’Donoghue and Ingram\textsuperscript{120} have previously examined the impact of the different court surfaces across each of the Grand Slam events. Rally lengths at the French Open (clay) were significantly longer than any other surface, while rallies at Wimbledon, on grass-court (the fastest of all surface types) were shortest.\textsuperscript{120} Additionally, effective playing times of matches on clay courts are reportedly between 20 and 40\%, while these times decrease to 10 - 15\% on hard court.\textsuperscript{6,125} More recently, further research reports similar results in lower level tennis players, with significantly greater mean effective playing times and rally lengths observed on clay (~ 26\% and 8.5 s, respectively), than resin (hard court; 19.5\% and 5.9 s, respectively). In terms of junior tennis training load prescription, these data should be taken into consideration when scheduling training drills and simulated match play, as external loads are likely to be impacted by differing court surfaces.\textsuperscript{21} Thus, coaches require astute knowledge of both individual athlete tournament schedules, alongside the associated physical effects of court variations, to justify training surface changes.\textsuperscript{21,125} That said, currently there is a specific dearth in the training load information of high-performance juniors on any playing surface.

Within the same investigation of the Grand Slam events, O’Donoghue and Ingram\textsuperscript{120} also identify a discrepancy in the rally lengths between male and female players. Specifically, rallies in women’s singles were significantly longer than those in men’s, with the longest rallies occurring at the French Open.\textsuperscript{120} Torres-Luque et al.,\textsuperscript{117} have examined gender differences between 32 national-level players on hard court surface. The researchers observed no difference between genders for match duration, effective playing time, work-to-rest ratio, rallies per game, strokes per rally, or rally length.\textsuperscript{117} While these results are intriguing, O’Donoghue and Ingram\textsuperscript{120} suggest that athletes should aim to devise match strategies based on their own strengths and weaknesses.
specific to their sex, and court surface required. This recommendation most likely speaks also to each of the abovementioned impacting variables of tennis matches in regard to prescribing external training loads. Owing to the complex array of variables that can affect tennis external loads, it seems logical to monitor these training stimuli in order to progressively prepare junior athletes for such professional rigors. However, part of this monitoring procedure is to further understand each athlete’s internal response to these match and training variables. Thus, the following sections will provide descriptive analysis of typical physiological and perceptual load responses from competitive matches as reference.

**Physiological Responses**

The use of portable gas analysers have previously been used to continuously measure and describe oxygen consumption (VO$_2$) during simulated matches.$^{1,97,145,146}$ Obviously, these types of analyses are restricted from being carried out during official tournament matches; however, simulated match play may represent somewhat of a reference context.$^{125}$ Accordingly, mean VO$_2$ during simulated match studies, has been reported to range from 23 to 29 mL·kg$^{-1}$·min$^{-1}$.1,6,97 While Smekal$^{97}$ reported VO$_{2\text{peak}}$ measures of ~ 50 mL·kg$^{-1}$·min$^{-1}$, equating to ~80% VO$_{2\text{max}}$, which is somewhat lower than previous observed ranges of 54 - 65 mL·kg$^{-1}$·min$^{-1}$.6,131,134,146

Furthermore, comparison of offensive and defensive player VO$_2$ demonstrates lower VO$_2$ of offensive players, which conforms with earlier suggested data that offensive players have reduced movement patterns, likely due to court placement.$^{143}$

While specific descriptions of VO$_2$ can be gathered through specialized gas analysers, a derivative marker of oxygen use (or rather delivery) is through measurement of HR responses.$^{121}$ Tennis matches are invariably associated with elevations in HR owing to the physiological stress reflective of short, high intensity bouts of play.$^6$ Due to the
scoring and rules associated with competitive tennis, rest intervals are frequent, resulting in relative fluctuations in HR similar to VO$_2$. Yet as referred to above, HR is likely to be reflective of VO$_2$, though is undoubtedly a more practical measure for use during tennis training and match play.$^6$ Notably mean HR’s have been reported to range between 140 and 160 bpm, and at 70 - 80 % maximum HR (HR$_{\text{max}}$).$^{1,6,125}$ During matches, HR$_{\text{max}}$ have been observed to be as high as 190 - 200 bpm during long, extended points ($>20$ s).$^{6,125}$ As acknowledged by Kovacs$^6$ and Fernandez-Fernandez et al.,$^{125}$ mean HR (or VO$_2$) is not the ideal measurement of match physiological load, due to its intermittent nature. As such, Gomes et al.$^{98}$ has subsequently provided a case study example of the HR responses of two tennis players over four match sets. Mean HR’s were observed to increase steadily throughout the match from 137 and 128 bpm in the first set, to 154 and 146 bpm in the fourth set for both players, respectively. Likewise, HR$_{\text{peak}}$ for each set increased from each player, beginning at 176 and 169 bpm throughout the first set, reaching 179 and 173 within the final set, respectively. Variations in the match itself that appear to affect HR, include an increase in HR for the serving player of each game, also reported in junior female matches.$^{14}$ An earlier study involving national-level male players, reported higher mean HR’s for defensive players ($156 \pm 16$ bpm) compared to offensive players ($145 \pm 19$ bpm), further aligning with the VO$_2$ and match play data reported earlier.$^{97}$ Fernandez-Fernandez et al.,$^{125}$ suggest that the increased HR observed in service players relates to a higher psychological or perceptual stress, likely owing to the necessity of players winning their own service game. Thus, perceptual stress placed upon tennis players during match play is also important to understand in an attempt to successfully prepare for match demands.$^{125}$

Within tennis literature, blood lactate testing – as an indicator of anaerobic glycolysis
occurs frequently as a method to estimate match intensity. For this purpose, blood lactate has been reported to fluctuate throughout matches, inherently increasing acutely in response to long rallies, limited recovery time and greater reliance on anaerobic glycolysis. In most cases where blood lactate was measured during matches, samples were collected during the change of ends. As such, during best of 3 set matches, where the duration of the match is unknown, results are highly variable with the amount of samples collected throughout each study. Furthermore, Mendez-Villanueva et al., report that in some cases, owing to negative responses of players following the games immediately prior to the change of ends, players refused to provide a blood sample, preferring to sit without the disruption. Regardless, post-match blood lactate typically remains low, with previously mean values for matches reported as ranging between 1.7 to 3.8 mmol/L, despite some outliers reportedly reaching ~ 6 mmol/L in state-level players and professional players playing on clay. In particular cases, volitional exhaustion tests related to tennis performance have been used, resulting in unrealistic values of up to 10 mmol/L, and given the context of such testing, could not be considered to representative of match play demands. Hence, Kovacs suggests that owing to competition points lasting < 10 s, and the inclusion of frequent rest periods, the physiological demand of match play are unlikely to lead to a large accumulation of blood lactate or to become a major cause of acute fatigue during tennis matches.

The discrepancy of increased blood lactate responses noted on clay, as reported by Martin et al., was part of an investigation into the effect of playing surface (i.e., clay vs. hard court). Although other literature concurs with these findings, however, Girard and Millet found no difference between clay and hard court responses,
possibly owing to the removal of recovery time at change of ends. Further analysis of match play variables in relation to blood lactate include responses between service and return games.\textsuperscript{8,14,93} Again, some disagreement within the literature exists, as Mendez-Villanueva et al.\textsuperscript{8} reported higher blood lactate concentrations in service games, while two studies by Fernandez-Fernandez et al.\textsuperscript{14,93} found no significant difference between service and return games for female players (~ 17 y). Fernandez-Fernandez et al.\textsuperscript{93,125} suggest that this discrepancy is likely due to the subtleties of match strategy in the female game, owing to a deficiency in serve power compared to male players. While service games may result in increased lactate due to addition the inherent maximal recruitment of lower-body musculature during the serve.\textsuperscript{8,125}

Other reported biological markers used to describe internal responses to match play, include salivary cortisol, CK, and glucose concentration.\textsuperscript{9,94,95,100,141,148} A recent paper describing the changes in salivary cortisol before and after a match and training session observed that salivary cortisol was greater in response to matches than training.\textsuperscript{9} This corresponds with an earlier study investigating the salivary cortisol changes of the first match of a tournament.\textsuperscript{10} Matches were further scrutinized by outcome, comparing salivary cortisol concentrations of winners and losers for selected points throughout the match, with greater values observed for losing players.\textsuperscript{9} As evidenced through alterations in cortisol measures around match day, these types of biological measures likely provide an accurate monitoring tool (reported coefficient of variation [CV] of 6.75%) for the stress response of athletes to training.\textsuperscript{9} However, despite these data showing potential benefit for both junior high-performance (and likely elite) athletes, limitations including the invasive and tedious nature of saliva collection, along with the cost of consumables pose an issue within academies and across large cohorts and wide variety of playing locations.
A recent study from Gescheit et al.,\textsuperscript{100} reported the change in markers of muscle damage, including blood CK prior to and post matches. Whilst part of a larger study investigating the effect of four consecutive days of matches, they reported substantial increases in CK following the 4 h match on the first day.\textsuperscript{100} Other papers have also reported elevations in CK in response to tennis matches; however, as highlighted in a recent review,\textsuperscript{2} these investigations were conducted on players of modest professional ranking,\textsuperscript{95} and during a simulated match that was standardized to 120 min.\textsuperscript{94} Regardless, the available data suggest increased CK following prolonged match play, although limited data is available from junior players or tournament matches.

Finally, blood glucose has been measured during match play in a number of studies.\textsuperscript{95,134,141,142,148} Hornery et al.,\textsuperscript{95} observed that hypoglycaemia did not occur in response to professional-level tournaments (2 hard, 1 clay court). In fact, in accordance with previous literature investigating the effect of carbohydrate drink intake during match play,\textsuperscript{134,142} and likely owing to availability of sports drinks for the players, significant increases in blood glucose were observed post-match.\textsuperscript{95} The researchers suggested that carbohydrate ingestion appears to sufficiently maintain blood glucose levels during $< 2$ h matches, however the effect remains unknown for 5-set matches.\textsuperscript{95} Again, while these data present impactful information regarding elite athlete (only) biological changes during training and match play, in a similar fashion to salivary cortisol, monetary and invasive restrictions likely limit the use of these tools outside of specific and acute research investigation contexts.
Neuromuscular Changes
Previous investigations have also focused on the changes in neuromuscular performance during and following match play. Studies have reported a reduction in muscle contraction function and increased muscle soreness through electromyography (EMG) activity, and maximal voluntary contraction (MVC) force and rate of force development in professional players. Girard and colleagues have described the alterations in neuromuscular function through analysis of the changes in EMG activity during simulated match play. In a similar manner to VO\textsubscript{2} measures, EMG requires instruments that are not suitable for tournament matches, thus simulated matches serve as a replacement. Regardless, Girard et al. previously demonstrated a progressive reduction from baseline neuromuscular activity of well-trained adult tennis players, using a 3 h tennis match play protocol. Specifically, a progressive reduction in muscle activation and a marked torque loss in voluntary contractions of the knee extensors. The researchers speculated that this activation deficit could be the result of impairment in central drive.

A later paper by Girard et al. further examined the time course of alteration in neural process during a 3 h protocol for the plantar flexors. The authors suggest that the compromised voluntary strength capacity of the lower limb muscles indicated a reduced neural input to the working muscles. Such findings reportedly present coaches with evidence that, in a bid to negate serious acute fatigue throughout extended match exposure, resistance training and high-intensity training should be prescribed within training methods. In turn, rate of force development of the lower-body during isometric and countermovement jump (CMJ) protocols has been also
used to gain an understanding of neuromuscular changes as a result of tennis match play.\textsuperscript{94,100} Specifically, Ojala and Häkkinen\textsuperscript{94} utilized an isometric bilateral leg press, finding that both MVC strength and rate of force development significantly reduced during the first match. However, despite the noted difference in movement patterns outlined earlier, there was no difference in skeletal muscle function between the winners or losers. Later, Gescheit et al.,\textsuperscript{100} analysed MVC force using an isometric mid-thigh pull protocol, as well as a CMJ protocol. Contrasting to the previous study, Gescheit et al.,\textsuperscript{100} found no reduction in peak force following 4 h of competitive match play in the isometric mid-thigh pull measure, although observed a reduction in peak force production (height) through CMJ. While information surrounding the performance changes of individual athletes is beneficial, from the perspective of transferring to training program development and understanding acute fatigue resistance, these data appear inconsistent. Thus, further investigation into the effects of extended and accumulated tennis training loads is required, as well as specific investigation into the neuromuscular changes experienced by junior-level compared to elite-level athletes.

\textit{Perceptual Responses to Match Play}
As frequently referred to within tennis literature, tennis is a sport that is of high physical and psychological demand.\textsuperscript{2,121} Following suit from many other sports,\textsuperscript{40,42,45} perceptual measures including RPE (Borg 6-20,\textsuperscript{93,94,99,150} and CR10 scales\textsuperscript{22,98,100,101}), and perceptual muscle soreness,\textsuperscript{94,100,115,150} have commonly been used within the literature to describe a player’s internal psycho-physiological response to external demands during tennis match play. Post-match RPE using the CR10 scale has been reported to range between 5 and 7.\textsuperscript{22,98,100} Regardless of post-match measures, RPE has been suggested to fluctuate throughout match play, ranging from 7 to 17 (Borg 6 -
20au) each change of ends, with mean values of 12 ± 2.4 (au). From these data Fernandez-Fernandez et al.\textsuperscript{125} suggest that this confirms periodic increases and decreases in exercise intensity during tennis match play, though as yet these have not been aligned with movement patterns of players. However, throughout a 3 h continuous match play protocol, Girard et al.\textsuperscript{150} observed progressive increases in RPE (CR 6 - 20) every 30 min until completion, peaking at values of ~ 15 (au).

Similarly, although using CR10 RPE scale, Gomes et al.\textsuperscript{98} found that during a best of 5 set match (4 sets), RPE’s of 3 and 4 (au) were reported in the first set, progressively increasing until the fourth (and final) set with a perceptual rating of 8 (au). Though only a case study (2 players), these data and those from Girard et al.\textsuperscript{150} reflect progressive increases of perceived intensity of match play. Moreover, Mendez et al.\textsuperscript{99} observed significantly greater RPE values (CR 6 - 20) following service (~ 14 au) than return games (~ 12 au), each significantly correlated with strokes per rally and rally duration. Girard et al.\textsuperscript{150} propose that an observed progressive increase of RPE throughout a 3 h simulated match protocol was likely owing to factors such as mechanical load, as evidenced by the relations between RPE and MVC force.

Currently there seem to be only four tennis match investigations that have utilized a muscle soreness scale; however, no literature has investigated the perceptual soreness responses to tennis in junior-level athletes.\textsuperscript{94,100,115,150} In a similar fashion to RPE, Girard et al.\textsuperscript{150} measured muscle soreness using a CR 6-20 scale every 30 min during a 3 h match protocol, observing muscle soreness to progressively increase at each time point peaking at ~ 16 (au). Another study measured muscle soreness using a visual analogue scale at time points immediately, 24 h, and 48 h following match play, observing an increase immediately post match and again 24 h later (compared to
pre and post match), before a decline to pre match levels at 48 h (p<0.05).\textsuperscript{115}

Gescheit et al.,\textsuperscript{100} observed increases in perceived muscle soreness from pre to post 4 h simulated match play on day 1 (~ 0 to 4 on a 10-point scale). These results reflect those of Ojala and Häkkinen,\textsuperscript{94} who also used the CR10 muscle soreness scale post match, and while post-match levels were rated < 2 (au), the authors chose to separate soreness into categories of upper, lower and core, thus making comparison difficult. These negative perceptual changes, albeit purely of senior and/or professional players, demonstrate the impact that training and match loads can have on players up to 48 h post session. Inherently, with the accumulation of training loads throughout extended training or tournament blocks, these perceptual soreness levels are supposed to become exacerbated. A clear understanding of perceptual soreness prior to subsequent training session will allow for appropriate adjustment of training intensity and mode. Thus, presenting strong evidence for the implementation of such training monitoring protocols (i.e., exertion, acute fatigue, muscle soreness). Moreover, whilst these data represent negative changes in professional level players, future research should investigate the perceptual soreness changes of junior high-performance players during heavy developmental blocks. Table 2.2 presents a summary of a range of studies, reporting a variety of internal load measures for tennis match play, as an example of the current state of knowledge on tennis match responses.
Table 2.2: Summary of studies implementing internal load measures to determine athlete response to match demands.

<table>
<thead>
<tr>
<th>Authors (y)</th>
<th>Cohort (n)</th>
<th>Match Format</th>
<th>Surface</th>
<th>Internal Load Measures</th>
<th>Key Findings</th>
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</thead>
<tbody>
<tr>
<td>Coussens et al.</td>
<td>Professional Male (1)</td>
<td>Grand Slam Singles</td>
<td>Clay</td>
<td>Perceptual</td>
<td>Match RPE ranged from 5 - 7 au</td>
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<td>RPE (CR10)</td>
<td>Weekly TL accumulated 2380 au</td>
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<td>Duffield et al.</td>
<td>Professional Male (8)</td>
<td>2 x Simulated 90 min Match (with and without recovery protocols)</td>
<td>Hard x 2</td>
<td>Physiological</td>
<td>HRR ↔ between conditions</td>
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<td>- HRR</td>
<td>Mean HR ↔ between conditions</td>
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<td>- Mean HR</td>
<td>Blood lactate ↔ between conditions</td>
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<td>- Blood lactate</td>
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<td>- Brunel mood scale</td>
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<td>- RPE (CR10)</td>
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<td>- MS and JS</td>
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<td>Fernandez-Fernandez et al.</td>
<td>Junior (17 ± 2.4 y) High-Performance Female (8)</td>
<td>3-Day Invitational Tournament</td>
<td>Clay</td>
<td>Physiological</td>
<td>Mean blood lactate levels 2.2 ± 0.8 mmol/L</td>
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<td>- Blood lactate</td>
<td>Mean RPE 12.1 ± 2.3</td>
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<td>Perceptual</td>
<td>Blood lactate and RPE ↔ between service and return games</td>
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<td>- RPE (CR6-20)</td>
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<tr>
<td>Fernandez-Fernandez et al.</td>
<td>Junior (13 ± 0.3 y) High-Performance Female (12)</td>
<td>1 x Tournament Match 1 x Simulated Match</td>
<td>Unknown</td>
<td>Physiological</td>
<td>Salivary cortisol ↑ for losers than winners at all time points on match day</td>
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<td>- Salivary cortisol</td>
<td>Salivary cortisol ↓ for all players on training compared to match</td>
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<td>- HR</td>
<td>Winners ↑ self confidence and ↓ anxiety than losers</td>
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<td>Perceptual</td>
<td>HR and RPE ↑ for losers than winners during the match</td>
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<td>- RPE (CR6-20)</td>
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<td>- CSAI</td>
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<td>Filaire et al.</td>
<td>Regional-level Male (8) and Female (8)</td>
<td>Prior to First Match of a Tournament</td>
<td>Unknown</td>
<td>Physiological</td>
<td>Pre-match anxiety ↑ in females than males</td>
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<td>- Salivary cortisol</td>
<td>Pre-match self confidence ↑ in males than females</td>
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<td>Perceptual</td>
<td>Winner ↑ self confidence and ↓ anxiety than losers</td>
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<td>- CSAI</td>
<td>Cortisol response ↔ for males and females</td>
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<td>Authors (y)</td>
<td>Cohort (n)</td>
<td>Match Format</td>
<td>Surface</td>
<td>Internal Load Measures</td>
<td>Key Findings</td>
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<td>Gescheit et al. 100</td>
<td>Professional Male (7)</td>
<td>Simulated 4 h Matches on 4 Consecutive Days</td>
<td>Indoor Hard</td>
<td>Physiological</td>
<td>- Blood CK ↑ during the match, each day</td>
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<td>- Mean HR ↑ days 2 and 4 compared to day 1</td>
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<td>Perceptual</td>
<td>- Match RPE ↔ between days</td>
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<td>RPE (CR10)</td>
<td>- MS ↑ at pre and post match time points compared to day 1</td>
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<td>- Mood states ↓ days 1-3 compared to pre match ratings</td>
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<tr>
<td>Gomes et al. 106</td>
<td>Professional Male (2) (Davis Cup)</td>
<td>Simulated Match (4 sets)</td>
<td>Hard</td>
<td>Physiological</td>
<td>- Blood lactate ↑ from set 1 to set 3, ↓ for set 4 for both players</td>
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<td>- Salivary cortisol, blood glucose, HR, and RPE ↑ each set until end of the match for both players</td>
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<td>Perceptual</td>
<td>- Session RPE was 8 and 6 au for player 1 and 2 respectively</td>
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<td>RPE (CR10)</td>
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<tr>
<td>Gomes et al. 115</td>
<td>Nationally-level Male (10)</td>
<td>Simulated 3 h Match</td>
<td>Clay</td>
<td>Physiological</td>
<td>- Blood CK ↑ from baseline at 24 and 48 h post-match</td>
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<td>- RPE ↑ each h, with a session RPE of 6.0 ± 1.9 au</td>
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<td>Perceptual</td>
<td>- MS ↑ and peaked at 24 h post-match, subsiding by 48 h post-match to pre-match levels</td>
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<tr>
<td>Martin et al. 106</td>
<td>Professional Male (4) and Female (2)</td>
<td>Simulated Match (16 games)</td>
<td>Hard Clay</td>
<td>Physiological</td>
<td>- Blood lactate and HR were ↑ during matches on clay compared to hard court</td>
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<td>- Blood lactate ↑ during match on clay, but ↔ during match on hard court</td>
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<td>Mendez-Villanueva et al. 106</td>
<td>Professional Male (8)</td>
<td>Simulated Match (best of 3 sets)</td>
<td>Clay</td>
<td>Physiological</td>
<td>- Mean blood lactate was 3.8 ± 2.0 mmol/L, ranging from 1.9 - 5.5 mmol/L during a match</td>
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<td>- Mean RPE was 12 ± 2 au, ranging from 11 - 15 during a match</td>
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<td>Perceptual</td>
<td>- Blood lactate and RPE both ↑ after service games compared to receiving games</td>
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</table>
### Chapter 2: Literature Review

<table>
<thead>
<tr>
<th>Authors (y)</th>
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<th>Key Findings</th>
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<tr>
<td>Ojala and Hakkinen(^a)</td>
<td>National-level Male (8)</td>
<td>Simulated 2 h Matches on 3 Consecutive Days</td>
<td>Hard</td>
<td>Physiological</td>
<td>- Blood cortisol ↑ before every match compared to pre-match</td>
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<td>- Blood cortisol ↑ for winners compared to control, at all time points</td>
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<td>- Blood testosterone ↑ during first match only, and ↔ for winners and losers</td>
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<td>- Blood CK and MS ↑ across all matches, with ↔ between winners and losers</td>
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<td>- Mean blood lactate, HR, and RPE ↔ between matches</td>
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<td>- RPE (CR6-20)</td>
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| Smekal et al.,\(^b\) | National-level Male (20) | Simulated Match (50 min) | Indoor Clay | Physiological | - Mean VO₂ for games was 29.1 ± 5.6 mL·kg⁻¹·min⁻¹, ranging from 10.4 - 47.8 mL·kg⁻¹·min⁻¹ |
| | | | | | - Mean HR for games was 151 ± 19 bpm |
| | | | | | - Mean blood lactate for games was 2.1 ± 0.8 mmol/L, ranging from 0.7 - 5.2 mmol/L |
| | | | | | - VO₂, HR, and blood lactate were all ↑ in games performed by two defensive players, compared to games with offensive players involved |
| | | | | | Perceptual |
| | | | | - CO₂ |
| | | | | - RPE (CR6-20) |
| | | | | - MS |

\(^a\) JS= joint soreness; CWI= cold water immersion; CSAI= competitive state anxiety inventory; VO₂= oxygen consumption.
\(^b\) 

↑= increased; ↓= decreased; ↔= no change; RPE= rate of perceived exertion; HR= heart rate; HRR= heart rate recovery; MS= muscle soreness; JS= joint soreness; CWI= cold water immersion; CSAI= competitive state anxiety inventory; VO₂= oxygen consumption.
2.3.2: Tournament and Consecutive Match Demands

Tennis Tournament Frequency
As mentioned previously, tennis matches can extend beyond 5 h in duration, particularly in the case of Grand Slam and Davis Cup events (5 sets), as is the example of the 2012 Australian Open men’s final, lasting 5 h 53 min, after completing over 12 h of match time during the tournament. Yet, the majority of available tennis literature has focused on tournament and simulated matches, approximating substantially lower durations. Outside of the four men’s Grand Slam and Davis Cup events, all other junior, men and women’s matches are best of three set matches, and comprise an annually saturated playing schedule. Gomes et al. explain, that there are almost innumerable opportunities for young tennis players to compete across all levels, including ‘Future Tournaments’, which even as entry-level professional tournaments, consist of up to 400 events a year. Gescheit et al. further describe that players commonly participate in multiple draws (i.e. singles and doubles within 1 day), and with each win comes another match the ensuing day. Acknowledging this, there is a lack of literature describing the demands of consecutive days of matches to replicate a tournament. The following section draws on the available literature that discusses tournament demand and highlights gaps in existing research. In turn, these data may assist to create the context of what players must set their training loads around in a bid to appropriately prepare for short and long-term competitive demands.
Accumulation of Load During Tournaments - Presence of Fatigue

Ojala and Häkkinen\textsuperscript{94} sought to amend the gap in the literature regarding consecutive day match demands. Their investigation involved the examination of hormone responses (cortisol and testosterone), maximum lower-body strength and speed, HR response, and perceptual markers (RPE and muscle soreness) for 8 adult male (23 ± 3.8 y), national level players, competing in 2 h matches across three consecutive days.\textsuperscript{94} It was observed that the tournament progressively impaired lower-body strength and force production, aligned to increased blood markers of muscle damage and perceptual soreness.\textsuperscript{94} These regressions were observed to return to almost baseline levels at follow up testing session 48 h following the final match.\textsuperscript{94} Consequently, the authors suggested that a tennis tournament appears to produce significant lower body strength and power reductions in adult male players, which in the absence of adequate recovery (> 24 h), increases over the course of a tournament, ultimately impairing physical performance.

Whilst Ojala and Häkkinen\textsuperscript{94} address the limited understanding of consecutive day matches, the match durations of the study design (2 h) remain incongruent with the potential durations and demands of professional matches.\textsuperscript{100} Gescheit et al.,\textsuperscript{100} therefore aimed to quantify the physical demands and responses to a 4 h competitive singles match, on four consecutive days, for 7 professional male players (21.4 ± 2.2 y). It was observed that there was reduction across the four days, in total movement (decline of ~5 to ~15 % across four days) and lower-body force production, inferred through accelerometry, and sprint and counter-movement jump data, respectively. Correspondingly, there were also apparent reductions in mood state, increases in perceptual fatigue and muscle soreness, and elevations in blood markers of muscle
The authors proposed that these changes suggest a complex interaction of neuromuscular, perceptual and physiological fatigue.\textsuperscript{100} Reid and Duffield\textsuperscript{2} later summated these two studies, asserting that despite differing research designs, these data infer changes in match play engagement and physiological function within and between days of match play. Whilst these data report changes of only male professional level athletes, colloquially these changes are also anecdotally observed within junior athletes. Still, future research is needed to fully understand the changes in physiological, neuromuscular, and psychological abilities of junior athletes throughout developmental years. Allowing evidence-based suggestions to be made of the training focus in junior athletes, including sufficient levels of training prescribed prior to tournaments, and appropriate recovery periods post-tournament. Yet, in order for these extrapolations to occur, coaches must have a clear understanding of the external loads experienced, and subsequent internal responses of junior athletes over an extended period of time. Such a state of knowledge reflects the potentially important use of monitoring loads throughout and in response to matches and tournaments.\textsuperscript{2} Owing to this, the following section of the current thesis will describe and examine the literature of optimising the measurement of training loads, as well as consequences of sub-optimal load management. While, limited research specific to tennis exists,\textsuperscript{152} built from evidence in other sports and contextualised within the tennis environment, an understanding of these research areas will provide rationale to effective load monitoring practices to be applied to tennis.
2.4: IMPORTANCE OF LOAD MONITORING IN SPORT

“Excellence is an art won by training and habituation. We are what we repeatedly do. Excellence then is not an act but a habit.”

Aristotle, Greek philosopher (384-322 B.C.) 153

2.4.1: Potential Benefits of a Successful Load Monitoring System

Athletes and coaches have long sought to push the limits of human adaptation in the goal of achieving sporting success. 154 As far back as Sir Roger Bannister and the race for the 4 min mile, performance has been noted to change in response to variances in training load. 153 Whilst not exactly the focus of this thesis, an example of the importance of effective load monitoring systems is demonstrated in the strategic planning of training load variations present in tapers and LTAD planning. Tapers have been classified into four distinct de-loading patterns describing their behaviour, including; linear taper, exponential taper with slow or fast decay, and step taper (Figure 2.2). 154 Le Meur et al., 155 highlight that a majority of taper research has implemented a progressive taper, with this involving all taper types except the step taper. An extensive amount of taper-based literature has demonstrated that training intensity during a taper should not be reduced in order to achieve an overall training load reduction. 154-158 Training volume on the other hand, has been shown to have a positive interaction with performance during a taper, even with markedly reduced volumes. 157-159 The inherent point here is that to plan a taper, first information on the training type and response is needed. Given the yearly cycle of professional tennis, 21,115 annual plans and tapers are integral and can be well supported by robust training load monitoring tools.
A recent meta-analysis of tapering on performance, summarized that performance during a taper period is highly sensitive to reductions in training volume, with maximal performance gains elicited with 41-60% total reduction of pre-taper load. Notably, a study by Mujika et al., observed positive performance changes in middle-distance runners with up to 75% reduction in training load over a 6 d period. A multitude of literature has reported positive benefits of tapering in the lead up to competition across a range of individual sports, with performance improved by
up to 6% (ranging between 0.5 - 6%).\textsuperscript{155,160} Owing to the difficulty in predicting and assessing tennis performance (outside of winning matches), physical capacity testing measures provide a proxy for athletic performance in junior athletes.\textsuperscript{162} This problem and implementation of physical capacity testing is also evident in team sports, whereby Coutts et al.,\textsuperscript{163} observed a range of improvements on fitness capacity measures including multi-stage fitness, vertical jump, 3 RM squat and bench press, chin up, and 10m sprint. As taper literature in tennis is non-existent, future research should examine optimal taper lengths within specific tennis populations. However, in order to achieve this, coaches require a clear understanding of typical athlete training loads - i.e., training load monitoring.\textsuperscript{159,161,164}

The accumulation of training load monitoring information collected and inferred towards future session prescription essentially aids coaches in evidence-based LTAD. Owing to the increasing use age of tennis players on the professional circuit, particularly within the top 100 ranked players, high-performance tennis environments, require implementation of long-term pathways designed to develop junior athlete into senior level competition.\textsuperscript{12} These pathways are usually developed in line with LTAD models.\textsuperscript{165} In terms of training load monitoring for junior (tennis) athletes, LTAD concept assist in the progression of both training load and exercise prescription. As such, in order for these models to accurately reflect chronological age and competency, training load monitoring strategies are important to track longitudinal changes in training response.\textsuperscript{21,166}
**2.4.2: Potential Issues Arising from Lack of a Tennis Load Monitoring System.**

High-performance athletes and coaches are notorious for pushing the boundaries of both training volume and intensity in pursuit of a competitive advantage. Reflective of high-performance tennis environments, issues arise with attempts to mimic the training loads, or perceived training loads, of past or present champions.\textsuperscript{114} Smith\textsuperscript{114}, succinctly describes that during a training cycle, an athlete is in a constant state of flux, moving along a continuum from negative to positive training responses. It is towards the end of this continuum, where sufficient recovery is excluded, that over-training may exist.\textsuperscript{114}

Smith\textsuperscript{114} also suggests that certain ‘basic errors’ in training and competition load may induce “over-training” symptoms, leading to performance decline. Such errors include:

- Recovery is often neglected with mistakes in the micro- and macrocycle sequence.
- Athletes are overloaded too quickly, relative to capacity, compromising the adaptive process.
- After a pause in training due to illness or injury, training load upon return is increased too rapidly.
- High volume of both maximal and sub-maximal intensity training.
- Excessive attention and time are spent training complex technical or mental tasks, without adequate respite.
- Excessive tournament frequency with maximum physical and psychological demands, combined with the associated disturbance of the daily routine and insufficient training.
- Bias of training methodology with insufficient balance.
- The athlete lacks trust in the coach due to high expectations or goal setting which has led to frequent performance failure.
It is this over-training that refers to a failure to fulfil appropriate recovery demands, resulting from either training and/or non-training stress that ultimately may reduce performance.\textsuperscript{114} As depicted in the fatigue continuum model (Figure 2.3), the onset of fatigue begins with an acute fatigue response following an initial training overload.\textsuperscript{24,167} It is here, when in the absence of appropriate recovery, the severity of fatigue symptoms increase.\textsuperscript{24,167}

![Figure 2.3: Schematic representation of the different stages of training, overreaching, and over-training syndrome.\textsuperscript{24,167}]

Accordingly, intensified training corresponds with possible outcomes of functional overreaching (short term fatigue), non-functional overreaching (extreme fatigue), and over training syndrome (OTS).\textsuperscript{24} As mentioned, in tennis, performance changes determined using a battery of physical capacity tests act as a proxy for detecting the
development fatigue.\textsuperscript{152,162} However, outside of performance decrement, within the literature extreme accumulation of fatigue reportedly result in a range of symptoms including: hormonal dysfunction, psychological disturbances, depressed immune function, and sleep disorders.\textsuperscript{24,85,114,168} Thus, training monitoring tools, appropriate for tennis, but sensitive enough to determine changes in these areas may also be suitable. Currently in tennis, there is only one case study of 3 male athletes that has examined functional overreaching within an elite population (top 30, 100, and 1000 ranked), observing overreaching state in each to be functional. However, while these observations may be misleading, certainly with an astute understanding of specific drill and match loads throughout hard training blocks and extended competition, coaches and practitioners will be enabled with a greater understanding of an athlete’s responses to load. Thus a need to monitor and quantify athlete training loads and responses becomes evident. The ensuing section will now explore the rationale and history of training load monitoring with a view to explaining the current state and limitations that exist in tennis.
2.5: THEORY BEHIND LOAD MONITORING

HISTORICAL OVERVIEW

You say, ‘I want to win at Olympia.’ Hold on a minute. Look at what is involved both before and after, and only then, if it is to your advantage, begin the task. If you do, you will have to obey instructions, eat according to regulations, keep away from desserts, exercise on a fixed schedule at definite hours, in both heat and cold; you must not drink cold water nor can you have a drink of wine whenever you want. You must hand yourself over to your coach exactly as you would to a doctor.

_Epictetus, Stoic philosopher (A.D. 101)_

2.5.1: Path to Modern-Day Load Monitoring Systems

Rationales for training load monitoring, as inherently found in the processes of periodised training program development, are suggested to originate from ancient Greece, as referred to in the manuscripts of prominent philosophers. The above excerpt, translated in 1987 by Sweet, is a quotation by Epictetus in A.D. 101, describing the level of commitment of athletes even in ancient times to (among other aspects of training) “exercise on a fixed schedule at definite hours”. Not only does this advice encapsulate modern tennis coach-athlete interactions, but according to Bourne, this logic was commonplace during the thousand year history of the ancient Olympic Games. The reported model of monitoring and manipulating volume and intensity of training incorporated a simple four-day ‘tetrad’ system, comprising of: 1) short, intense movements, 2) strenuous all-out test, 3) relaxation, moderate day, 4) technical work.

To skip to the redevelopment of modern training monitoring theory, numerous recounts of the training methods employed by Sir Roger Bannister and rival athletes John Landy and Wes Santee in ‘the race to break the four-minute mile’, gave new
insight and lead to scientific advancement of training monitoring theories, including tapering. Later, the Soviet Union’s debut in the 1952 Olympics and next 30y sporting dominance, was reportedly owing (among other things) to the systematic, sequential and progressive approach to the planning and organization of training in order to obtain optimal development of an athlete’s performance, founded through the translation of theories designed by Professor Lev Pavlovich Matveyev. Matveyev analysed the training loads and performances of thousands of elite athletes, with the specific aim of devising a theory to facilitate continual progress and ultimate performance and peaking at the right time.

In relation to systematic methods of training load monitoring, one model is perhaps most significant. In 1956 a publication by Hans Selye, *The Stress of Life*, assisted in the later formulation of athletic improvement principles, namely the general adaptation syndrome (GAS). Selye, through describing a theory of alterations in homeostatic equilibrium for general human function, pioneered the understanding of the adaptation process and how different stressors of influence subsequent adaptation (Figure 2.4). For example, when the body is exposed to cold temperature, the body experiences a disturbance to homeostatic equilibrium to produce what is known as the *Alarm* stage. In turn, the body reacts to the stressor and forms a new level of homeostatic equilibrium called the *Resistance* stage. Ultimately, the body’s ability to continue this cycle is finite, and when the *Exhaustion* stage is reached the stressor will eventually cause the body to fail.

Parallels for the above observations were subsequently drawn for an athlete’s response to training load, and provided the basis for the principle of overload (Figure 2.5). It was also acknowledged that this response is heavily
individualised.\textsuperscript{167,170,174,175} Hence, in order for the training process to be individualized within sports such as tennis, the training stimuli must be measured, and coaches must be able to interpret where their athlete sits at any time along the spectrum of the adaptation sequence. The next section will outline models proposed to illustrate the complex interactions of multiple training load “inputs” that may affect athletic “output” (i.e., performance), theoretically allowing prediction of performance at specific times.

![Diagram of general adaptation syndrome (GAS principle).](image)

Figure 2.4: Model of general adaptation syndrome (GAS principle).\textsuperscript{172}
2.5.2: Athletic System Models - Modelling Performance

The rationale for training load monitoring is to assist in accurate training periodisation based upon increases in training stressors (i.e., number of actions, or number of matches), causing catabolic events to occur to disrupt athletic homeostasis through training overload.\textsuperscript{170-172,174,176} Amongst a myriad of physiological and psychological reactions to stress, the body regenerates in an attempt to return to a state of homeostasis.\textsuperscript{32,109,167,177} Provided sufficient recovery before further stress is imposed, the principle of supercompensation results in a state of improved performance potential (i.e., the athlete has adapted to the imposed training load).\textsuperscript{32,109,167,170,177}

Through systems modelling, the effect training impulses have on subsequent performance, termed the dose-response effect, have been studied. These mathematical models, commonly denoted as performance models,\textsuperscript{178} are heralded as important

![General adaptation syndrome model applied to athletic training (overload principle).](image)
developments which have led to modern training planning, analysis, and optimization. As justification of ensuing sections on TL monitoring tools, the following section will review the evolution of key models in measuring and predicting performance outcomes; highlighting the model rationale and how the model’s design regulates athlete ‘input’ and ‘output’ markers.

**The Impulse-Response Model**

The research of Banister et al., and Calvert et al. saw mathematical models of training and performance gain traction in the research literature. Banister et al. proposed an equation weighing the training effect (dose), on subsequent performance (response), to establish a quantifiable relationship. It was proposed that performance could be predicted at any time through the relationship between fitness impulse, and fatigue impulse. The model proposed that the functions that positively (i.e., fitness), and negatively (i.e., fatigue) influenced performance would both decline between training sessions, though the decay time would differ. It was estimated that fitness decay time was 45 d, while fatigue decay would last just 15 d, with these estimations to be replaced with individualised athlete data based on real performances. Initially, Banister’s model attempted to predict performance outcome through the interaction of multiple components specific to each athlete (Figure 2.6). These included elements of endurance, strength, skill, and psychological factors. Subsequent models have attempted to test the accuracy and simplify the original model, due to the inability to precisely quantify skill and psychological factors. Morton et al., for example presented a simplified version of the model, which only considers the input dose effect that training has on simply by the relationship of \( \text{Fitness} - \text{Fatigue} = \text{Performance} \) (Figure 2.7).
Multiple other variations of the model exist, including alterations made by Busso et al.,\textsuperscript{188} whereby accuracy was tested using only the fitness impulse. However, all variations of impulse-response models suffer from several practical challenges and scientific limitations for training optimization. The use of modelling primarily requires utmost diligence from researcher or athlete in data collection, entry and maximal performance testing.\textsuperscript{178} Further, the suggested time decay of both fitness and fatigue are individualized and will most probably vary across sports and athletes depending on metabolic demands.\textsuperscript{173} Due to the typical structure of training schedules within weekly blocks (i.e., 1-week micro cycles), it has been suggested that a rolling 6-week average training load metric be used to calculate fitness, and a 1-week rolling average be used to calculate fatigue.\textsuperscript{173} The limitations of the training load metric initially used by Banister et al.,\textsuperscript{181} (i.e., HR), also present a challenge due to documented varying factor of the measures including; hydration, rest, illness, or cardiac drift.\textsuperscript{178} Thus, training load metrics such as session-RPE (to be discussed in following section) present an alternate strategy of impulse-response models.\textsuperscript{49}
Figure 2.6: Banister’s Impulse-Response model.\textsuperscript{181}

Figure 2.7: Simple 2-component systems model of training and performance.\textsuperscript{185}
A Holistic Load Monitoring Model

Whilst the impulse-response model has experienced success in quantifying fitness-fatigue responses and prediction of performance, these analyses have largely occurred on endurance sports (i.e., running, swimming and triathlon).\textsuperscript{178,181,182,185} Another significant drawback of the impulse-response model, is the limited ability to account for the multitude of environmental and hereditary factors impacting athletes.\textsuperscript{178} These variations in the training adaptation process were acknowledged by the creators of the impulse-response model, however were accepted and viewed as uncontrollable variables and an integral part of performance.\textsuperscript{177,178,185} Yet, these variables inevitably result in highly variable inter-individual responses to similar training plans (particularly for team and racquet sports), as such, a more appropriate, holistic approach to training quantification was desired.\textsuperscript{67,177}

In an attempt to resolve this limitation, Impellizzeri et al.\textsuperscript{67} opined a model to explain the training process, including accounting for environmental stressors (Figure 2.8). The model effectively demonstrated the capability of training monitoring to relate training prescription (i.e., external load), to the psycho-physiological responses of individual athletes (i.e., internal response), to explain training outcomes.\textsuperscript{67} Specifically, the athlete’s internal response to external load describes certain stages in the adaptation to training, therefore providing scope for highly individualised training load recording.\textsuperscript{67}
Figure 2.8: Holistic model of variables that may affect training adaptation.\textsuperscript{67}

The above model currently sits as one of the more favoured perspectives as related to training load monitoring.\textsuperscript{67} From a tennis perspective, owing to highly individualised external load responses typical of high-performance tennis academies,\textsuperscript{6} practitioners must consider the most appropriate training monitoring system within their training environment.\textsuperscript{32,67} Herewith, tennis coaches must embrace the integration of external load description alongside athlete internal response, to allow: i) verification of the validity and meaningfulness of testing protocols; ii) effective interpretation of training loads for appropriate training prescription i.e., planned v actual; iii) identification of responders and non-responders to certain training exposures; and iv) modification of planned training loads depending on effectiveness and adaptation level.\textsuperscript{67} For these reasons, it becomes vital for tennis practitioners to devise and validate appropriate methods of quantifying external and internal training loads specific to their environment. Whilst research literature in a host of sports would attest that training monitoring practices are yet to be perfected, the following section will draw upon a range of external and internal training load monitoring tools, critiquing their use in tennis currently (if at all), and deliberate on the relevance of the use within junior high-performance environments.
2.6: IMPLEMENTATION OF ATHLETIC SYSTEM MODELS

INSTRUMENTS FOR LOAD MONITORING

You have to believe in the long-term plan you have, but you need the short-term goals to motivate and inspire you.

Roger Federer\textsuperscript{189}

Traditionally, the development of successful coaching strategies have been attributed to the evolution of training prescription via a coach’s personal experience.\textsuperscript{177} However, the introduction of athletic performance modelling has resulted in a more modern and arguably, more scientific approach for the optimization of training programs.\textsuperscript{67,172,178,182-184,186} The implementation of these scientific theories, has been heralded as an important component in the prescription of optimal training programs.\textsuperscript{32,67,113,177} In turn, these same load monitoring theories can assist in systems aiming to reduce the risk of non-functional overreaching, illness, and injury.\textsuperscript{24,32,109,175,176} Owing to the emphasis placed on performance and athlete wellbeing, as well as the inflated training load exposure of high-performance athletes, the following section will describe current measures of external and internal load and how each provides assessment of athlete responses to training, to then evaluate their potential utilization in tennis.
2.6.1: External Load Monitoring

Historically, the actual output during training (i.e., external load) was the core foci of training monitoring systems. Hopkins\textsuperscript{113} assessed the quantification of training in sports (at the time of publication in 1991), along with common analytical methods and the applications of these methods to provide evidence-based suggestions for sports training.\textsuperscript{113} External load (or direct observation as it was termed) was deemed to be the most appropriate method of training prescription (most likely due to the state of technology).\textsuperscript{113} Accordingly, training speed or pace (derived from time and distance) were suggested to be measured very accurately over well-defined courses (i.e., lap pool or running track).\textsuperscript{113} Direct observations were also described as methods of measuring training intensity, with observed speeds expressed as either absolute intensity (i.e., m/min) or relative intensity (i.e., percentage of previous exercise attempts).\textsuperscript{113} In tennis, intuitive training drill prescription is common, and hence drill quantification is loosely monitored through an estimation of the number of stroke hit or session duration.\textsuperscript{3} With advances in technology, current methods of monitoring external load have improved to allow enhanced data accuracy, collection in field-based “real world” environments and/or multi-measures from micro-technology. In a generic sense, tools to measure external load can be categorized under respective areas including: performance testing (i.e., physical capacity testing and power output), time-motion analysis, and neuromuscular function.\textsuperscript{32}
Chapter 2: Literature Review

Performance Testing
It is postulated that changes in on-court tennis performance can be impacted through improvement or decrement of physical fitness capacities. These ensuing fluctuations in physical capacities are ultimately the result of adaptations to the external load applied. Figure 2.9 highlights from a generic sense the immense magnitude of variables that interact on this front with training exposure. The current thesis will not discuss all aspects of this holistic model, as performance testing is not training load per se, it does represent the change in physical capacity. It is important though to recognise the highly individualised characteristics that assist in successful performance. A recent study surveyed 65 practitioners about their use of performance testing within a range of high-performance sporting environments, including volleyball, track and field, swimming, football codes, cycling, basketball and tennis. Despite innate limitations of the survey due to distributions of sports surveyed, the authors observed that the most popular form of performance testing was explosive strength or power, monitored most commonly on a monthly basis. It was found that typically, all other modes of performance testing were completed quarterly, including maximal strength, aerobic power, and anaerobic power. The following section will examine common methods of testing performance, with reference to literature, practicality and current/potential use as both a training monitoring tool and assessment of physical ability in tennis.
Figure 2.9: A holistic model of the variables that interact with training exposure. 191
Explosive Strength and Power

According to McKeown and Ball, jump performance is most predominantly used as the surrogate measure of explosive strength, though often include CMJ, squat and drop jump variations. In tennis, such measures have been considered when quantifying changes in performance over time, by aiding understanding of neuromuscular responses to training and fatigue. Many varying testing protocols exist within lower-body power testing, using a variety of displacement recording technology. Force platforms are regarded as the gold standard measure of force measurement. However, owing to the high cost of force platform systems, alternative methods have been investigated, including the use of linear position transducers. An example system is the Plyometric Power System, which measures power through software calculating mass of the barbell, the displacement of the barbell, and the time taken for displacement of the barbell. Another more common, and cost effective example is using a Yardstick vertical jump device, which requires athletes to maximally jump and physically move a measuring marker above their head. These methods have both been described throughout numerous high-performance sport studies, including rugby league, volleyball, and AFL with typical error of measurement reportedly < 2.5 %. Within high-performance tennis environments, vertical jump is reported to be assessed using both a Yardstick vertical jump device, and contact platform technology. Reid and Schneiker emphasize the importance of muscle power in the lower extremities to create explosive actions required for tennis. In tennis, vertical jump is regarded as not only biologically similar to the upward drive motion of the serve and smash, but also thought to be related to explosive power of athletes within tennis specific movement patterns.
In terms of sport specific power assessment, upper body explosive strength was typically assessed through bench-press throw using displacement software (i.e., Plyometric Power System) or recorded displacement of medicine ball throw in sports such as rugby league.\textsuperscript{165,200-202} Reliability and validity investigations into these use of these measures in the field have identified them as cost-effective, versatile, and valid means for the measurement of force.\textsuperscript{192,203-205} Outside of tennis specific measures of serve and groundstroke velocity, Fernandez-Fernandez et al.\textsuperscript{162} report medicine ball tests as the most prominent and useful upper-body power measure available. The protocols reported of most frequent use include overhead, forehand side and backhand side throws using a 2 kg medicine ball, with performance assessed from throw distance.\textsuperscript{162,199} These medicine ball throw protocols are reported to demonstrate high external validity, owing to the coordination of body segments through the kinetic chain typical of tennis strokes, with throw distance also reported to relate to serve velocity, thus facilitating as suitable tennis-specific performance test.\textsuperscript{162,206}

\textit{Maximal Strength}

The most popular measure of maximal strength generally included the use of repetition or predicted repetition maximum for traditional strength exercises such as the back squat, bench press and bench pull.\textsuperscript{165} Typically, in order for practitioners to prescribe appropriate resistance training programs, determination of the athlete’s maximum lifting capacity is required.\textsuperscript{207} Such strength capacity is generally presented as percentage of 1 repetition maximum (1RM), or calculated from the maximum repetition that can be produced from a certain resistance.\textsuperscript{105,197,200} As muscular strength varies depending on muscle groups involved and type of lift employed, maximal lifting testing needs to be utilised for each prescribed exercise.\textsuperscript{207} Outside of the time consuming element of testing each individual prescribed exercise, another
limitation of 1RM testing is that depending on athlete training experience, lifting maximal weights may increase risk of injury.\textsuperscript{207} As such, depending on competency and age of athlete’s, RM testing can vary from 1 repetition through to, but not limited to, 20 repetitions.\textsuperscript{105,197,200,208}

In tennis the rationale for testing and improving maximal strength is to monitor and address an athlete’s underlying ability to produce maximal power.\textsuperscript{162} For tennis, strength testing using free weights with RM protocols is generally negated due to the risk compared to reward of maximal testing in relatively young and developing bodies; which are also unlikely to be proficient in the movement patterns required (i.e., back squat).\textsuperscript{162} Saying this, Kraemer et al.,\textsuperscript{29} has previously demonstrated that improvements in military press 1RM tests moderately relate to increased serve and groundstroke velocity in female players (19 ± 1 y). Yet, particularly within junior developmental tennis environments, strength testing is often limited to hand-grip strength using an isometric dynamometer in standing position, owing to its safety, simplicity, low cost and technical reproducibility.\textsuperscript{162,190,199} Future research, may also attempt to examine relationships between changes in maximal strength or power and training load prescription, though the regular use of RM testing in tennis as a monitoring tool remains doubtful.

\textbf{Repeated Speed and Anaerobic Power}

To assess anaerobic power, it is reported that the two most common field tests include the Yo-Yo intermittent recovery level 2 (IR2) test and repeated sprint ability (RSA) tests.\textsuperscript{165,191,209} The Yo-Yo IR2 and RSA protocols have been developed to assess the athlete’s ability to recover from repeated exercise with majority contribution from the anaerobic system.\textsuperscript{209-211} The Yo-Yo IR2 involves 2 x 20-m shuttle runs interspersed by a 10 s active recovery period (controlled by audio signal). Previous investigations
have reported the CV of the Yo-Yo IR2 to be ~9.6% in elite soccer athletes, though up to 12.7% has been reported in recreationally active subjects. The test audio signal increases in speed until the athlete can no longer maintain the speed; the distance to that point is then recorded. RSA protocols vary in both the number of sprints and in the distance covered per sprint; however typically range between 5-10 repetitions, over 20- and 40-m, interspersed with 10-30 s recovery (CV < 2.7 %). Laboratory investigations most commonly utilize Wingate tests (20-30 s) to measure the maximal anaerobic response of subjects to singular all-out efforts. While these are observed to be of high validity and reliability within a research setting, to understand the performance evaluation of athletes within athletic training environments, field-based tests are generally more commonly used.

From a tennis perspective, it has been reported that anaerobic energy supply during matches is critical, owing to frequent intermittent, high-intensity bouts interspersed with recovery periods (highlighted earlier in the literature review). Thus, anaerobic and repeated effort tests seem appropriate for assessing athlete performance standard following training programs. It is also seems logical to monitor any changes in anaerobic performance along with training load to both ensure training prescription is developing this energy system or to minimise the presence of detraining, especially during tournament environments. Outside of laboratory-based measurements of anaerobic energy production (i.e. 30 s Wingate cycle test), which have questionable applicability to tennis, junior high-performance environments typically rely on field tests such the RSA test protocol. A common RSA protocol adopted for junior tennis involves 10 x 20 m with 20 s rest, with accumulated total sprinting time foreshown to be the most reliable measure. While the RSA test has been used
reliably within tennis environments for some time (CV < 3 %), the validity has been frequently questioned for tennis specific movements and the excessive duration of the test (~ 5 min each individual athlete). Thus, anaerobic performance testing and training load monitoring for tennis athletes may benefit from future development of an equally reliable, but valid performance test.

Aerobic Power
Aerobic power tests have received a much wider variety of test interest. There are numerous variations and methods available to cater for easily accessible field-testing as well as laboratory protocols. Of the aerobic power field tests available, the Multi-stage fitness test (CV 10 %) and Yo-Yo IR level 1 (CV < 5 %) have been reported to be most common within high-performance environments, including tennis. The Yo-Yo IR level 1 test is basically a slower version of the above described Yo-Yo IR level 2 test (also an indicator of aerobic power), which seemingly has been adapted from the much earlier developed Multi-Stage fitness test. The major difference between the two aerobic power field tests is the recovery period. In Yo-Yo IR tests, the recovery is active, whereas in the Multi-stage fitness test the running is continuous, with athletes required to maintain pace with each continuous audio signal. One alternative method of assessing aerobic power from a more controlled, laboratory setting is the maximal aerobic power test (MAP).

The MAP test (CV 1.32 %) was introduced as a less time consuming performance measure to peak power output tests, and have been correlated to both laboratory and time trial endurance performance. MAP testing involves an incremental ramp protocol which peak power is recorded at the highest mean power during a complete stage of the test, prior to exhaustion. Whilst there is evidence to support the use of a
MAP test, owing to the exhaustive nature, it is not entirely feasible to implement this testing protocol on a regular basis. Hence, the Multi-stage fitness test and Yo-Yo IR level 1 appear more ecologically valid for high-performance training environments, owing to the brief testing time, cost efficiency, and ease of conducting the testing.\textsuperscript{48,57}

Although tennis matches rely predominantly on anaerobic energy systems, sufficient aerobic capacities reportedly allow athletes to recover from high-intensity effort more efficiently.\textsuperscript{6,106} Within tennis environments the 20 m Multi-stage fitness test has been reported of relevance owing to the progressively exhaustive nature, and frequent change in direction.\textsuperscript{198} However, similar to other intermittent sports, the validity of its continuous nature of the test has been questioned, along with the non-specific muscular involvement (i.e., lower-body only and non-tennis specific).\textsuperscript{162} Thus, Fernandez-Fernandez et al.,\textsuperscript{162} highlight the development of two specific “tennis endurance” protocols, the Girard test and the Hit and Turn test, which have been identified owing to their use of court dimensions and combination of specific footwork and hitting actions.\textsuperscript{162,221,222}

The Girard, and Hit and Turn tests involve a series of incremental stages, which each involving several shuttle runs at increasingly difficult stages, separated by 10-15 s passive recovery.\textsuperscript{221,222} Both tests utilize the dimensions of one half tennis court, where the player is based in the centre of the baseline and is instructed by visual and/or sound feedback to move and mime a match intensity groundstroke. In the Girard test movements involve reactive shuttles to on of six cones randomly (forward, lateral and backwards, both sides).\textsuperscript{221} The Hit and Turn test movement patterns involve side shuttle and running along the baseline, to mime strokes on each doubles sideline in time with the bleep tone.\textsuperscript{222} One benefit of this protocol over the Girard
test, is that the test can easily cater for testing of multiple athletes simultaneously, however, conversely the movement patterns of the Hit and Turn test do not incorporate the same specific forward and backwards movement demands of the Girard test. In terms of use as tennis specific performance tests, both tests may provide valid measures of testing external training load effectiveness for tennis. Thus, while further research may be required as to efficacy and validity across all tennis environments and levels (i.e., elite), these tests seem of benefit to training monitoring systems of high-performance tennis environments.

**Sprint and Agility Performance**

Maximal sprint tests are employed to assess an athlete’s ability to express movement as fast as possible, generally in a linear fashion. Further, the rationale behind measuring changes in movement speeds can be to provide insight into movement-specific fatigue. The linear distances assessed are mostly sport dependent, but generally range from 5- to 60-m depending on sport-specific requirements (i.e., tennis typically < 5 m). These tests are most commonly measured using infrared timing gates, reportedly reliable across these short and linear distances. Notably, frequent underestimation of displacement and movement velocity in other linear sprint test measures (i.e., GPS) means at present, infrared timing gates are more appropriate in high-performance environments. These methods are consistent with most high-performance tennis environments, yet as alluded to above, typically consist of distances 5-, 10-, and 20-m (CV 1.0 - 1.5 %). This is owing to the movement characteristics of tennis, with players typically required to cover less than 4 m in each direction for each stroke (i.e., 5-m sprints), whilst 10- and 20-m distance are reportedly utilized for consideration of maximal sprint ability.
Inherently, tennis requires these sprint distances to be both maximal to the ball, but also in returning to reach subsequent strokes. However, previously Little and Williams\textsuperscript{227} have demonstrated minimal relationship between linear sprint time and time to complete agility (change of direction) tests. Owing to the fact that it has been previously reported that these relationships further decrease with the inclusion of sport-specific skills (i.e., mimed tennis strokes), some high-performance tennis environments have elected to utilize general agility tests, particularly with junior athletes where skills are still being developed.\textsuperscript{162,198,228} The most common “general agility” tests include the Illinois agility test (timed slalom cuts through 4 cones with 180° turns at each end; CV 0.24 %), and the 5-0-5 agility test (timed 5-m sprint with 180° turn and sprint back, either from a fly or stationary start; CV 2.5 %).\textsuperscript{228-230} However, Ulbricht et al.,\textsuperscript{199} describes a tennis specific agility test which has been adopted by German high-performance tennis environments. The protocol measures reactive agility, where players respond to two reactive lights (right and left), from a frontal position on the baseline midpoint.\textsuperscript{199} Upon light emission, the player must react and sprint to the corresponding sideline and perform a mimed groundstroke (or hit a ball pendulum) before returning to starting position.\textsuperscript{199} The test involves two repetitions each direction, with 90 s recovery between bouts.\textsuperscript{199} While authors could not find any reported reliability data for this test, it may pose a suitable and specific alternative to general agility test, so long as practitioners concede that the inclusion of mimed strokes will affect comparisons to other tests.

Again, the aforementioned series of performance tests represent physical capacity testing, and thus not explicitly training load monitoring per se. Consequently, it should be acknowledged that whilst integral parts of successful training monitoring systems, monitoring of external load requires explicit quantifiable tools. As such, the
following will now examine current external load monitoring tools, and assess the
efficacy or current use within high-performance tennis environments.

**Time-Motion Analysis**
With sports analytics evolving rapidly through the development of micro-technology,
a range of methods used to objectively assess human locomotion now exist. These
include the development of GPS technologies, tri-axial accelerometers, and motion
tracking software. These systems have been utilized to improve
quantification of in-field sport performance, though unfortunately, logistical issues
exist including questionable validity and reliability, and labour-intensive nature when
related to tennis. The following section will describe both benefits and limitations
of each system in high-performance sport, as well as relating these to the potential use
of each system in high-performance tennis.

**GPS**
A growing body of literature reviewing the use of integrated micro-technology,
predominantly addressing the use of GPS to; 1) quantify movement demands, 2)
assess differences between training and competition, 3) and measure selected
physiological and metabolic demands. While these defined areas are not
investigated solely through the interpretation of GPS data, the current section will use
this model to review how GPS technology has been used within the literature to assist
load monitoring. One common rationale for the use of GPS technology in high-
performance environments is to quantify the movement demands of athlete’s specific
to their performance needs. Literature in this area has generally been utilized to
describe patterns in movement during different competitive scenarios, providing
assistance in tactical strategies or improve fitness from training demands. There is a
range of descriptive literature assessing the movement demands of field-based sports
including AFL, cricket, hockey, soccer, rugby league and union.\textsuperscript{50,52-55,58-61} Often these data are collected in real-time through GPS software, which holds particular merit in the monitoring of load during return from injury, and again, for differing positions in team sports.\textsuperscript{135,231-233} For example, Gabbett,\textsuperscript{231} assessed the competition demands of elite women’s hockey players to loads experienced during game-based training sessions. It was observed that the demands of training did not equate to these elicited through competition, specifically through a reduction in training time spent at moderate-high intensity.\textsuperscript{231} Analysis of external load data from GPS has also been used in the assessment of recovery needs, and formulation of recovery interventions. For instance, Minett et al.,\textsuperscript{234} monitored running intensity during a rugby union match, comparing the anti-catabolic properties of a multi-nutrient supplement. Authors suggested that owing to the maintenance of very high intensity running accumulation throughout the match, that the supplement was successful in avoidance of muscle degradation.\textsuperscript{234}

In tennis, previous studies have utilized GPS to examine distances covered at different velocities during a simulated match in high-performance junior tennis players.\textsuperscript{51} Through analysis of movement characteristic during the matches using 10 Hz units, it was insinuated that junior high-performance need not focus on development of running abilities, as movement velocity did not change during the match, nor differ between winners or losers.\textsuperscript{51} Further, GPS technology in tennis has been implemented to quantify external load demands (distance covered and velocity) of 4 discrete tennis drills.\textsuperscript{3} Through movement analysis from GPS data it was reported that the 4 drills critiqued were reflective of the external load demands of previously reported match play.\textsuperscript{3} Yet, while these data and future GPS usage would, in theory, greatly assist
coaches in the training prescription and training load monitoring, significant limitations of the measure, specific to tennis, have been identified.\textsuperscript{50,52,53,55,235} Despite the extensive range of descriptive studies available, GPS accuracy and reliability has been repeatedly questioned, particularly in tennis.\textsuperscript{50,52,53,55,235} In sum, these investigations highlight that description of high intensity running, multiple direction changes within a small areas, and total distance suffer increased reliability errors of up to 15\% regardless of the power of the device (1 Hz through to 15 Hz).\textsuperscript{50,52,53,55,235} Owing to the potential increased accuracy using higher frequency GPS devices, Vickery et al.,\textsuperscript{55} specifically compared 5, 10, and 15 Hz units to gold-standard VICON criterion data in a range of sports including cricket, hockey and tennis. Overall, it was reported that no improvement in accuracy of reliability of GPS devices were observed with an increase in sampling frequency.\textsuperscript{55} These limitations - which are reportedly further unattainable due to increased atmospheric pressure, tall surrounding buildings, and highly populated areas - mean tennis practitioners should be cautious of distance and speed data, being aware of serious underestimations of training distance and speed.\textsuperscript{50,55,135,236}

\textit{Accelerometry Systems}

While the use of accelerometry data for load monitoring has grown in popularity in recent times, the majority of devices used within the literature are housed within the same unit as GPS technology.\textsuperscript{100} This technology consists of quantification of movement through the sum of accelerations in a tri-axial plane, with the analysis combining magnitude data (expressed in g-force) from three separate axes (x, y, and z).\textsuperscript{226} While traditionally accelerometer data has been used for the purpose of objectively recording physical activities from a public health perspective, their use in
high-performance sport can both compliment and replace GPS data for the quantification of external load.\textsuperscript{135,226,237} For example, collision sports such as rugby have addressed the quantification of collision intensity during training and competition into (4-6) body-load zones.\textsuperscript{59,233,237,238} While, most of these investigation have solely reported on discrepancies of body-load between playing positions within the team (i.e., forwards and backs), Gabbett et al.,\textsuperscript{238} has also compared competition body-load to training. Similar to the suggestions made from GPS data, it was recommended that body-load should be reflective of matches within training to prepare athletes for heavy collisions\textsuperscript{238}. These recommendations should nevertheless be viewed cautiously within training (particularly in-season) as these additional collision loads may increase post-training recovery time.\textsuperscript{135}

In tennis, a recent investigation has utilized accelerometers to quantify the external load (3D body load) demands of 4 h simulated match play, over 4 consecutive days in male professional players.\textsuperscript{100} These data observed reduced 3D body load on days 2 and 4 in comparison to day 1, as well as a reduction within a 4 h match (second 2 h compared to first) on day 2, 3 and 4.\textsuperscript{100} These data form preliminary investigation into quantifiable accelerometer data for tennis matches, allowing future training and training load monitoring practice to compare. Although, it should be acknowledged that validation and reliability of these measures in tennis is non-existent.

While these literature highlight positive uses of accelerometry data, limitations of this technology has been reported.\textsuperscript{226} Specifically, Waldron et al.,\textsuperscript{226} designed a comparative investigation of the validity and reliability of GPS and accelerometers with electronic timing lights. It was observed that accelerometer measurements were least reliable across sprinting movements, particularly for the frequency of
accelerations. As such, it should be acknowledged that while summation of strong force production and change in direction - typical of tennis - can be helpful in external load quantification, limitations exists within accelerometry technology in detecting changes in training loads due to the high volume of short accelerations with multiple changes in direction.

**Movement Recognition**

While the development of technology will progressively advance GPS and accelerometry devices within high-performance sports, substantial development of wireless tracking and positioning systems has also occurred. Through the use of extensive and complicated algorithms, these systems utilize cinematographic surveillance data to formulate multi-tracking occupancy maps. This technology originates from research of pedestrian tracking, where (typically for security purposes) projected silhouette imagery from video footage, detects 3D objects perpendicular to their plane (i.e., ground). While these studies have been of some success, Lui et al. report significant differences between the tracking of pedestrians and of team sports, including erratic movements and lack of deviation for collision avoidance (i.e., contact sports). This being said, recent work has reportedly validated an occupancy map algorithm on 30 min of international field hockey, and 10 min of college basketball for movement trajectory from a single camera. While this technology is seemingly in early stages of development, significant performance improvements are reported.

Other examples of motion tracking software within the literature include radio localization devices. The system uses a low-cost wireless sensor network platform, which, using algorithms determining time-of-arrival, periodically transmits beacon
signals to the detection platform. Of note, the researchers conducted a dynamic trial, which consisted of tracking a cyclist around a velodrome. Based on the dynamic trial and static trials, Sathyan et al. report accuracies of 0.15 m outdoors, and 0.5 m indoors, using a 12 node system. While these observed accuracies appear positive for the advancement of external load monitoring in sport (and better than GPS), the authors acknowledge that continued research into the performance of this system and algorithms across a wide range of applications is required.

In tennis, there are currently systems designed to track both player and ball movement during matches, including multi-camera tracking systems (Hawkeye), computer system analysis (SAGIT), and automated computer software. These systems have typically been used to describe the in-point distances traversed by players during matches, as well assisting in officiating of line calls. Specifically, SAGIT has been utilized within training load research for the examination of movement pattern trends. The research used the system to identify and classify the typical distances travelled of tennis athletes (inner, mid and end-range of court movements) ultimately assisting in the specific distances required to prescribe movement drills.

While the abovementioned tracking systems appear favourable in the advancement of gross external load movement patterns for tennis, several major limitations are of note. Firstly, outside of the contracted rights to use during Grand Slam and certain Association of Tennis Professionals (ATP), Women’s Tennis Association (WTA) events, the cost of implementation of these systems is excessive, with reported costs of permanent multi-camera installation upwards of $100,000 per court. Thus, logistically only the elite will benefit from these systems and generally only during these events. Many junior high-performance environments simply cannot afford these
systems, and due the multi-camera analysis needed, these tools are nearly impossible to implement in training and while on-tour.\textsuperscript{2,102-104} Of further concern, these technologies fail to cater for the detection of fine and discrete movements specific to performance in sports such as tennis.\textsuperscript{62-65} Generally, high-performance sport will rely on video analysis to quantify specific movement occurrences that GPS and motion tracking software cannot detect (i.e., limb movements with a static centre of gravity). Throughout the literature, the gold standard in movement analysis in tennis is the VICON biomechanical system.\textsuperscript{242-246} Whilst, these systems hold little use in the quantification of external load in tennis, it is appropriate to acknowledge their use in the development of reliable systems and critiquing technical trends.\textsuperscript{247-249}

\textit{Notational Analysis}

Before the saturation of technology within the methods of quantification in sport, notational analysis was commonplace.\textsuperscript{250-253} The use of notational analysis represents performance analysis in its purest form, involving physical counting and recording of relevant information within training or competition. Typically notational analysis benefits from excellent reliability in tennis (CV \(\sim 0.07\%\)),\textsuperscript{46} and owing to the issue raised above with integrative external load technology, perhaps notational analysis still presents the most effective method of external load quantification, despite its manually laborious nature.

In tennis, a number of studies and high-performance environments utilize notational analytical systems to quantify the stroke demands of training and competition.\textsuperscript{3,46,100,101,117,120} Specifically, O’Donoghue and Ingram\textsuperscript{120} analysed the in-point stroke demands of each Grand Slam event between the years 1997 and 1999. Information gathered, such as the proportion of rallies played at the French Open
(clay court surface) compared to other events, has helped shape the current load prescription mentality and drill composition to embrace the increased physical demand required on clay.\textsuperscript{120} Other research, specifically regarding junior high-performance athletes, has utilized notational analysis to compare match external loads to professional standards in an attempt to further design long-term development plans around the physical tennis demands of the elite game (i.e., stroke rates as a proxy for match and training intensity).\textsuperscript{117}

While an understanding and implementation of the external load demands, typical of elite tennis, is beneficial to the development of junior tennis players, inherently an individual sport such as tennis requires individual load prescription. In order to best achieve this, coaches must also understand the athlete response to the progressive increase in load, as well as just “mimicking” elite player programs. As emphasized by the abundance of recent training load monitoring literature within the current thesis, internal load markers provide vital information of how athletes are responding to external loads. As such, the following will examine internal load monitoring tools relevant to junior high-performance tennis and evaluate the efficacy of potential efficacy of these tools.
2.6.2: Internal Load Monitoring

As suggested by Hopkins,\textsuperscript{113} although external load can be accurate for the monitoring and prescription of training in predominantly linear movement planes or sports competed over strictly defined courses (i.e., swimming and track events); in sports where activity and opposition is undefined, speed and distance are potentially less accurate than internal measures. Furthermore, as developed in the work of Impellizzeri et al.,\textsuperscript{67} consideration of an athlete’s internal response to prescribed external load becomes critical in assessing the actual response, and in time, adaptation to training. As a result, the importance of employing both external and internal load measures to provide greater differentiation between fresh or fatigued athletes is now better understood.\textsuperscript{32}

**Biological Measures**

Blood lactate analysis has become increasingly accessible with the advancement of collection and processing equipment. Hopkins,\textsuperscript{113} records that historically, blood lactate concentrations were determined through venous or arterial blood samples. However, recent advances have seen the development of capillary blood (commonly fingertip of earlobe) and salivary collection.\textsuperscript{254-256} Despite these recent advances in lactate testing technology, research is seldom positive of its use in high-performance sport. This is often owing to the invasive, time-consuming nature and inter- and intra-individual variations, ranging from mode of exercise, hydration status, diet, and ambient temperature.\textsuperscript{32,67,113,177} Nevertheless, literature has previously utilized lactate analysis as an internal load marker, paying particular attention to determining lactate threshold.\textsuperscript{177,257} Literature suggests that training stimuli that elicits blood lactate levels of \(\sim 4\text{mmol/L}\) corresponds to an appropriate pace for inducing positive physiological adaptation, although it is recognised this is rarely translated to the specific constraints
of tennis.\textsuperscript{113,177} In this fashion, blood lactate concentration has reported in numerous studies to be sensitive to changes in prescribed training.\textsuperscript{256-258}

As evident of above, a recent investigation into lactate threshold response across a professional youth soccer season, highlights the ability of blood lactate monitoring to indicate athlete endurance performance over a period of time.\textsuperscript{258} Within the tennis literature, blood lactate analysis has been employed to describe anaerobic demand in a range of training and match load scenarios; including, estimation of match intensity, quantification of training load demands associated with specific tennis drills, and during intervention studies to establish subject internal response to testing protocols.\textsuperscript{3,8,14,93,101,131} Specifically from the understanding of training load in junior tennis, Fernandez-Fernandez et al.,\textsuperscript{14} assessed the lactate responses of junior high-performance female players during a 2 day invitational tournament. It was observed that blood lactate responses were influenced according to the specific match characteristics (i.e., duration and stroke rate).\textsuperscript{14} Activity profile data was also available for the specific population (junior females),\textsuperscript{14} however beneficial inferences can likely be made to junior male athletes also. These data allow informed prescription of possible stroke intensities that will elicit a desired adaptation. Thus, while care should be taken in standardization of lactate collection, measurement of blood or salivary lactate may prove a useful tool for measuring the effectiveness of training in sports where there is a high anaerobic demand (i.e., tennis).

Whilst analysis of lactate concentration is the most common biological method of monitoring athlete training loads, it should be acknowledged that various other blood and salivary markers have been investigated in regard to biological changes following exercise, and used to identify athletes at risk of training-induced infection and over-
training. Other biological markers used inform training load monitoring include analysis of; ratio between glutamine and glutamate blood concentrations, hormones such as norepinephrine, cortisol and testosterone, plasma CK, iron; and salivary immunoglobulin-A. While these biological measures are not expressive of training prescription outcomes, an athlete’s biochemical profile has been suggested to be of assistance to practitioners in providing specific training goals.

As an example of the above, a reduction in testosterone to cortisol ratio has been suggested to be indicative of a catabolic hormonal profile for elite male rugby league athletes for up to 24 hours after a match. Recently, an investigation of junior female high-performance tennis players has compared the stress responses prior to and during a match, as well as during training through analysis of salivary cortisol (CV 6.75 %). Accordingly, it was observed that cortisol values were clearly linked to match demands as well as outcome (i.e. greater increase in losers). As such, it was suggested by the researchers that coaches must take into consideration the elevated stress during competition in junior high-performance players, with accumulation of these stress responses likely to be detrimental over an entire competitive block. These observations infer that training monitoring strategies should aim to incorporate tools to measure stress levels (i.e., salivary cortisol or questionnaires) to ensure appropriate recovery and that preparatory situations are prescribed. In saying that, ultimately owing to the invasive nature of all blood-based, biological procedures, coaches and athletes typically do not endorse these practices, thus limiting their ongoing applicability in professional tennis environments.
**Heart Rate**

Training load monitoring has long been associated with the use of HR-derived measures (i.e., exercise HR \([\text{HR}_{\text{ex}}]\), resting HR \([\text{HR}_{\text{rest}}]\), and maximal HR \([\text{HR}_{\text{max}}]\)) to establish physiological responses to training stimuli. While HR monitoring has historically occurred within a laboratory setting, using electrocardiograph monitors, reliable telemetry bands are widely available.\(^{113}\) The following sections will review common uses of HR-derived measures. The most prominent uses include: 1) within-individual relative exercise intensity (i.e., exercise HR), 2) understanding of aerobic training adaptations (i.e., HR recovery), 3) interpretation of athlete parasympathetic activity (i.e., HR variability), and 4) understanding of the adaptation through the impulse-response model (i.e., training impulse; TRIMP).

Before reviewing these customary uses of HR data, it is important to acknowledge the associated limitations of HR monitoring. It has been previously reported that the day-to-day variation in HR is \(~6 \text{ beats.min}^{-1}\) or \(~6.5\%\).\(^{265,266}\) Factors such as training status, environmental conditions, diurnal changes, exercise duration, hydration status, medication and altitude all can the potential to alter HR response to activity or recovery.\(^{177}\) Furthermore, it is important to note that a vast majority of studies investigating the acute and chronic HR response to exercise have been conducted on endurance-trained athletes.\(^{267}\) Acknowledging the difference in training status of tennis players to endurance athletes, further research is required to determine the appropriateness of these measures in this tennis population. Specifically in tennis, players often detest HR monitors, due to the perception of restrictiveness during stroke play - therein resulting in limited comparative information between training and “live” match HR data. However, if the peripheral factors are well controlled (i.e., environment, hydration etc.), and coaches and athletes are informed of the benefits of
their HR interpretation, an accurate measure of athlete response to training can occur. Given the low-cost, high portability and ease of implementation in tennis settings (despite athlete dislike), provide obvious advantages over oxygen consumption systems.\textsuperscript{113,177}

**Exercise Heart Rate**
The simplest, and most accessible use of HR measurement is collected during exercise, known as exercise HR. The mean HR across a period of time during exercise (typically 30-60s) is analysed to provide an expression of within-individual exercise intensity.\textsuperscript{267} Whilst exercise HR has been closely associated with both oxygen uptake at steady state exercise and improvements in high-intensity exercise performance, research by Buchheit et al.,\textsuperscript{89} in youth soccer emphasises that increased HR should not be used as a clear marker of fatigue and/or impairment of physical capacities. As such, while exercise HR can be a useful tool for analysing training intensity, more in-depth HR analysis (i.e., HRR, HRV) is likely required to detail physiological responses accurately.\textsuperscript{267}

**Heart Rate Recovery**
The rate at which an athlete’s heart rate declines following cessation of exercise is known as HRR.\textsuperscript{268} In physiological terms, HRR is a measure of the reactivation of parasympathetic branch of the autonomic nervous system, and sympathetic withdrawal.\textsuperscript{269} Daanen et al.,\textsuperscript{268} report that HRR has the potential to become a valuable internal load monitoring tool, identifying changes in athlete training status, however literature in athletic populations, particularly tennis, is limited.\textsuperscript{268} Despite concluding that HRR response in the context of overreaching remain unclear, Daanen et al.,\textsuperscript{268} found HRR improves with a better training status, remains stable with stable training status, and decreases with a decline in training status, and therefore is suitable
in the identification of over-training. Contrarily, recent research by Dupuy et al.,\textsuperscript{270} and Aubry et al.,\textsuperscript{271} observed that, in fact, the development of functional overreaching was associated with a faster HRR in endurance athletes. One of the limited tennis investigations to have reported HRR is an intervention-based study which examined the effect of a battery of recovery methods on within-day and next-day recovery.\textsuperscript{101} However, no change in HRR was observed between conditions nor within the same day and condition.\textsuperscript{101} Hence, given the limited information, it seems evidence for HRR is lacking for tennis regarding internal training load assistance, possibly due to the minimal use of HR monitors and requirement for standardisation of exercise bouts to determine HRR.

**Heart Rate Variability**

With advances in HR monitoring technology, modern HR monitoring tools (i.e., telemetric bands and watches) allow the magnification of variances in the autonomic nervous system activity. In doing so, practitioner can seemingly assess an athlete’s HRV instantaneously, with an understanding of their sympathovagal balance (i.e., parasympathetic and sympathetic activity).\textsuperscript{114,272} A descriptive case study by Plews et al.,\textsuperscript{273} - whom demonstrated signs of over-training of an elite triathlete - identified that interpretation of HRV from a single training dose (i.e., single day) suffered a number of issues, owing to factors including ambient temperature and prior exercise. Accordingly, through long-term HRV data collection on an athlete, Smith\textsuperscript{114} suggests HRV may provide a suitable monitoring tool for the prescription of appropriate training. However, tennis specific literature regarding HRV is lacking. A case study of three professional male tennis players (ranked top 30, 100, and 1000, respectively) monitored HRV for 30 d, whilst strength and conditioning training was increased by 120, 160 and 180 \%.\textsuperscript{152} Whilst the study was designed to evaluate the response of
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each athlete and determine presence of and recovery from functional overreaching, results were seemingly inconclusive. Yet, the authors suggest that it was likely each of the athletes reached a state of functional overreaching, in part owing to an observed reduction in HRV time and frequency across all players. Thus, while there is potential for HRV protocols to assist in tennis load monitoring in heavy training blocks and on-tour, particularly with advances in HR technology, a lack in longitudinal and tennis specific data, combined with difficulties in player compliance, warrant further evidence before use in junior high-performance tennis environments.

**HR TRIMP**
As described in a previous section, Banister et al., Calvert et al., and later Morton et al., proposed arbitrary training unit called TRIMP, to assist in the interpretation and prediction of training response through performance modelling. Originally, a TRIMP was calculated using the mean HR during exercise, calculated from measures made randomly at least 3 times during the training session, and subsequently expressed as a percentage of maximal HR, then transferred to all training modalities (i.e., cardio-respiratory and strength training).

\[
\text{STRAIN} = \frac{\text{HR}_{\text{mean}}}{\text{HR}_{\text{max}}} \times 100%
\]

\[
\text{STRESS} = \text{training session volume (distance covered, or weight lifted)}
\]

\[
\text{TRIMP} = \frac{\text{STRESS} \times \text{STRAIN}}{10^*}
\]

*The arbitrary division of 10 is to make TRIMP numbers more manageable.
This method was then refined to include resting HR to establish a HR ratio, and apply weighting factors for both males and females.\textsuperscript{185,274}

\[ \text{TRIMP} = \text{duration of training (min)} \times \Delta \text{HR ratio} \times Y \]

Where \( \Delta \text{HR ratio} = (HR_{\text{ex}} - HR_{\text{rest}}) / (HR_{\text{max}} - HR_{\text{rest}}) \)

Where, \( Y^* = 0.64e^{1.92x} \) for males, and \( =0.86e^{1.67x} \) for females,

\[ e = 2.712, \text{ and } x = \Delta \text{HR ratio}. \]

\textsuperscript{*}Based observed exponential rise in blood lactate in both males and females, associated with increased intensities of work.\textsuperscript{185}

Notably, a series of studies by Thierry Busso and colleagues,\textsuperscript{186,187,275} simplified the TRIMP equation by using the average fraction of the maximum aerobic power output sustained (i.e., VO\textsubscript{2max}), multiplied by the duration of the training session. During this time another method to quantify internal training load was proposed by Edwards.\textsuperscript{276}
The method involves the summation of 5 HR zones (50-60\%, 60-70\%, 70-80\%, 80-90\%, and 90-100\% HR\textsubscript{max}), specifically designed to avoid previous limitations surrounding quantification during interval training.\textsuperscript{276} Lucia et al.,\textsuperscript{277} and Earnest et al.\textsuperscript{278} proposed a further adaptation, which summated HR accumulation into only 3 zones in an attempt to describe and compare the internal load of each stage of the Tour de France and Tour de Spain, respectively. The modifications of HR zones consisted of: Zone 1) below ventilatory threshold, Zone 2) between ventilatory threshold and the respiratory compensation point, and Zone 3) above the respiratory compensation point.\textsuperscript{277} These zones are then multiplied by a standard coefficient and
finally totalled, in a similar fashion to Edwards TRIMP (i.e., zone 1 = 1, zone 2 = 2, zone 3 = 3). The rationale for this design was to give stronger weight to higher intensity session, supposedly more reflective of the individual internal load response. However, this method, similar to Edwards TRIMP, does not reflect each individual’s unique response to exercise above the anaerobic threshold. Hence, a modified TRIMP protocol was proposed incorporating lactate threshold (LT) and onset of blood lactate accumulation (OBLA) to create 5 weighted HR zones (HR\textsubscript{Lac} and HR\textsubscript{OBLA}, respectively), for a hockey team (team TRIMP). However, Manzi et al. highlighted that no empirical evidence suggests that team TRIMP provides superior information to support the use of such complex methodology.

As such, recently Manzi et al. present a individualised TRIMP technique (iTRIMP) aimed at alleviating the above limitations associated with arbitrary zones and weightings. Manzi et al. took the methods described by Stagno et al., however, each individual (soccer) athlete’s HR zones were generated from their own HR\textsubscript{Lac} and HR\textsubscript{OBLA} data, calculating the relationship between elevations in HR and blood lactate concentration throughout an entire session. This method has been shown recently to relate better to changes in fitness and performance compared to Banister’s TRIMP, team TRIMP, and s-RPE, for both individual events and team sports (i.e., distance runners, marathon runners, and soccer).

Likely owing to the animosity of tennis players towards wearing HR monitors, to date, no tennis literature exists that has investigated the use of any HR-based TRIMP method to interpret and predict training responses, or performance modelling. While the obvious limitation, surrounding the restrictive nature of HR chest straps, has been addressed previously, the continued advance in HR technology may eventually amend...
these issues with accurate HR measurement from other palpable body regions (i.e., wrist). If these technologies do advance, it seems logical that iTRIMP (the most modern versions of these training monitoring methods), which have held such merit in other individual sports (i.e., running and swimming)\textsuperscript{71,281}, and intermittent team sports (i.e., soccer)\textsuperscript{87} is worth future investigation in tennis.

The section below will examine in greater detail the literature of RPE based training load quantification. However, within dialogue regarding TRIMP it is important to briefly recognise RPE-based TRIMP (session RPE [s-RPE]) and monotony-TRIMP (session-TL [s-TL]) as proposed by Foster and colleagues\textsuperscript{25,49,282}. These calculations are appealing in terms of practical application within high-performance tennis environments, owing to the ability to quantify training load into a single number and the capabilities of monitoring without HR bands. While the following section will cover RPE in depth, it should be acknowledged that there are numerous studies debating the use of RPE over HR monitoring. However, current consensus highlights that a combination of tools will likely aid in a complete understanding of the internal training response\textsuperscript{32}. 
RPE Measures
As mentioned above, in the midst of the multitude of variations and adaptations of TRIMP equation, RPE was also suggested as a means to resolve limitations to HR in the quantification of internal load. Historically, RPE originated from a collection of work by Gunnar Borg to arrive at a full understanding of how people at work subjectively perceive all working conditions in relation to preferred intensities of effort, adaptation levels, and stress conditions. In a sporting sense, RPE is based on the level of understanding that athletes have over their body and mind, through the adjustment of exercising intensity based on the physiological stress experienced. As highlighted in studies of steady state and high-intensity exercise, RPE reported by athletes was strongly associated with mean HR and acute changes in HR. Originally, the Borg 15-point RPE scale was used to quantify the above mentioned understanding of ‘work’. However, Borg later proposed the Borg CR10 scale, as a CR scale anchored at the number 10, which represents extreme intensities. Borg outlined that the CR10 RPE scale was a general intensity scale for most subjective magnitudes that with special anchors can be used to measure exertion and pain (i.e., training load).

Later, Foster et al. applied the CR10 RPE scale to capture the perception of an entire session, not just specific segments, terming session RPE (s-RPE). This method was subsequently applied to endurance and basketball athletes, multiplying athlete CR10 RPE with the session duration to derive a single internal load unit (i.e. s-TL). Since then, s-RPE has been observed to be a simple and valid technique quantifying endurance, team sports, and resistance training sessions. Notably, a recent study by, Wallace et al. and later Rodriguez-Marroyo et al. compared HR-based measures and training distance covered as criterion measures to validate s-RPE
for swimming and professional cycling, respectively. Both studies identified s-RPE as an appropriate method for quantifying internal load, with mean individual correlations between s-RPE and HR-based measures ranging between $r = 0.74$ (Banister’s TRIMP), and $r = 0.75$ (Edward’s TRIMP).

Similar comparative studies have been conducted on team sports athletes, including soccer, AFL, rugby league, and water polo. Again, each study confirmed s-RPE as an easy and reliable tool to evaluate internal load, with individual correlations between $r = 0.50$ and $r = 0.85$ for soccer (Banister’s, Edward’s and Lucia’s TRIMP), $r = 0.83$ for AFL (both Banister’s and Edwards’s TRIMP), and an overall high correlation for water polo ($r = 0.88$, Edward’s TRIMP). Lovell et al. also analysed the validity of s-RPE for rugby league with overall moderate to very large within-individual correlations observed between s-RPE and various internal and external load measures; including, GPS data (distance [m], high-speed running [m], body load [au], and impacts [n]), and Banister’s TRIMP.

Comparative studies such as these have not yet been conducted, thus at present, high-performance tennis literature and practice rely on the reliability status of RPE from other sports and general validation research. Nonetheless, tennis literature has utilized RPE to establish typical demands of match play and training drills. Specifically, a case study by Coutts et al. reported RPE and TL data of a professional player during a week at the French Open. While the CR10 RPE and TL method has not explicitly been used to monitor junior high-performance athletes within development blocks, these data present insightful information coaches surrounding the demands of elite-level tournaments. The noted practical application of these training load monitoring procedures also provide valuable insight into appropriate and simple
method of continuously monitoring load throughout a tournament, as the logistical
demands compared to other monitoring tools are minimal.

Another example of recent validation of the implementation of s-RPE involves the
timing of response to RPE questionnaires following exercise. Specifically, using
the CR100 RPE scale, Fanchini et al. examined the differences in RPE responses
of soccer athletes both immediately following a training session, and 30 min post-
session (traditional method). It was found that there was little discrepancy between
the 2 time points of RPE collection, with authors suggesting that either method can be
used. Owing to the extensive travel and individual nature of tennis, the traditional
method of RPE collection 30 min post session can present logistical issues. These
issues are likely exacerbated in junior high-performance tennis players, who in some
cases may travel as much as professionals. Thus, flexibility in the timing of
collection in tennis becomes valuable. At the same time, the ability of coaches to
accurately provide substitute RPE’s for their athlete in case of athlete geographic
isolation would also be beneficial to the maintenance of training load data collection,
although this requires astute athlete understanding from the position of the coach.

Overall, the literature on RPE and training load monitoring, appear to demonstrate the
validity of RPE and its derivatives in high-performance environments. However, RPE
is not without its limitations, as Borresen and Lamberts explain, by outlining the
complex interaction of a range of factors such as hormonal changes (e.g. catecholamines), substrate concentrations (e.g. glucose, glycogen and lactate), personality traits, ventilation rate, neurotransmitter levels, environmental conditions
or psychological states that affect RPE. In turn, RPE may vary in the accuracy of
quantifying perceived exercise intensity due to any number of these uncontrolled
factors.\textsuperscript{178} Despite continued cross-examination regarding validity and the need for further investigations of specific factors that can influence RPE, this simple method appears to be a key tool for coaches and sport scientists to monitor internal load. For these reasons, RPE could be a precious tool for high-performance coaches, across all sports, to monitor the training process by quantifying in a single term the overall internal load in tennis.
2.7: COMPLICATIONS OF LOAD MONITORING IN TENNIS;  

KEY LIMITATIONS

Evidently, within the current literature review there are a number of measures capable of quantifying load within high-performance sporting environments (i.e. GPS, accelerometry, lactate, VO\textsubscript{2}); however, in terms of ecological validity, few are appropriate in tennis\textsuperscript{50,95,97,99,100} While the current literature review highlights the abundant use of external load measures available to other sports, in tennis there are many limitations involving external load technology. Within the literature specific tennis, measures to quantify external load exist, including Hawkeye and SAGIT\textsuperscript{2,116} Both measures involve multiple cameras and sophisticated computer software to analyse movement characteristics and displacement. Yet, while these data are valuable in the quantification of external load, the large expense of Hawkeye systems, and limited validity of the SAGIT tracking system means tennis requires more suitable tools. Furthermore, whilst GPS is appropriate to a range of team sports, within tennis there are severe limitations to the accuracy of measures\textsuperscript{50} compacted with the prohibition of GPS units during matches\textsuperscript{135} Given the above constraints, tennis typically relies on session count, duration, and notational analysis (i.e, stroke volume, rate and errors)\textsuperscript{2,46,116,120,149}

Likewise, internal load measures include a wide array of quantifiable measures in sport, many of which have been utilized within tennis literature (i.e., HR, lactate, VO\textsubscript{2}, salivary and blood markers of stress, and perceptual measures)\textsuperscript{1,6,8,14,22,93,98,100,125,131} However, owing to the high physical and technical demands typical of high-performance tennis measures such as HR, lactate, VO\textsubscript{2}, salivary and blood markers are often complicated by athlete and coach hesitancy,
portability or lack of availability on-tour. Consequently, within tennis training environments and during competition, load monitoring relies on practical, valid, and low cost tools such as perceptual scales and reliable performance tests. However, even with these practical methods of quantifying external and internal load, limitations occur from the interpretation and understanding of each measure and hence issues present with the prescription of load within tennis training.

While no current literature specifically describe and suggest ecologically valid training load monitoring strategies in tennis, there are several studies that describe the physiological and perceptual demand of training drills. These training studies have used have utilized a range of measures of load demands, from non-invasive perceptual scales and invasive blood and heart rate measures to portable, but highly complex oxygen analysis systems. Specifically, Reid et al. describe the physiological and performance characteristics of 4 discrete tennis drills, using measures of blood lactate, RPE, HR, displacement and notational analysis. These quantified drills, along with other slight variations, have been used to guide specific training demands, including the prescribed work-to-rest ratios for on court training, the influence of court surface (clay vs. hard court), pre-cooling in the heat, and post training recovery protocols. However, these studies are acute descriptions and do not directly inform ongoing training load monitoring or prescription reflective of annual drill prescription. Accordingly, to assist in micro-, macro- and annual prescription of session drills, general drill catalogues, which describe a wide array of drill types, may assist in the longitudinal prescription of training demand.
Another pertinent issue in tennis is the complication of training and match load monitoring when on-tour. High-performance tennis is typified by constant travel and time zone deviations, consecutive day/week tournament schedules, inherently leading to restricted training phases.\textsuperscript{16,21,107} Even junior high-performance players may travel and compete at upwards of 26 tournaments (up to 100 singles matches) every calendar year.\textsuperscript{20,21} Alas, owing to funding confines, in many cases junior athletes are required to travel to events without coach support, coinciding with variable access to resources, facilities or telecommunications.\textsuperscript{16,21,110} Naturally, such isolation of junior athletes poses severe limitations for the implementation of training load monitoring systems when coaches and support staff are not present, thus simple methods such as perceptual scales are likely most appropriate, requiring little technical expertise and minimal athlete (and coach) education.

These issues are colloquially interpreted to suggest regression in fitness levels upon return from extended tours. It seems logical that intensive travel, which entails restricted facilities access, and lack of professional support, may jeopardize training and match preparation, and is liable to impact LTAD. Whilst not related to travel\textit{ per se}, Kovacs et al.\textsuperscript{190} report that for collegiate level tennis players, a period of 5 weeks, unsupervised time away from coach and support facilities (Spring Break) lead to declines in speed, power and aerobic capacity.\textsuperscript{190} It is evident the potential of these physical capacity regressions to accumulate across on-going congestive annual touring schedules. Add to this mix highly variable load demands while on tour as a result of the unpredictable nature of tournament scheduling, opposition draw and match results. Hence, without astute understanding of training and match exposure these issues may lead to physiological maladaptation and performance declines.\textsuperscript{94} Additionally, with a premium placed upon skill maintenance and recovery from
match demands, physical (S&C) training during tournament blocks is commonly overlooked (i.e., athletes do not prioritize the time to train their fitness).\textsuperscript{21,106,108} As such, the implementation of classic periodisation models is challenged by tennis coaches and athletes due to the reactive scheduling inherent of multitude of unknown variables (i.e., match outcome). Therefore, in situations where funding restrictions may not pertain to support personnel (i.e., national tennis federations), presence of the S&C coach may prove constructive in the prevention of physical capacity decline, owing to an ability to implement monitoring systems on-tour, and precisely prescribe appropriate types and volumes of on- and off-court training to be undertaken.

In summary, the ability to accurately and longitudinally quantify training load in high-performance junior and elite tennis players is hampered by both the available evidence for appropriate measures, as well as logistical conditions. Specifically, external load measures are either too expensive or impractical to carry on tour. Further, internal load measures are again too expensive, in appropriate or logistically too cumbersome to use in a variety of training and competition environments. Accordingly, measures such as RPE, HR and notational analyses extant as the most likely markers of use to quantify training load in high-performance junior players.
2.8: STATE OF THE LITERATURE

The rationale behind the path of the current literature review was to first highlight the current understanding of tennis match demands, highlighting associated loads within acute matches foremost and then accumulated through tournaments. Accordingly, it is identifiable that whilst there is now a developed understanding of the acute match demands and load markers to measure such demands, limited understanding of the actual implementation of load monitoring strategies in training exists. For instance, while the associated RPE’s of competition are detailed, limited information is available of the variables surrounding its implementation within training, including coach and athlete communication and interpretation. Furthermore, despite sound knowledge of match demands, there are few studies that quantify training drill demands, outside of a handful of controlled, discrete on-court drills, with no within-cohort study design concurrently comparing training demands to match data.

Currently evidence-based training prescription is limited to coach intuition, imitation of training intensity from specific-context match literature, and the small number of quantified, specific drills in the literature. Hence, owing to the fact that implementation strategies were not apparent in tennis, the literature review also described the benefits of load monitoring strategies for optimal performance as well as potential repercussions of an absence of load monitoring. Following this, the review gave a historical overview of the evolution of load monitoring and description of load monitoring protocols within other sports, examining current practice or potential of adoption within high-performance (junior) tennis environments. Where limited literature exists in junior high-performance tennis, the current thesis sought to
provide context to the rationale behind effective load monitoring practices to hopefully spark future development of monitoring strategies within tennis.

Although, new tennis literature has begun to examine the load demands of consecutive matches on tennis players, replicating tournament conditions, these are currently highly controlled simulated tournament investigations. Thus, research is limited in the effect that highly variable tournament conditions have on load demand and understanding of athlete response, both domestically and internationally. These gaps in the literature compromise athlete preparation with a lack of knowledge of load demands prior to, and during tournaments.

This apparent disconnect ultimately places athletes at risk during lapses of sport scientist availability, unless an appropriate support staff member (i.e., S&C coach) is accessible. Thus, tennis literature requires further investigative studies aimed to assist tennis coaches independently utilise training load monitoring strategies. Specifically, this process should involve initial identification of the current state of coach interpretations of their assigned tennis athletes. Further, as reflected within the literature review, there is a current lack of quantifiable training data in which tennis coaches can prescribe and be guided from, thus the implementation of drill and match play databases are required. Finally, owing to a lack in research examining the effect of tours both domestically and internationally, quantifiable data regarding the demands of these tournaments is required to assist in training load management strategies during tournaments, as well as pre- and post-tour. In sum, whilst sports scientists clearly implement and test training and competition load theories, there seems an apparent lack of information specifically targeted to the education and up-skilling of tennis coaches.
CHAPTER THREE

Comparison of athlete-coach perceptions of internal and external load markers for elite junior tennis training

As based on the publication:

Chapter 3: Athlete-Coach Load Discrepancy

ABSTRACT

This study examined the discrepancy between coach and athlete perceptions of internal load and notational analysis of external load in elite junior tennis. Fourteen elite junior tennis players and 6 international coaches were recruited. RPE was recorded for individual drills and whole sessions, along with a rating of mental exertion, coach rating of intended session exertion, and athlete HR. Further, total stroke count and unforced error count were notated using video coding following each session, alongside coach and athlete estimations of shots and errors made. Finally, regression analyses explained the variance in the criterion variables of athlete and coach RPE. Repeated measures analyses of variance and interclass correlation coefficients revealed that coaches significantly (p<0.01) underestimated athlete session-RPE, with only moderate correlation (r=0.59) demonstrated between coach and athlete. However, athlete drill-RPE (p=0.14; r= 0.71) and mental exertion (p=0.44; r= 0.68) were comparable and substantially correlated. No significant differences in estimated stroke count were evident between athlete-coach (p=0.21), athlete-notational analysis (p=0.06), or coach-notational analysis comparison (p=0.49). Coaches estimated significantly greater unforced errors than either athletes or notational analysis (p<0.01). Regression analyses found that 54.5% of variance in coach RPE was explained by intended session exertion and coach drill-RPE, while drill-RPE and peak HR explained 45.3% of the variance in athlete session-RPE. Coaches misinterpreted session-RPE but not drill-RPE, whilst inaccurately monitoring error counts. Improved understanding of external and internal load monitoring may assist coach-athlete relationships in individual sports like tennis to avoid maladaptive training.
INTRODUCTION

The quantification of training load is important for monitoring and successfully prescribing periodised training programs for elite level athletes. Appropriate and informed manipulation of training load is important in tennis given the limited training time resulting from busy international competition schedules. Consequently, when opportunities arise for intensive training periods, coaches must ensure optimal loads and recovery are prescribed for forthcoming competition. Effective manipulation of training loads requires that coaches have an understanding of the athletes’ response to load, recovery and ensuing adaptation. Common descriptors of training load include external load (i.e., the training stimulus), and internal load (i.e., athlete response to a stimulus). Currently, tennis lacks evidence-based tools for training load monitoring, potentially leaving tennis athletes at risk of maladaptation to training.

Alongside physical testing, external load measures are commonly used within many sports to assess training outcomes. Generally, coaches prescribe by external load (i.e., a distance to run or velocity to maintain). GPS, accelerometry and movement tracking systems are considered appropriate tools in the analysis and prescription of external load. AFL, hockey and soccer research suggests that the aforementioned motion-analysis systems offer valid and reliable measures of distance and velocity in both training and match play. However, whilst team sports have access to multiple appropriate external load measures, there is an absence of similar, suitable, reliable or valid technology in tennis. Consequently, tennis currently relies on session count, duration, and stroke analysis (i.e., stroke volume and errors) to objectively measure external tennis load. Internal load measures such as HR,
VO₂, lactate, salivary and blood markers of stress, and RPE are suggested to be of prominence. However, the nature of tennis means measures of HR, VO₂ and lactate are often complicated by travel, portability, or reluctance from athletes.⁴⁶,⁸³,²⁹⁵ As such, RPE is broadly acknowledged as one of the most suitable methods of monitoring load in tennis.²²,⁹⁸,²⁹⁵

To precisely prescribe training loads and interpret athlete responses in tennis, it is important to establish the level of agreement between the RPE’s of the coach and athlete. Research comparing these perceptions in other sports however, reports mixed results. For example, Viveiros et al.²⁹⁶ found that judo coaches underestimated the session RPE reported by athletes. This contrasts with empirical work in athletics, where session RPE’s were generally well matched with the prescribed intensity from coaches; albeit with some discrepancy in perceived load for sessions of varying intensity.²⁹⁷ More specifically, it was observed that athletes trained with internal loads greater than intended on easy days, and lighter than intended on heavy days.²⁹⁷ Such discrepancies have the potential to cause maladaptation to training⁴⁸, while inappropriate manipulation of training loads can result in highly monotonous training and non-functional overreaching.²⁴,²⁹⁷ Moreover, in technically demanding sports such as tennis, the contrary (i.e., under-loading) is not desirable for long-term athlete development.¹⁷

With the above backdrop in mind, the present paper aims to determine the magnitude of discrepancy between coach and athlete perceptions of internal, (i.e., RPE and mental exertion) and external load (i.e., stroke count) in on-court training. Coach and athlete perceptions of external load compared to objective notational analysis will be further pursued to assess the sensitivity or veracity of their ratings. Finally, for
discrepancies that do exist, regression analysis will be used to determine what constitutes both an athlete and coaches concept of RPE. In light of previous coach-athlete RPE comparisons in relevant literature, we hypothesize that coaches will underestimate measures of athlete internal load, whilst demonstrating a greater understanding of stroke and error rates than athletes.

**METHODS**

**Subjects**
Fourteen elite-level junior tennis players, who train permanently as scholarship holders (>2 y), were recruited from a national tennis development program. Players routinely trained 2-3 sessions per day, completing 98±20 matches for the year. The cohort had the following characteristics; gender: 8 male, 6 female, age: 15±1.2 y, mass: 60±14.2 kg, stature: 167±10.8 cm, Australian junior ranking: 7±4, and ITF junior ranking 91±72. Six qualified coaches with whom the players worked (>6 months), were also recruited for the study. Coaches reported 10±3 y of elite level coaching experience, and completion of Tennis Australia’s highest level coaching qualification. Coaches and athletes were familiarized with HR, RPE, mental exertion, and stroke and error rates during a 4-week training block prior to commencement of data collection. Players possessed an intimate prior familiarity with each drill. The University Ethics in Human Research Committee approved all experimentation, with consent given by participants, parents/guardians and Tennis Australia.

**Design**
A total of 285 drills were included for analysis, with a mean duration of 24.6±19.0 mins. Athletes completed 21±3 sessions with a mean on-court duration of 71.8±10.9 min for sessions included in data collection. This study involved intermittent collection of training loads over a 16-week hard court training period. Training weeks
were determined by the absence of competitive match play. Data were only collected from sessions that involved ≥2 athletes. We examined both internal and external load measures during ecologically valid training sessions, matched for duration and training focus. Coaches reported the following themes or training foci: 2 on 1 drills, accuracy (target hitting), pre-determined pattern drills, closed technical drills, and defensive drills. Mean training load for respective sessions was calculated as a function of training volume and intensity, by multiplication of session-RPE and session duration in minutes. Training duration, stroke count and error rate were used to measure external load based on post-session observational notation from video footage.

**Methodology**
All training sessions were filmed using a digital video camera (DSR-PDX10P, Sony, Japan) positioned 10-m above and 6-m behind one baseline. The recorded footage was downloaded and later notated to establish total stroke count, stroke rate, and unforced error counts. A trained analyst (Coefficient of Variation <2%) performed notational analysis using customised software (The Tennis Analyst, V4.05.284, Fair Play, Australia). Coaches and athletes were asked to individually estimate the exact number of shots and errors that characterized each individual drill within each session. Coaches and athletes responded privately during recovery periods between drills, allowing sessions to continue uninterrupted.

Prior to each training session, coaches reported - for each individual athlete - a rating of intended session exertion (Borg CR-10) which was later compared to their post session perception of the athletes’ RPE. Athletes were fitted with individual HR monitors, (Suunto Memory Belts, Suunto Oy, Vantaa, Finland) to record HR at 1s intervals for the entirety of each session. HR was downloaded after the session to
calculate mean and peak HR for each drill (Suunto Training Manager, Suunto Oy, Vantaa, Finland). Immediately following the completion of individual drills, athletes provided a RPE (Borg CR-10) and mental exertion evaluation (0-10 Likert scale). Mental exertion rating (0-10) was used to establish a holistic rating of mental intensity perceived throughout drills. Athletes provided a single rating based on descriptions of mental demand (i.e., “How much mental and perceptual activity was required?” “Was the task easy or demanding, simple or complex, exacting or forgiving?”). All ratings were provided privately to ensure no predisposition of internal load perception between coach and athlete. Finally, post session RPE was independently collected from the athlete and the coach (for the athlete) 30 minutes after the completion of the session.

**Statistical Analysis**

Data are reported as mean ± SD and within-individual mean range (mean minimum - mean maximum), unless otherwise specified. As gender was mixed, and age varied within the cohort, within-individual statistical procedures were used to alleviate any potential gender or age bias. The within-individual correlations between coach, athlete and notational analysis (RPE, mental exertion, stroke and error count) were analysed using interclass correlation coefficient (ICC). The following criteria were adopted to interpret the magnitude of the correlations: 0.10–0.30 small, 0.30–0.50 moderate, 0.50–0.70 large, 0.70–0.90 very large, and 0.90–0.99 nearly perfect. Ratio measures for 95% limits of agreement (confidence interval; CI) were calculated and expressed within Figures 3.1 and 3.2. Differences in coach, athlete and notational data were assessed using a one-way Analysis of Variance (ANOVA) with Tukey HSD post hoc comparisons. Stepwise multiple regression analyses were used to explain the variance in criterion variables of coach and athlete session RPE.
variables included; drill duration, RPE, HR, mental exertion, stroke and error count measures, according to the corresponding coach or athlete analyses. Partial correlations, standardized coefficients, and level of significance for coach and athlete predictors of session RPE were also reported. Collinearity tolerance statistics ascertained correlations between predictor variables, whereby associations <0.10 were considered beyond an acceptable tolerance level and were removed from the model. All data analysis was conducted using PASW statistic software package (PASW, Version 17, Chicago, USA). Statistical significance was set at p<0.05.

**RESULTS**

Coaches significantly (p<0.01) underestimated athlete session RPE (Table 3.1). However, within-individual coach and athlete comparisons of session RPE (Figure 3.1) were strongly correlated (r=0.59, p<0.05). Coach rating of intended session exertion was not significantly different (p=0.63) to coach post-session RPE and strongly correlated (r=0.79, p<0.05), however, coach intended RPE was significantly greater than athlete post-session RPE (p<0.01). In contrast, coach drill RPE was comparable (p=0.14; Table 3.1) and strongly correlated (r=0.71, p<0.05; Figure 3.1) with athlete drill RPE. Similarly, rating of drill mental exertion reported by the coach and athlete was not significantly different (p=0.44, Table 3.1), and strongly correlated (r=0.68, p<0.05; Figure 3.1).
Table 3.1. Athlete, coach and notational analysis of load for individual drills and global sessions.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Range (Mean Min - Mean Max)</th>
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<tbody>
<tr>
<td><strong>Athlete</strong></td>
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<tr>
<td>sRPE (au)</td>
<td>6.2 ± 1.4</td>
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<tr>
<td>Shot Count (no.)</td>
<td>163 ± 148</td>
<td>39 - 553</td>
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<tr>
<td>Unforced Errors (no.)</td>
<td>18.0 ± 14.2</td>
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<tr>
<td>Drill Physical RPE (au)</td>
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<tr>
<td>Drill Mental RPE (au)</td>
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<tr>
<td><strong>Coach</strong></td>
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<td></td>
</tr>
<tr>
<td>Predicted sRPE (au)</td>
<td>5.5 ± 1.2 *</td>
<td>4 - 7</td>
</tr>
<tr>
<td>sRPE (au)</td>
<td>5.4 ± 1.1 *</td>
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<tr>
<td>Shot Count (no.)</td>
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<tr>
<td>Unforced Errors (no.)</td>
<td>22.1 ± 15.9 #*</td>
<td>9 - 64</td>
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<tr>
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<td>Drill Mental RPE (au)</td>
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<td><strong>Notational Analysis</strong></td>
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<td>Mean HR (bpm)</td>
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<tr>
<td>Peak HR (bpm)</td>
<td>174 ± 18</td>
<td>140 - 194</td>
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</table>

* Significantly different (p<0.05) to athlete perception

# Significantly different (p<0.05) to descriptive performance measures
Figure 3.1. Within-individual inter-class correlation coefficients with 95% limits of agreement (ICC±CI) for internal load measures between athlete and coach of session RPE (sRPE), drill physical RPE (dpRPE), drill mental RPE (dmRPE), and coach pre-post session RPE (csRPE).
Figure 3.2. Within-individual inter-class correlation coefficients (ICC) for external load measures between athlete, coach and notational analysis of total shots (aShots, cShots, a-cShots), and total errors (aError, cError, a-cError).
Table 3.2. Partial correlations, standardized coefficients and level of significance for predictors of Athlete sRPE and Coach sRPE.

<table>
<thead>
<tr>
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<th>Standardised Coefficient (β)</th>
<th>Significance of Standardised Coefficients</th>
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<td>Unforced Errors</td>
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<td>Peak HR</td>
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<td>-0.319</td>
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<td><strong>Coach sRPE</strong></td>
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<td></td>
</tr>
<tr>
<td>Shot Count</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unforced Errors</td>
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<tr>
<td>Duration</td>
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</tr>
<tr>
<td>Peak HR</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Across all drills, stroke rate was calculated as 0.12 strokes/sec. No significant differences in stroke count were evident between athlete-coach (p=0.21), athlete-notational analysis (p=0.06), or coach-notational (p=0.49) comparisons (Table 3.1). Large correlations were evident between athlete perception and notated stroke counts (r=0.63, p<0.05), as well as athlete and coach perceptions of stroke count (r=0.67, p<0.05) (Figure 3.2). Further, coach perception showed large agreement with notational analysis (r=0.56, p<0.05; Figure 3.2).

There was no significant difference (p=0.24; Table 3.1), and large correlation (r=0.61, p<0.05; Figure 3.2), between athlete perception and notational count of unforced errors. However, coaches reported significantly greater unforced errors than either athletes (p<0.01) or the notated count (p<0.01) (Table 3.1). Further, unforced error count as perceived by the coach revealed large positive associations with the athletes’ perception (r=0.54, p<0.05) of the same variable and notational analysis (r=0.51, p<0.05).

Table 3.2 summarizes the results of the stepwise multiple regression analysis, where 54.5% of the adjusted variance in coach RPE could be explained by the coach’s rating of intended session exertion and coach drill RPE \( (Y = 1.37 + 0.51 \text{ coach predicted RPE} + 0.25 \text{ coach drill RPE}) \) [Adjusted \( R^2 = 0.55; F_{2, 273} = 163.71; p<0.001 \)]. The collinearity of this equation was acceptable for both variables with tolerance levels at 0.907. Meanwhile, 45.3% of the adjusted variance in athlete session RPE could be explained by drill RPE and peak HR \( (Y = 9.60 + 0.53 \text{ drill RPE} - 0.37 \text{ peak HR}) \) [Adjusted \( R^2 = 0.45; F_{2, 50} = 20.73; p<0.001 \)]. Collinearity statistics were acceptable for both variables with tolerance levels at 0.996.
DISCUSSION

The purpose of this study was to assess the level of agreement between coach and athlete perception of internal load as well as their agreement with notational analysis of external load during tennis training. Further, where discrepancies in internal and external load existed, regression analyses explained the variance in the criterion variables of athlete and coach RPE. The results showed significant incongruity between coach and athlete session RPE. Also, within training sessions, large correlations were demonstrated between coaches and athletes for RPE and mental exertion of individual drills. Good agreement was also found between coach, athlete and notational analysis of stroke counts within drills. However, coaches report significantly greater unforced errors than both athletes and a notated count. Finally, regression analyses revealed the variables that best predicted post-session coach RPE to be the rating of intended session exertion and individual drill RPE; drill RPE and peak HR were the greatest determinants of session RPE as reported by the athletes.

Analysis of internal load measures demonstrated that coaches significantly underestimate athlete RPE for the overall training session, highlighting a potential disconnect in the perception of session load. Indeed, previous literature has highlighted this discrepancy between coach and athlete RPE in athletics, judo and swimming.\textsuperscript{48,296,297} We also found coach rating of intended session exertion to be significantly lower than athlete RPE, suggesting a misconception of athlete state following the previous session’s load. This is consistent with the work of Foster et al.\textsuperscript{297} and Wallace et al.\textsuperscript{48}, whom reported differences between planned sessions by coaches and the ensuing athlete loads in running and swimming respectively. These studies also highlighted that coach and athlete perceptions were comparable for
Chapter 3: Athlete-Coach Load Discrepancy

moderate intensity sessions, however high and low intensity sessions produced
significant discrepancies. Although our investigation did not distinguish between
intended hard and easy sessions, the relationship between athlete session RPE and
both coach intended and post-session RPE was large. Interestingly, athletes in these
sports have been reported to train harder than intended on coach-designated recovery
days and easier than intended on hard days. Our findings highlight similar
incongruity in coach-athlete training perception for global tennis sessions, perhaps
increasing the risk of maladaptive training.

In a novel finding from the present study, coaches and athletes report comparable
RPE’s for individual drills. To our knowledge, no previous research has explored
differences in coach-athlete perceptual load within a session. Due to the nature of
tennis sessions, whereby a session may be comprised of multiple drills, it is important
that coaches are aware of the loading subtleties of drills throughout the session. The
current findings suggest the coaching cohort were able to detect these subtle
differences in athlete RPE within specific drills. However, as highlighted above,
session RPE was significantly underestimated, suggesting that coaches display a
poorer understanding of the accumulating effect of training loads of the drills over an
entire training session. As such, this poses a potential issue in understanding athlete
response to full training loads, not only within a session, but also potentially over
multiple sessions within training blocks. Thus, the current findings emphasize the
importance of coach awareness of athlete RPE, rather than sole reliance on coach
perception.

Interestingly, there also existed large correlation between coaches and athletes for
ratings of mental exertion. These data also suggest that coaches are able to interpret
athlete mental exertion more accurately than RPE. Whilst conceptually measuring different components, Minganti et al.\textsuperscript{45} reported no differences between perceptions of acute mental and physical fatigue in springboard and platform diving. Meanwhile, Marcora et al.\textsuperscript{300} report that mental stress can limit exercise tolerance, as evidenced through higher RPE, rather than cardiorespiratory and musculoenergetic mechanisms. Thus, as the technical demand increases during an open skilled, highly complex sport such as tennis, the discrepancy between physical and mental measures of exertion may increase. Further, as coaches show a greater level of accuracy in appreciating mental exertion than RPE, coaches may use signs of mental effort to assist determine session load tolerance in open skilled sports such as tennis. Yet, whilst it seems coach perception of drill mental exertion is of greater accuracy than drill RPE, the efficacy of mental exertion as a load-monitoring tool is yet to be thoroughly investigated in elite sports, including tennis. Further, it should be acknowledged that there is a lack of validated tools to measure mental exertion within exercise, however Visual Analogue Scales and Likert scales- such as the one used in the current study- are commonplace within literature.\textsuperscript{301,302}

Stroke count comparisons between coach perception, athlete perception and notational analysis were comparable. Analysis of stroke count perception shows large correlation between athletes and both coaches and notational analysis. Previous swimming data report that athletes are able to comply with coach prescribed swim distances, suggesting that no additional monitoring of external load in training is warranted.\textsuperscript{303} Similarly, the high-level of awareness of external load (i.e., stroke volume) from tennis athletes in this study suggests that prescription of external load in un-supervised practice may be appropriate, so long as athletes are well educated on the required intensity. A secondary finding indicates that shot rates during drills were
0.12 strokes sec\(^{-1}\), seemingly lower than previously reported drill and match play stroke rates.\(^3\)\(^{120}\) Reid et al.\(^3\) describe four common training drills - designed to induce heavy physiological stress - reporting stroke rates between 0.13-0.40 sec\(^{-1}\), while O’Donoghue et al.\(^{120}\) reported similarly inflated stroke rates (0.81±0.04 sec\(^{-1}\) for men and 0.76±0.03 sec\(^{-1}\) for women) for match play at the Australian Open in 1997–1999. To the authors’ knowledge, no previous study has compared coach-athlete perception of external load measures in tennis. However, issues with coaching strategies and the perception of external load (stroke count) have previously been raised.\(^3\) Reid et al.\(^3\) discuss the problematic lack of quantitatively driven training sessions within tennis environments; describing current methods as intuitive, perhaps failing to provide for optimal physiological and developmental improvement. Therefore, it would appear to stand to reason that coach awareness of external load prescription may be vital for athlete preparation and development. In a similar vein, athletes travelling unaccompanied by a coach, or during periods of self-practice should also be sensitive to their external load to best maintain physical condition and skill levels. These results are also the first to show coach overestimation of errors within tennis training drills. Coaches estimated significantly more errors during drills than both athletes and notational analysis. Interestingly, athletes show no difference in the estimation of errors compared to a notated count. At present, no coaching research has compared estimations of errors made between coach, athlete and post session notation for any sport. However, coaches’ progress or regress drills depending on errors made and the ability of an athlete to handle a task.\(^{304}\) While the present study did not directly investigate the relationship between unforced errors and physical or mental exertion, previous research suggests that with an increase in drill duration and intensity more variable ball placement, reduced precision and lower consistency in
shot outcomes becomes evident. Potential misunderstanding of drill outcomes may alter the design, selection and progression of drills; therefore, emphasizing the importance of coaches being aware of error rates to ensure appropriate drill feedback and learning to athletes, and better design, select and progress drills.

Similar to previous research, the current study has shown discrepancies in coach and athlete perception of internal and external load. Whilst awareness of deviations in coach-athlete perceived load are key, understanding the internal and external load variables that explain variance in session RPE is arguably more important. In rugby league, Lovell et al. have shown a combination of load and intensity measures best explain the variance in session RPE. That is, distance covered, impacts, body load and training impulse accounted for 62.4% of the variance in session training load (duration x RPE), while 35.2% of variance in session RPE was explained through %\(\text{HR}_{\text{peak}}\), impacts/min, m/min and body load/min. Our data show that 54.5% of variance in coach session RPE could be explained using drill RPE combined with the pre-session rating of intended session exertion. As such, this suggests that the combination of drill RPE and predetermined session RPE explain the variance in coach session RPE better than any other measures. Meanwhile, 45.3% of variance in athlete session RPE could be explained by measures of drill RPE and peak HR. Therefore, it would seem that internal load markers explain more of the variance in athlete session RPE than external load measures, though the limitations in providing accurate measures of external load are acknowledged. These data highlight the complexity of load perception in tennis, and whilst knowledge of the variables that explain session RPE is valuable, they may be unique to this elite tennis setting. Consequently, care should be taken when attempting to apply these interpretations to other tennis settings.
Chapter 3: Athlete-Coach Load Discrepancy

PRACTICAL APPLICATIONS

Owing to the extensive travel and competition schedules of tennis players, planning and periodisation are important in maximizing the value of training time. External and internal load monitoring allows for optimal planning during preparation phases, however coaches must also correctly understand the load experienced by athletes. With a clearer understanding of athlete load, training may be structured to elicit greater gains and reduce injury and illness risk. Although our results demonstrate incongruity between coach, athlete and notational analysis of load within an elite junior tennis environment, this mismatch may be alleviated with continued athlete education or proactive communication between athletes and coaches. Future research in tennis load monitoring should attempt to differentiate load discrepancies for low, moderate and high intensity sessions, as well as develop other suitable methods of external load measurement. Moreover, replication of the current methodological design with a greater sample size, and a comparison between experienced and less experienced coaches may improve coach understanding of athlete load response and assist the professional development of coaches.
CONCLUSIONS

Coach perception of individual drill RPE does not differ from that of athletes. However, it would appear that coaches misinterpret the accumulating effect of drill load over an entire training session, demonstrated through their lower perceptions of session RPE. It was further evident that coaches were better equipped to interpret the mental exertion required for individual drills than physical exertion. Stroke count demonstrated discrepancies between notational analysis and the perception of coaches and athletes, with these two groups overestimating total stroke count. Finally, it was observed that coach perception of session RPE may be primarily informed by drill RPE and a rating of intended session exertion, while a significant amount of the variance in athlete session RPE was explained through drill RPE and peak HR. Overall, these findings provide coaches with a practical, evidence based insight into the monitoring of load across typical tennis training sessions. Appropriate load quantification and coach-athlete communication is vital to best use this information and to avoid maladaptive responses to training.
CHAPTER FOUR

A descriptive analysis of internal and external loads for elite-level tennis drills

As based on the publication:

ABSTRACT

Planning tennis sessions accentuating physical development requires an understanding of training load. This study aimed to describe the external and internal training load of drills, and analyse relationships between drill-RPE, drill-TL and other measures. Fourteen elite-level junior tennis athletes completed 259 individual-drills. Six coaches helped devise classifications for all drills: Recovery/Defensive, Open-Pattern, Accuracy, 2-on-1 Open, 2-on-1 Net-Play, Closed-Technical, Point-Play, and Match Play. Notational analysis on stroke and error-rates was performed post-session. Drill-RPE, and mental-exertion were collected post-drill, while HR was recorded continuously. Recovery/Defensive, Open-Pattern and Point-Play were significantly greater than Closed-Technical drills (p<0.05) for drill-RPE and mental-exertion, as were Accuracy drills and Match Play (p<0.05). Recovery/Defensive, Open-Pattern, Accuracy, and 2-on-1 Open drills were of greater stroke-rates than Match Play (p<0.05). Error-rates of Closed-Technical drills were significantly higher than Open-Pattern, 2-on-1 drills, Point-Play, and Match Play (p<0.05). No HR differences were observed (p>0.05) between categories. Substantial correlations existed for drill-RPE and drill-TL with mental-exertion (r>0.62) for several categories. Drill-TL was substantially correlated with total-strokes (r>0.65), whilst HR, stroke and error-rates were in slight-moderate agreement with drill-RPE and drill-TL (r<0.51). Recovery/Defensive drills are of highest physiological stress, making them ideal for maximizing physicality. Recovery/Defensive drills compromised training quality, eliciting high error-rates. In contrast, 2-on-1 Net Play drills provided the lowest error-rates, potentially appropriate for error-amelioration practice. Open-Pattern drills were characterized by significantly higher stroke-rates, suggesting congruence with high-repetition practice. Finally, with strong relationships between physical and mental-perception, mental-exertion may compliment currently used monitoring strategies (i.e., RPE).
INTRODUCTION

The extensive competition demands of junior elite-level tennis athletes challenges coaches’ abilities to ensure physical, technical and tactical capacities are sufficiently developed. Consequently, training time is at a premium within high performance tennis environments. Coaches often prioritize on-court integrated training sessions in order to blend technical and tactical development within match-specific conditioning. In order to maximize the efficiency of such integrated sessions, internal and external training load monitoring is necessary to ensure optimal load and recovery needs are met. However, presently there are limited resources available to coaches to describe internal loads in response to external loads prescribed in elite-level training sessions.

Numerous studies have reported the external and internal load demands of tennis tournament play. Previous literature reveals tennis matches (3 sets) are typically comprised of 300-500 high intensity efforts over 1.5-4 h. Stroke rates have been reported between 2.5-4.7 shots/rally, dependent on gender and surface. During competitive matches, mean HR is between 130-170 bpm with peak HR reaching 190-200 bpm. RPE has been reported as ranging from 5-7 au (CR-10) and 10-16 (Borg 20-point), with service games of higher intensities. Despite such quantification of the psycho-physiological responses to tournament loads, considerably less is known about the response to common on-court tennis training to prepare athletes for such match-based loads.

Of the literature to date, Reid et al. quantified the physiological and performance characteristics of four discrete, hand-fed, tennis drills involving movement and stroke patterns of Star, Box, Suicide and Big X. Reid et al. reported external loads through
stroke count (0.7-2.3 strokes.min\(^{-1}\)) and velocity (113-123 m/s) as well as distance covered (76-114 m) through GPS measures. Internal responses were measured via HR (178-182 bpm), lactate (6.7-10.6 mmol/L) and RPE (5.0-7.6 au).\(^3\) Later, Bekraoui et al.\(^{92}\) compared the energy cost associated with 6 common tennis movements, performed at both low and high speeds, estimated from VO\(_2\). Movements included 2-handed backhand, forehand, sidestep without striking the ball, defensive striking of the ball, and attacking striking of the ball, each performed over full- and half-width court distances (7 and 3.5 m). It was established that attacking styles of play increase energy cost by 6.5% compared to defensive styles, 2-handed backhand strokes increase energy cost by 7% than forehands, and striking the ball costs between 8-12% more energy than not striking the ball.\(^{92}\) Regardless, neither of the abovementioned studies directly informs on-going training load monitoring or prescription - particularly given the small sample size of drill and players. Specifically, the discrete number of drills investigated is too constrained to be related to the vast number of drills used in year round periodised training.\(^3,91\) As such, to offer greater information of the external and internal loads associated with currently prescribed drills to coaches, general classifications - encompassing a range of homogenous drills - might help to inform and guide the prescription of session loads.

Currently, there are a range of measures used to monitor training loads (i.e. GPS, lactate, VO\(_2\)), however many are either inappropriate or yet to be validated in tennis.\(^{50,95,97,99}\) Unfortunately, many of these load measures rely heavily on technology and often lack practicality (i.e., portability to competition).\(^{22}\) As a consequence, load-monitoring tools, like RPE, that are low cost and practical are desirable. Further, RPE has been extensively demonstrated as a valid and reliable load-monitoring tool in the endurance, team sport and resistance exercise.
At present, tennis load monitoring relies on coach intuition of stroke count and intensity during sessions, highlighting the need for an accurate and easily quantifiable measure, such as RPE. As such, the focus of the present study was to describe the internal and external loads of common on-court drills within broader drill classifications. Specifically, we aimed to describe homogenous on-court drills within common categories for external and internal training loads. Furthermore, a secondary aim was to determine the relationship of a common internal load measure in drill-RPE and calculated drill-TL to other load monitoring tools in tennis. It was hypothesized that the physiological and perceptual demands would increase with increased external load, specifically Recovery/Defensive drills, due to more intensive running efforts. Secondly, both drill-RPE and drill-TL were hypothesized to be strongly, positively associated with other load measures including mental-exertion, mean-HR, stroke rate, and error rate.

**METHODS**

**Subjects**
Fourteen elite-level junior tennis athletes (gender: 8 male, 6 female, age: 15±1.2 y, mass: 60±14.2 kg, height: 167±10.8 cm, Australian junior ranking: 7±4, and ITF junior ranking 91±72) as well as their parents/guardians consented to the present study. Athletes routinely trained 2-3 sessions per day, completing 98±20 matches for the year. This study involved intermittent collection of training loads over a 16-week hard court training period. Training weeks were determined by the absence of tournament match play.
Chapter 4: Analysis of Elite-Level Tennis Drills

Design
All drills were performed on a Plexicushion tennis court, with each athlete appropriately dressed in training gear and using their own racquets. Athletes completed 21±3 sessions, with a mean on-court duration of 71.8±10.9 min. A total of 259 drills were included for analysis, with a mean duration of 24.6±19.0 mins per drill. Six qualified coaches, with whom the athletes worked, devised the eight drill classifications based on open/closed nature, external influences, and number of athletes (Table 4.1). Coaches reported 10±3 y elite-level experience, and completion of Australia’s highest coaching qualification. The classifications included: Recovery/Defensive, Open-Pattern, Accuracy, 2-on-1 Open, 2-on-1 Net Play, Closed-Technical, Point-Play, and Match Play. Athletes were familiarized with HR, RPE, mental-exertion, and stroke and error rate measures during a 4-week training block prior to the commencement of data collection. Athletes possessed an intimate prior familiarity with each drill during each session. The University Ethics in Human Research Committee approved this investigation.
Table 4.1. Descriptions of tennis training categories and examples of drill types.

<table>
<thead>
<tr>
<th>Drill Category</th>
<th>Category Description</th>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery/Defensive</td>
<td>Groundstroke, open play from baseline. Involving repeated strokes from positions under pressure (i.e. time, acute fatigue, position).</td>
<td>Half court point-play. 2 athletes both must hit cross-court, recover past centre mark after each stroke.</td>
<td>Point is played, losing athlete must complete shuttle run to far doubles sideline. Coach feeds ball to losing athlete. Point is then open.</td>
</tr>
<tr>
<td>Open-Pattern</td>
<td>Groundstroke, open play from baseline. Involving point-play constricted to a prior indicated pattern.</td>
<td>One athlete remains in a corner, hits alternating shots crosscourt then down line. Other athlete must return ball to same corner.</td>
<td>Both athletes on court must continue pattern of 2 shots crosscourt then 1 down line.</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Groundstroke, open play from baseline. Involving point-play relying accuracy (i.e. targets) to gain points.</td>
<td>Tramline hitting, ball must remain within tramlines hitting down one sideline.</td>
<td>Hitting to physical markers placed in crosscourt corners.</td>
</tr>
<tr>
<td>2-on-1 Open</td>
<td>Groundstroke, open play involving 2 athletes at the opposite court of 1 single athlete. All athletes remain at baseline.</td>
<td>Each athlete must hit only forehands, alternating shots between the 2 athletes at one end.</td>
<td>Point-play 2-on-1. 3 chances given to single athlete. Timed for which single athlete remains with a life longest.</td>
</tr>
<tr>
<td>2-on-1 Net Play</td>
<td>Open play involving 2 athletes at the opposite court of 1 single athlete. Any combination of athletes/coach volley from close to the net (1 minimum).</td>
<td>2-on-1, single athlete in half court must try volley all attempted passing shots. Playing for points.</td>
<td>2-on-1, single athlete has 5 strokes before a volley or smash must be played.</td>
</tr>
<tr>
<td>Closed-Technical</td>
<td>Closed, deliberate drills designed to focus on improvements to a specific quality in stroke technique.</td>
<td>Coach fed pattern, 3 backhand slice, 1 backhand crosscourt topspin</td>
<td>Hand fed pattern, backhand topspin down the line, inside out forehand crosscourt.</td>
</tr>
<tr>
<td>Point-Play</td>
<td>Open play similar to match play constricted to specific scoring systems and no involvement of serve.</td>
<td>Point-play out of the hand, first to 21 points.</td>
<td>10-point tiebreakers.</td>
</tr>
<tr>
<td>Match Play</td>
<td>Match intensity play in training, including serve.</td>
<td>Match play 3 sets.</td>
<td>Match play for time.</td>
</tr>
</tbody>
</table>
Methodology
All sessions were filmed using a video camera (DSR-PDX10P, Sony, Japan) positioned 10-m above and 6-m behind one baseline. The footage was later notated to establish stroke-rate, and unforced errors. Strokes were summated throughout the entire drill involving any time in which the ball struck the racquet face. Errors were distinguished inside the coach-prescribed constraints (if any) of the particular drill, which were clearly described by the assigned coach to both the athlete and the research team. These measures are frequently used for coaching purposes to monitor athlete development during tournaments and training, providing athlete feedback, and monitoring external load. A trained analyst (Coefficient of Variation <2%) performed notational analysis using customised software (The Tennis Analyst, V4.05.284, Fair Play, Australia).

Athletes wore individual HR monitors, (Suunto Memory Belts, Suunto Oy, Vantaa, Finland) recording at 1s intervals for each session. HR was downloaded post-session to calculate percentage HR maximum (% HRmax), mean and peak HR for each drill (Suunto Training Manager, Suunto Oy, Vantaa, Finland). Peak HR was established from the highest HR reached during the drill, while mean HR was calculated across the entire drill duration. Due to an inability to perform maximal testing on the subject cohort (a noted experimental limitation), estimated %HRmax was compared between drill categories using the formula 211 - 0.64·age (standard error, 10.8 bpm). Athletes provided RPE (Borg CR-10) and mental-exertion evaluations (0-10 Likert scale) for each individual drill immediately post-drill. Drill-TL was established post-session through multiplication of RPE and duration, similar to that used for session-TL. Mental-exertion rating (0-10 Likert scale) was used to establish a holistic rating of mental intensity perceived. Athletes rated based on descriptions of
mental demand (i.e. “How much mental and perceptual activity was required?” “Was the task easy or demanding, simple or complex, exacting or forgiving?”). All perceptual ratings were provided privately to ensure no predisposition or bias of perceived internal load. Such internal measures are favoured over other markers (i.e. lactate, VO₂) owing to their practicality and utility.

Statistical Analysis
External and internal load data were reported as mean±SD, unless otherwise specified. Comparison of external and internal load differences between categories was undertaken by repeated measures two-way (category x load measure) ANOVAs with Tukey HSD post-hoc tests to locate differences. Statistical significance was set at p<0.05. Within-individual correlations of drill- RPE and -TL with other variables (mental-exertion, mean-HR, stroke and error-rate) were analysed using Pearson’s correlation coefficients. As gender was mixed, and age varied within the cohort, within-individual statistical procedures were used to alleviate any potential gender or age bias. The following criteria were adopted to interpret the magnitude of the correlations: 0.10–0.30 small, 0.30–0.50 moderate, 0.50–0.70 large, 0.70–0.90 very large, and 0.90–0.99 nearly perfect. All analysis was conducted using PASW statistic software package (PASW, Version 17, Chicago, USA).
RESULTS

Table 4.2 shows stroke and error rate measures for each drill classification. Stroke-rates of Recovery/Defensive, Open-Pattern, Accuracy, and 2-on-1 Open drills were all significantly greater than during Match Play (p<0.05). Further, Open-Pattern drills had significantly greater stroke-rates than Point-Play (p<0.05). Error-rates of Closed-Technical drills were significantly higher than Open-Pattern, 2-on-1 Open, 2-on-1 Net Play, Point-Play, and Match Play (p<0.05). Internal load measures are reported in Table 4.3. RPE was significantly greater in Recovery/Defensive, Open-Pattern drills, and Point-Play than Closed-Technical drills (p<0.05). Similarly, mental-exertion was significantly greater in Recovery/Defensive, Open-Pattern drills and Point-Play, as well as Accuracy drills and Match Play than Closed-Technical drills (p<0.05). No differences were observed in %HRmax, peak or mean HR between respective categories (p>0.05).

Analyses revealed substantial relationships (p<0.05) between drill RPE and mental-exertion for Open-Pattern, 2-on-1 Open, 2-on-1 Net Play, Closed-Technical drills, and Match Play (Table 4.4; r>0.61). Substantial correlations were also found with drill-TL and mental-exertion for Recovery/Defensive and 2-on-1 Net Play (r>0.61). A substantial correlation was also displayed between mean HR and RPE in Open-Pattern (r=0.62), yet generally in slight to fair agreement with RPE and drill-TL for all other drill categories (r<0.40). Total stroke count was substantially correlated to drill-TL for Recovery/Defensive, Accuracy, 2-on-1 Open drills, and Point-Play (r>0.65). However, total stroke count and stroke rate for all categories were only slightly to moderately correlated with RPE (r<0.49). Finally, slight to moderate associations were evident between both drill-RPE and -TL, and error rate (r<0.51).
Table 4.2. Measures of shot count and error rate for all sessions, divided into training categories (n= 259, mean±SD).

<table>
<thead>
<tr>
<th>Drill Category</th>
<th>N</th>
<th>Shot Rate (per 6 sec)</th>
<th>Error Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-on-1 Open Drills</td>
<td>25</td>
<td>0.9 ± 0.3</td>
<td>12.8 ± 5.8</td>
</tr>
<tr>
<td>2-on-1 Net-play Drills</td>
<td>27</td>
<td>0.8 ± 0.4</td>
<td>11.8 ± 3.4</td>
</tr>
<tr>
<td>Accuracy Drills</td>
<td>27</td>
<td>0.9 ± 0.3</td>
<td>14.7 ± 9.2</td>
</tr>
<tr>
<td>Open-Pattern Drills</td>
<td>30</td>
<td>1.2 ± 0.8</td>
<td>12.4 ± 4.2</td>
</tr>
<tr>
<td>Closed-Techical Drills</td>
<td>36</td>
<td>0.8 ± 0.5</td>
<td>19.2 ± 11.1</td>
</tr>
<tr>
<td>Recovery/Defensive Drills</td>
<td>26</td>
<td>0.9 ± 1.0</td>
<td>17.3 ± 6.5</td>
</tr>
<tr>
<td>Point-Play</td>
<td>56</td>
<td>0.6 ± 0.3</td>
<td>13.2 ± 4.9</td>
</tr>
<tr>
<td>Match Play</td>
<td>32</td>
<td>0.4 ± 0.2</td>
<td>11.9 ± 5.6</td>
</tr>
</tbody>
</table>

a Significantly different (p<0.05) to Closed-Techical Drills
b Significantly different (p<0.05) to Recovery/Defensive Drills
c Significantly different (p<0.05) to Point-Play
d Significantly different (p<0.05) to Match Play
Table 4.3. Internal load and intensity measures of all sessions, divided into training categories (n= 259, mean±SD).

<table>
<thead>
<tr>
<th>Drill Category</th>
<th>N</th>
<th>Drill RPE</th>
<th>Drill Mental-Exertion</th>
<th>% HRmax</th>
<th>Peak HR</th>
<th>Mean HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-on-1 Open Drills</td>
<td>25</td>
<td>5.5 ± 1.8</td>
<td>5.8 ± 1.6</td>
<td>89 ± 7</td>
<td>180 ± 13</td>
<td>154 ± 16</td>
</tr>
<tr>
<td>2-on-1 Net-play Drills</td>
<td>27</td>
<td>5.7 ± 1.4</td>
<td>5.9 ± 1.8</td>
<td>86 ± 6</td>
<td>173 ± 13</td>
<td>146 ± 19</td>
</tr>
<tr>
<td>Accuracy Drills</td>
<td>27</td>
<td>5.7 ± 1.3</td>
<td>6.6 ± 1.1  (^a)</td>
<td>85 ± 12</td>
<td>172 ± 23</td>
<td>148 ± 29</td>
</tr>
<tr>
<td>Open-Pattern Drills</td>
<td>30</td>
<td>5.9 ± 1.6  (^a)</td>
<td>6.3 ± 1.6  (^a)</td>
<td>89 ± 6</td>
<td>176 ± 21</td>
<td>148 ± 24</td>
</tr>
<tr>
<td>Closed-Techical Drills</td>
<td>36</td>
<td>4.6 ± 1.9 (^bc)</td>
<td>4.8 ± 1.8 (^bcd)</td>
<td>86 ± 8</td>
<td>171 ± 13</td>
<td>152 ± 13</td>
</tr>
<tr>
<td>Recovery/Defensive Drills</td>
<td>26</td>
<td>6.5 ± 1.8</td>
<td>6.5 ± 1.2</td>
<td>90 ± 9</td>
<td>181 ± 13</td>
<td>154 ± 18</td>
</tr>
<tr>
<td>Point-Play</td>
<td>56</td>
<td>5.8 ± 1.5</td>
<td>6.0 ± 1.3</td>
<td>87 ± 9</td>
<td>181 ± 11</td>
<td>150 ± 17</td>
</tr>
<tr>
<td>Match Play</td>
<td>32</td>
<td>5.8 ± 1.4</td>
<td>6.4 ± 1.5</td>
<td>82 ± 12</td>
<td>175 ± 14</td>
<td>143 ± 16</td>
</tr>
</tbody>
</table>

\(^a\) Significantly different (p<0.05) to Closed-Techical Drills

\(^b\) Significantly different (p<0.05) to Recovery/Defensive Drills

\(^c\) Significantly different (p<0.05) to Point-Play

\(^d\) Significantly different (p<0.05) to Match Play
### Chapter 4: Analysis of Elite-Level Tennis Drills

Table 4.4. Within-individual correlations between both drill-RPE and drill-TL with various measures of load and intensity (mean ± SD).

<table>
<thead>
<tr>
<th>Drill-RPE</th>
<th>Mental-Exertion</th>
<th>Mean HR</th>
<th>Total Strokes</th>
<th>Stroke Rate</th>
<th>Error Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery/Defensive</td>
<td>0.33 ± 0.21</td>
<td>0.01 ± 0.26</td>
<td>0.49 ± 0.14</td>
<td>-0.28 ± 0.04</td>
<td>0.04 ± 0.13</td>
</tr>
<tr>
<td>Open-Pattern</td>
<td>0.69 ± 0.21</td>
<td>0.62 ± 0.33</td>
<td>-0.29 ± 0.24</td>
<td>-0.06 ± 0.28</td>
<td>-0.51 ± 0.67</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.17 ± 0.12</td>
<td>-0.24 ± 0.53</td>
<td>0.31 ± 0.25</td>
<td>-0.23 ± 0.58</td>
<td>0.05 ± 0.28</td>
</tr>
<tr>
<td>2-on-1 Open</td>
<td>0.86 ± 0.15</td>
<td>0.29 ± 0.36</td>
<td>0.37 ± 0.11</td>
<td>-0.04 ± 0.23</td>
<td>0.41 ± 0.19</td>
</tr>
<tr>
<td>2-on-1 Net Play</td>
<td>0.62 ± 0.14</td>
<td>0.05 ± 0.12</td>
<td>0.40 ± 0.09</td>
<td>0.04 ± 0.26</td>
<td>0.23 ± 0.36</td>
</tr>
<tr>
<td>Closed-Technical</td>
<td>0.69 ± 0.31</td>
<td>-0.40 ± 0.52</td>
<td>-0.41 ± 0.34</td>
<td>0.41 ± 0.72</td>
<td>0.42 ± 0.37</td>
</tr>
<tr>
<td>Point-Play</td>
<td>0.46 ± 0.56</td>
<td>0.19 ± 0.71</td>
<td>0.17 ± 0.27</td>
<td>0.34 ± 0.51</td>
<td>-0.15 ± 0.42</td>
</tr>
<tr>
<td>Match Play</td>
<td>0.84 ± 0.12</td>
<td>0.29 ± 0.52</td>
<td>-0.03 ± 0.19</td>
<td>0.09 ± 0.41</td>
<td>-0.17 ± 0.23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drill-TL</th>
<th>Mental-Exertion</th>
<th>Mean HR</th>
<th>Total Strokes</th>
<th>Stroke Rate</th>
<th>Error Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery/Defensive</td>
<td>0.74 ± 0.13</td>
<td>0.14 ± 0.16</td>
<td>0.65 ± 0.23</td>
<td>-0.16 ± 0.20</td>
<td>0.32 ± 0.47</td>
</tr>
<tr>
<td>Open-Pattern</td>
<td>-0.05 ± 0.35</td>
<td>0.09 ± 0.29</td>
<td>0.43 ± 0.19</td>
<td>-0.38 ± 0.45</td>
<td>0.04 ± 0.53</td>
</tr>
<tr>
<td>Accuracy</td>
<td>-0.10 ± 0.28</td>
<td>-0.04 ± 0.50</td>
<td>0.83 ± 0.28</td>
<td>-0.46 ± 0.41</td>
<td>0.24 ± 0.28</td>
</tr>
<tr>
<td>2-on-1 Open</td>
<td>0.42 ± 0.34</td>
<td>0.25 ± 0.54</td>
<td>0.77 ± 0.25</td>
<td>-0.38 ± 0.27</td>
<td>-0.34 ± 0.18</td>
</tr>
<tr>
<td>2-on-1 Net Play</td>
<td>0.64 ± 0.31</td>
<td>-0.29 ± 0.18</td>
<td>0.59 ± 0.18</td>
<td>0.16 ± 0.41</td>
<td>0.12 ± 0.67</td>
</tr>
<tr>
<td>Closed-Technical</td>
<td>-0.23 ± 0.21</td>
<td>0.10 ± 0.58</td>
<td>-0.04 ± 0.61</td>
<td>-0.36 ± 0.23</td>
<td>0.27 ± 0.15</td>
</tr>
<tr>
<td>Point-Play</td>
<td>0.38 ± 0.38</td>
<td>-0.07 ± 0.44</td>
<td>0.70 ± 0.20</td>
<td>-0.32 ± 0.39</td>
<td>-0.07 ± 0.47</td>
</tr>
<tr>
<td>Match Play</td>
<td>0.50 ± 0.15</td>
<td>0.13 ± 0.24</td>
<td>0.33 ± 0.66</td>
<td>-0.28 ± 0.24</td>
<td>-0.34 ± 0.42</td>
</tr>
</tbody>
</table>
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DISCUSSION

The aim of the present investigation was to describe the external and internal loads associated with a range of drills that fitted homogeneously within eight, coach deduced, categories deemed common to elite junior tennis environments. Critically, there were apparent trends for open, end range type drills to be characterized by greatest RPE, HR and stroke-rates. Accuracy and defensive drills were otherwise perceived to elicit the greatest mental intensity, whilst technical and defensive drills induced the greatest error-rates and open, 2-on-1 and pattern drills were ideal for error-amelioration practice.

Specifically, established from mean drill rankings, Recovery/Defensive drills were punctuated by the highest internal load (RPE, mental-exertion and HR), Open-Pattern drills recorded elevated RPE, and Accuracy drills demanded the greatest mental-exertion. Physiologically, Recovery/Defensive and Open-Pattern drills induced the greatest %HRmax, while Point-Play and 2-on-1 Open drills showed the uppermost peak and mean-HR respectively. Analysis of stroke-rate revealed Open-Pattern and Recovery/Defensive drills to elicit the largest number of strokes. Technical outcomes (error-rate) were poorest in Closed-Techinal and Recovery/Defensive drills and best throughout 2-on-1 Net-Play and Match Play. A secondary aim was to determine the relationship of drill-RPE and -TL with other training load monitoring variables. Correlations across each drill category revealed strong relationships between drill-RPE and mental-exertion. Furthermore, drill-TL was positively correlated with total strokes, but negatively correlated with stroke-rate. Finally, mean HR and error-rate were only characterized by slight-moderate associations with both drill-RPE and -TL.
Open-Pattern drills were punctuated by significantly higher stroke-rates (1.2 ± 0.8 strokes sec\(^{-1}\)) than Closed-Technical drills, Point-Play, and Match Play (0.4 ± 0.2 strokes sec\(^{-1}\)). Further, Recovery/Defensive, 2-on-1 Open, and Accuracy drills were significantly greater than Match Play (p<0.05). Previously, Reid et al.\(^3\) described the stroke-count of 4 hand-fed drills over 30 and 60 s. After adjusting the 60 s stroke-counts to reflect our data (6 s periods as per mean point duration in matches), two of the drills (Star and Box) presented much higher stroke rates than any drill categories in this study. Star (2.0 strokes sec\(^{-1}\)) and Box (2.3 strokes sec\(^{-1}\)) drills were characterized by considerably higher stroke-rates than any current category.\(^3\) The discrete, hand-fed, nature of these drills (1 set/6 repetitions) combined with high metabolic demand, suggest Star and Box drills may not be sustainable if comprising the bulk of a 90-120 min session.\(^3\) However, Suicide (0.7 strokes sec\(^{-1}\)) and Big X (0.8 strokes sec\(^{-1}\)) drills were comparable to 2-on-1 Open, Closed-Technical drills and Point-Play. Moreover, it appears that drill stroke-rates during Point-Play and Match Play are generally below that of stroke-rates reported from tournament data. Previous tournament play stroke-rates have been reported as 2.7 strokes/rally (7.5 sec),\(^7\) through to 4.7 strokes/rally (6.7 sec).\(^95\) Therefore, stroke frequency during drills aimed at skill development is below that considered optimal to simulate tournament intensity. Although, it should be acknowledged that drills designed to achieve technical outcomes are usually not completed at tournament intensity. In any case, the current data show that whilst below tournament intensity, stroke-rate was greatest within Open-Pattern drills, making these drills ideal for instilling “match-like” stroke frequencies into training.

Currently there is limited literature reporting the error-rates associated with tennis tournaments and training. Pieper et al.\(^305\) analysed seven hard-court men’s singles
matches of ATP players ranked 1-63. Percentile error ratios described low, medium and high time pressure situations on hard-courts with respective error-rates of 13.7, 21.0 and 26.4% on the forehand with 13.5, 16.8 and 25.6% on the backhand.\textsuperscript{305} Reid et al.\textsuperscript{46} reported the error-rates of four 2-on-1 tennis drills on both hard and clay-courts. The error-rates reportedly increased through drills one to four from 10.6 ± 6.1% (hard-court) for basic 2-on-1 rally patterns, through to 23.9±11.8% (hard-court) as movement intensity and drill difficulty increased.\textsuperscript{46} In contrast, our data suggests \textit{Closed-Technical} drills (19.2±11.1%), which were the least physically demanding (low stroke-rates), produced the greatest error-rates. This is likely due to technical adjustments and changes in stroke mechanics during these drills, whereby errors are tolerated in the optimization of technical outcomes. However, the higher intensity \textit{Recovery/Defensive} drills (17.3±6.5%) also comprised of high error-rates, likely due to the heightened physical load. Coaches should take caution in prescribing drills of increased physical intensity when the session focus is to alter stroke mechanics or specific movement patterns, as excessive loads may affect stroke performance. Further, during rally-based drills, where the intensity is high, increased error-rates may alter the duration of continued exertion of effort, resulting in reductions to the physical demands of sessions. Contrastingly, 2-on-1 \textit{Net Play} drills (11.8±3.4%) provided the lowest error-rates making them ideal for error-amelioration practice.

Internal load measures determined from drill-RPE were highest for \textit{Recovery/Defensive} drills (6.5±1.8au), followed by \textit{Open-Pattern} drills and \textit{Point-Play}. \textit{Recovery/Defensive}, \textit{Open-Pattern} drills and \textit{Point-Play} were each perceived to be significantly harder than \textit{Closed-Technical} drills (4.6±1.9au). Similar to external load measures related to stroke-rate, there is limited literature describing the internal loads associated with tennis training.\textsuperscript{3,92} As aforementioned, Reid et al.\textsuperscript{3}, post-drill
RPE (6 reps/60 sec) of the Star drill (5.8±1.2au) were of similar intensity to Accuracy, 2-on-1 Net Play drills, Point-Play and Match Play. Furthermore, Reid et al. report the Box drill (5.0±1.5au) to be of lower intensity, resembling Closed-Technical drills. Meanwhile, Suicide (7.6±1.1au) and Big X (7.6±1.0au) drills were of intensities higher than any category documented currently. Case studies have previously reported Tournament RPE’s of 5–8au for elite athletes (ranking<120 ATP). As such, these data suggest that the intensity of the present training categories, including Match Play, may not compare favourably to the intensity of tough matches for aspiring professional athletes, despite obvious age and expertise differences. The current relationships between external load and RPE are not as developed as previous literature in other sports, most likely due to the younger age of the present cohort, and a lack of understanding or ability to associate drill intensity with external stimuli despite prior familiarization. Conversely, it could be argued that the current internal and external load markers differ from that of previous studies and are of different specific mechanical loads to the small accelerated displacements typical to tennis (i.e., water-based team sports and individual contact sports). Nevertheless, there is a need to monitor loads in such developing subject cohorts in tennis due to early specialization, but how valid these measures are is unknown.

As tennis involves precise movements, with multiple short bursts over long periods, the mental skills required from athletes (i.e. concentration, anxiety and arousal management) should not be overlooked. Currently, no quantitative literature exists on the mental-exertion perceived by tennis athletes during training or tournaments. However, somewhat predictably, Accuracy (6.6±1.1au) drills recorded the greatest mental-exertion followed by high-pressure drills (i.e, Recovery/Defensive drills, 6.5±1.2au) and open, match-like situations (i.e., Match Play, 6.4±1.5au; Open-Pattern
drills, 6.3±1.6au; and Point-Play, 6.0±1.3au). Each of the abovementioned drills was of significantly greater mental demand than Closed-Technical drills (4.8±1.8au), which involved closed-skill focus. Seemingly, when considering load for session design, Recovery/Defensive drills appear to most closely reproduce physical and mental intensities typical of tournaments.22,98 Similarly, Open-Pattern drills can induce sizeable physical exertion, whilst a by-product of Accuracy drills might be mental skill development.

Despite significant perceptual differences between drill categories, there were no significant differences in any HR measure (%HRmax, peak or mean HR) between any of the categories. Whilst it is surprising that there was such an inconsistent relationship between drill category HR and RPE, the psycho-physical nature of RPE perhaps captures the high stress of high concentration drill categories that are not overtly physical in nature. Regardless, categories inducing the greatest absolute peak-HR and relative (%HRmax) were Point-Play (181±11bpm; 87±9%), Recovery/Defensive drills (181±13bpm; 90±9%), and Open-Pattern (176 ± 21bpm; 89±6%), with Closed-Technical drills (171±13bpm; 86±8%) producing the lowest peak-HR – consistent with the trends observed for RPE and mental-exertion. Mean-HR however, were greatest in 2-on-1 Open (154±16bpm) and Recovery/Defensive drills (154±18bpm), whilst lowest during Match Play (143±16bpm). Previously, Reid et al.3 report similar HR’s (160-180bpm) to the present study. Bekraoui et al.92 report HR following 4 min of activity to be of a much larger range (150-182bpm). However, each of the present drill categories is comparable to the peak-HR reported during drills conducted at high speeds.92 Meanwhile, mean HR’s during tournaments reportedly range from 140-160bpm.97 The present data represent physiological demands comparable to these tournament ranges; albeit towards the lower end.
Surprisingly, *Match Play* in training induced the lowest %HRmax and mean-HR, again indicating that the physiological demands of training-based tournament preparation is insufficient. However, *Point-Play, 2-on-1 Open* and *Recovery/Defensive* drills elicited the greatest absolute peak and mean-HR values that are comparable to tournament-like demands. This is most likely due to the increased intensity and pressure associated with the open-play nature of these drills. Conversely, drills that could be prescribed for reduced physiological load are closed, technical and target-hitting drills. Prescription of these drills could be used during de-loading cycles, tapers, or within sessions designed to reduce cardiovascular strain.

A unique finding from this study is the substantial within-individual correlations between both drill-RPE and -TL with other measures of internal and external load in tennis (i.e., mental-exertion and stroke rates). Previously, Lovell et al.\(^40\) used within-individual correlations to demonstrate strong relationships between session-RPE and -TL respectively, with speed, body load, and HR, ultimately suggesting a multifactorial approach to load monitoring. Previously, no literature has compared the RPE (intensity) or TL (volume) of tennis drills to load variables. Current data suggests that mental-exertion is related closely to the perceived intensity of drills (i.e., substantial correlations with RPE). Interestingly however, the two categories of greatest mental-exertion (*Accuracy and Recovery/Defensive* drills) were only slightly-moderately correlated with RPE. While, *Recovery/Defensive* drills were substantially correlated with drill-TL. Therefore, it can be inferred that athlete perception of mental exertion in affected by drill duration. Meanwhile, both stroke-count and rate were only slightly-moderately correlated with RPE. However, analysis revealed that drill duration (i.e., as a basis of TL) interacts substantially and positively with total stroke volume, yet negatively with stroke rate. Consequently, drill duration plays a larger
role in stroke-specific external load than intensity (i.e., stroke rate); though and as would be expected, stroke rate is negatively affected as drill duration increases. Therefore, such data suggests that for tennis drills strong interactions exist between drill duration and load.

Error-rates were slightly-moderately correlated to drill-RPE and -TL for all categories. Intriguingly, one of the largest correlations for error-rate with drill-RPE and -TL was Closed-Technical drills, suggesting that in “closed” drills, stroke production and execution likely contribute to the perception of intensity. Finally, in contrast to previous studies, only slight-moderate correlations were observed for drill-RPE and -TL with mean-HR. The slight-moderate associations were evident for all drill categories except for Open-Pattern drills - a category of high RPE. Collectively, these observations - similar to Lovell et al. - indicate that poor relationships of drill-RPE and -TL with HR, stroke and error rate in the current study, reaffirming that a multitude of variables contribute to variation in perceived load in tennis training.
PRACTICAL APPLICATIONS

Due to the limited training time in elite junior tennis development, appropriately integrated training session design is vital. As such, informed drill and session prescription of internal and external loads are critical. Whilst previous tennis studies have provided selected quantitative data on the internal and external loads of discrete drills, a larger, catalogued description of drills provides greater applicability to session design and implementation across all tennis environments. A ranking summary of categories (highest-lowest) for each load variable is reported (Table 4.5) to assist in the prescription of external and internal load for tennis training. Results highlight open, recovery drills as being greatest for drill-RPE, HR and stroke-rates, whilst target-hitting, defensive drills place athletes under highest mental pressure. Technical and high time-pressure (defensive) drills induced the greatest error-rates. Open, 2-on-1 and pattern drills tended to encourage lower error-rates, making them ideal for high-repetition practice. Furthermore, we have provided a holistic ranking of drill categories for physiological intensity based on internal load and stroke rates, and technical development ranking based on drill stroke rate and error rates. As the use of load monitoring is becoming more common within elite tennis environments, the present descriptive analysis can be used as a tool for prescribing load-appropriate training drills within a periodised development plan.
Table 4.5. Ranking summary of drill categories highest to lowest dependent on each external and internal load variable.

<table>
<thead>
<tr>
<th>Internal Load</th>
<th>Drill-RPE</th>
<th>Mental-Exertion</th>
<th>% HRmax</th>
<th>Peak HR</th>
<th>Mean HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>Recovery/Defensive</td>
<td>Accuracy</td>
<td>Recovery/Defensive</td>
<td>Point-Play</td>
<td>2-on-1 Open</td>
</tr>
<tr>
<td>Highest</td>
<td>Open-Pattern</td>
<td>Recovery/Defensive</td>
<td>Open-Pattern</td>
<td>Recovery/Defensive</td>
<td>Recovery/Defensive</td>
</tr>
<tr>
<td></td>
<td>Match Play</td>
<td>Match Play</td>
<td>2-on-1 Open</td>
<td>2-on-1 Open</td>
<td>Closed-Technical</td>
</tr>
<tr>
<td></td>
<td>Point-Play</td>
<td>Open-Pattern</td>
<td>Point-Play</td>
<td>Open-Pattern</td>
<td>Point-Play</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>Point-Play</td>
<td>2-on-1 Net Play</td>
<td>Match Play</td>
<td>Open-Pattern</td>
</tr>
<tr>
<td></td>
<td>2-on-1 Net Play</td>
<td>2-on-1 Net Play</td>
<td>Closed-Technical</td>
<td>2-on-1 Net Play</td>
<td>Accuracy</td>
</tr>
<tr>
<td></td>
<td>2-on-1 Open</td>
<td>2-on-1 Open</td>
<td>Accuracy</td>
<td>Accuracy</td>
<td>2-on-1 Net Play</td>
</tr>
<tr>
<td></td>
<td>Closed-Technical</td>
<td>Closed-Technical</td>
<td>Match Play</td>
<td>Closed-Technical</td>
<td>Match Play</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>External Load</th>
<th>Stroke Rate</th>
<th>Error Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>Highest</td>
<td>Lowest</td>
</tr>
<tr>
<td></td>
<td>Open-Pattern</td>
<td>Closed-Technical</td>
</tr>
<tr>
<td></td>
<td>Recovery/Defensive</td>
<td>Recovery/Defensive</td>
</tr>
<tr>
<td></td>
<td>2-on-1 Open</td>
<td>Accuracy</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>Point-Play</td>
</tr>
<tr>
<td></td>
<td>2-on-1 Net Play</td>
<td>2-on-1 Open</td>
</tr>
<tr>
<td></td>
<td>Closed-Technical</td>
<td>Open-Pattern</td>
</tr>
<tr>
<td></td>
<td>Point-Play</td>
<td>Match Play</td>
</tr>
<tr>
<td></td>
<td>Match Play</td>
<td>2-on-1 Net Play</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Author’s Suggestions</th>
<th>Physiological Load</th>
<th>Technical Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>Highest</td>
<td>Lowest</td>
</tr>
<tr>
<td>Match Play</td>
<td>2-on-1 Net Play</td>
<td>2-on-1 Open</td>
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<tr>
<td>Accuracy</td>
<td>Point Play</td>
<td>Open-Pattern</td>
</tr>
<tr>
<td>2-on-1 Net Play</td>
<td>Match Play</td>
<td>Match Play</td>
</tr>
<tr>
<td>Closed-Technical</td>
<td>Accuracy</td>
<td>Point Play</td>
</tr>
<tr>
<td>Match Play</td>
<td>Closed-Technical</td>
<td>Recovery/Defensive</td>
</tr>
</tbody>
</table>
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CONCLUSIONS

The current tennis investigation has developed a hierarchy of drill categories considering drill-RPE, mental-exertion, %HRmax, peak and mean-HR, stroke and error-rate. Results indicate that categories were of insufficient load to replicate those previously reported during mean or maximal components of tournaments. Regardless, stroke-rate analysis revealed Open-Pattern and Recovery/Defensive drills to be of greatest external load, while Point-Play and Match Play recorded the lowest. Technical performance (error-rate) was poorest in Closed-Technical and Recovery/Defensive drills and best throughout 2-on-1 Net-Play and Match Play. Furthermore, Recovery/Defensive drills were characterized by high internal load (RPE, mental-exertion and HR), while Open-Pattern drills recorded high RPE. Whereas, 2-on-1 Open and Closed-Technical drills were perceived contrarily. 2-on-1 Open and Closed-Technical drills elicited the lowest mental-exertion, while Accuracy drills required the greatest. Physiologically, Recovery/Defensive and Open-Pattern drills were of highest %HRmax, while Point-Play and 2-on-1 Open drills presented greatest peak and mean-HR respectively. Contrastingly, Closed-Technical and Match Play presented with the poorest %HRmax, peak and mean-HR. Substantial correlations were observed for drill-RPE and -TL with mental-exertion. Further substantial relationships were found between drill-TL and total-strokes. Such information enables trainers and coaches to develop evidence-based training sessions using quantifiable insights into the most commonly used drill categories. Drill prescription can therefore be tailored to target on-court preparation specific to the physiological, psychological and technical needs of elite tennis athletes.
CHAPTER FIVE

A comparison of the perceptual and technical demands of tennis training, simulated match play and tournament match play

As based on the accepted manuscript:

ABSTRACT

High-performance tennis environments aim to prepare athletes for competitive demands through simulated match scenarios and drills. With a dearth of direct comparisons between training and tournament demands, this study compared the perceptual and technical characteristics of training drills, simulated match play, and tournament matches. Data were collected from 18 high-performance, junior tennis players (gender: 10 male, 8 female, age: 16±1.1 y) during 6±2 drill-based training sessions, 5±2 simulated match play sessions, and 5±3 tournament matches from each participant. Tournament matches were further distinguished by win or loss, and against seeded or non-seeded opponents. Notational analysis of stroke and error rates, winners, and serves, along with RPE and mental-exertion were measured post-session. Repeated-measures analyses of variance and effect-size analysis revealed training sessions were significantly shorter in duration than tournament matches (p<0.05; d=1.18). RPE’s during training and simulated match play sessions were lower than in tournaments (p>0.05;d=1.26,d=1.05 respectively). Mental exertion in training was lower than both simulated match play and tournaments (p>0.05;d=1.10;d=0.86 respectively). Stroke-rates during tournaments exceeded those observed in training (p<0.05;d=3.41) and simulated match play (p<0.05;d=1.22) sessions. Further, the serve was used more during tournaments than simulated match play (p<0.05;d=4.28), while errors and winners were similar independent of setting (p>0.05;d<0.80). Training in the form of drills or simulated match play appeared to inadequately replicate tournament demands in this cohort of players. Coaches should be mindful of match demands to best prescribe sessions of relevant duration as well as internal (RPE) and technical (stroke-rate) load to aid tournament preparation.
INTRODUCTION

High-performance tennis athletes are exposed to a myriad of training stimuli in preparation for tournaments, including technical and tactical drills, and simulated match play.\(^3,92,308,309\) Whilst previous discrete\(^3,92\) and catalogued drill studies\(^309\) establish typical training loads associated with high-level tennis environments, comparisons of training sessions, simulated match play, and tournaments within the same cohort are non-existent; with past research inferring insight from data gathered from different competition cohorts (i.e., developmental vs. elite).\(^3,92\) In a similar vein, given the significance attached to training during developmental years (i.e., 8-20y),\(^166\) a more granular understanding of the actual training and competitive demands imposed on this particular cohort of players is needed.\(^14,21\) Ideally, during developmental periods, training drills and simulated match play should mimic conventional or ‘worst case’ tournament scenarios (i.e., highest demands required during competition) depending on developmental stage of the involved players.\(^117,309\) In other sports (i.e., rugby league), a primary objective of training is to replicate certain patterns of play, enabling players to cope with the highest demands placed upon them during competition.\(^310,311\) Unfortunately, in tennis, current literature has provided negligible insight into the appropriate prescription of training loads to mimic competition play, particularly in specific cohorts through early - late developmental stages.\(^2\)

The loads of different cohorts of tennis players completing training drills, simulated match play scenarios, and tournament play have been investigated through an assortment of internal (i.e., HR, RPE, and mental-exertion) and external (i.e., stroke-rate) measures. Previously we have described the internal and external loads of
various drill categories within a high-performance youth tennis population. Specifically, Recovery/Defensive drills were of greatest internal load (HR, RPE, and mental-exertion). Physiologically, more ‘open’ drills were characterized by higher peak and mean-HR, whilst match play and more ‘closed’ or technical drills presented with lower peak and mean-HR. Reid et al. earlier characterized four discrete, hand-fed, drills including the Star, Box, Suicide and Big X. Internal load was reported using HR (178-182 bpm), and RPE (5.0-7.6 au), while external load was documented through stroke count (0.7-2.3 strokes/min\(^1\)), ball velocity (113-123 m/s), and distance covered (76-114 m) via GPS measures. Furthermore, previous data suggests that stroke-rates during point-play and match play in training are below the stroke-rates characterized in separately reported tournament data (2.7±2.2 - 4.7±1.4 strokes/rally). Moreover, tournament RPE has been reported as ranging between 5-7 au (CR-10)\(^{22,98}\) and 10-16 (Borg 20-point). On the surface, while this empirical backdrop appears extensive, it is the aggregate of independent, discrete training and competition insights and lacks any consideration of training or matches within a single cohort, therein placing practitioners in situations that require ongoing assumptions to inform training loads.

Nevertheless, based on a comparison of previously notated and perceived match demands with the observational data describing typical training sessions, loads in training and tournament play appear disparate. Indeed, this type of discrepancy may contribute to mismatches in the preparation of high-performance athletes for tournaments; albeit it is assumed – perhaps incorrectly – that players are training at suitable intensities and durations. Given the lack of empirical support for this assumption, the aim of this study was to analyse the technical and perceptual characteristics of drill-based training sessions in comparison to simulated match play.
and tournaments in the same cohort of elite players. A secondary aim was to compare loads within tournament matches won vs. lost, and against seeded vs. non-seeded opponents to further explore the nuances of load responses related to match outcome. It was hypothesized that (a) training sessions would present lower load than simulated match play, which would in turn be lower than tournament matches, and, (b) tournament demands would be elevated in matches lost and against seeded opponents.

**METHODS**

**Subjects**
Eighteen high-performance, junior tennis players (gender: 10 male, 8 female, age: 16±1.1 y, mass: 63±16.2 kg, height: 171±11.4 cm, Australian junior ranking: 6±5, and International Tennis Federation [ITF] junior ranking 85±61) and their parents/guardians provided written consented following full explanation of the study. The University Ethics in Human Research Committee approved this investigation. Athletes routinely trained 2-3 sessions per day, completing 96±24 matches for the year. This study involved collection of internal and external measures from at least one training session per day, over a 10-week hard court training period (December-February; Australian summer). Athletes were well familiarized with each drill during each session as a result of extensive exposure during previous training blocks. Training sessions were selected when at least 2 subjects were included in the session, and coach designed session plans involved open nature drills (i.e., higher physical demands) with lesser emphasis on technical proficiency or outcomes.

**Design**
All training drills, simulated match play and tournament matches were completed on a Plexicushion tennis court. Athletes each completed 6±2 open-drill training sessions, 5±2 simulated match play, and 5±3 tournament matches. Athletes within the testing
cohort were encouraged by coaching staff to standardize nutritional habits around training in preparation for competition. However, the inclusion of physical (S&C) sessions within the training day meant that additional energy intake was required. Similarly, owing to the real world settings, characterized by uncertain match start and finish times, travel demands and the variable selection and timing of meal/hydration options, nutritional practices were not standardized. This approach aligns to previous match investigations, however, due to the within-cohort analysis, a similar approach was adopted for training also. However, whilst conditions across all sessions were dry and relatively warm (Australian summer), these were unattainable across all training sessions and matches, creating a limitation to load analysis. While the strength of the current investigation surrounds the within-cohort comparisons, it is recognized that the variety of training and match locations limits an ability to standardize environmental conditions and hydration state. Accordingly, this is recognized as a limitation of the present study.

**Tournaments**
Analysis of tournament load (i.e., match load) was carried out across four, outdoor, hard court (i.e., category 4 court surface) tournaments within Australia. Specifically, the first two tournaments were domestic Australian tournaments (National title events in Sydney and Melbourne), the further two events were junior ITF events (grade 1 and A, respectively) All matches followed ITF junior guidelines and were best of three sets, contested between 0900 and 1900 hours. Further, tournament matches were distinguished by outcome (win or loss), and opponent (against a seeded or non-seeded opponent) as separate analyses, with data obtained from Tennis Australia and ITF websites.
Simulated Match play
Simulated match play sessions were organised by assigned coaches, ensuring similar between-player capabilities. All sessions began with initial coach instruction and outline of the session focus. However, aside from encouragement, coaches observed, but refrained from interference of technical or tactical feedback within the match. Each match was best of three sets, self-controlled using ITF rules, and conducted on outdoor, hard court (i.e., category 4 court surface).

Training Sessions
Training drill sessions were selected for drills that were of open nature only (in accordance with our previously reported data), as these drills types are of greatest physical and mental demands of typical elite-oriented tennis drills. Specifically, these types of drills consisted only of “Recovery/defensive”, Open-pattern”, and “2-on-1 open” drill categories. These drills were each typified by high strokes rates (>0.9 strokes per 6 sec), RPE (>5.5 au), mental-exertion (5.8 au) and % HRmax (>89%). Sessions were excluded from analysis post hoc if the aforementioned criteria were not met. All sessions were conducted on outdoor, hard court (i.e., category 4 court surface).

Methodology
All sessions were filmed using a video camera (DSR-PDX10P, Sony, Japan) positioned 10-m above and 6-m behind one baseline. The footage was later notated to establish stroke-rate, and unforced errors. Strokes were summated throughout the entire session or match involving any time in which the ball struck the racquet face. Errors in training sessions were distinguished inside the coach-prescribed constraints (if any) of the particular drill, which were clearly described by the assigned coach to both the athlete and the research team. Strokes, errors, winner and serves were
counted and analysed relative to session/match duration (mins). Work durations - the effective playing time - were distinguished from the point of a successful serve until a winner or error, (analysed only for simulated match play and tournaments). Rest durations were then calculated as remaining time within simulated match play or tournament matches (i.e., change-over rest periods). Standard match rules were implemented for errors in both simulated match play and tournament play.46,118

Athletes were familiarized with physical RPE and mental-exertion as measures of internal load collected daily within their environment. Athletes provided RPE (Borg CR-10)82 and mental-exertion evaluations (0-10 Likert scale) for each drill session, simulated match play, and tournament match 30 mins following completion.22,298 Session-TL (au) was calculated through multiplication of duration and RPE.22 Mental-exertion rating (0-10 Likert scale) was used to establish a holistic rating of mental intensity perceived. Athletes rated based on descriptions of mental demand.298 All perceptual ratings were provided privately to ensure no predisposition or bias. As RPE and duration are the main measures of the current investigation, it is useful to note that previous research on adolescents has reported correlation coefficient between RPE and HR as strong ($r=0.74$).312 Furthermore, a trained analyst (Coefficient of Variation <2%) who was familiarized with the notational analysis system (The Tennis Analyst, V4.05.284, Fair Play, Australia), conducted all notational analysis post-session. These measures are commonly used within training and post-tournament analysis to provide feedback and monitor external load.308,309
Statistical Analysis
External and internal load data were reported as mean (±SD), unless otherwise specified. Comparison of external and internal load responses between different scenarios i.e., training, simulated match play, or tournaments, was undertaken by repeated measures two-way (Session Mode x Measure) ANOVA’s with Tukey HSD post-hoc tests to locate differences. Statistical significance was set at p<0.05. Cohen’s $d$ effect size analysis established the magnitude of difference with effect sizes of <0.20 classified as small, 0.40-0.60 as medium, and >0.80 as large. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) (Version 20, SPSS Inc., Chicago, IL, USA).

RESULTS
Figure 5.1 shows session duration and the internal load measures (session-TL, RPE and mental-exertion) for training drills, simulated match play and tournament play. Furthermore, session duration and internal load measures for tournament matches won vs. lost, and against seeded vs. non-seeded opponents are presented in Figures 5.2 and 5.3, respectively. No significant differences in session-TL were present between session types (p>0.05; d<0.80). However, there was significantly lower session duration evident for training compared to tournament play (p<0.05; d=1.18). Simulated match play durations were similar to both training and tournaments (p>0.05; d<0.80). Large effects indicated a greater session RPE in tournaments than training (p>0.05; d=1.26) and simulated match play (p>0.05; d=1.05). Matches within tournaments that were won were perceived to be of significantly greater RPE than matches lost (p<0.05; d=1.40). Furthermore, large effect sizes suggest a greater mental exertion was perceived during simulated match play and tournaments than training drills (p>0.05; d=1.10, d=0.86 respectively).
**Figure 5.1.** Mean ± SD for training load (A), session duration (B), session RPE (C) and mental exertion (D) between training, match play and tournament play.

* Large effects for lower interaction effect than tournaments (d≥0.8)

# Large effects for lower interaction effect than match play (d≥0.8)

§ Significantly lower interaction effect than tournaments (p<0.05)
Figure 5.2. Mean ± SD for training load (A), session duration (B), session RPE (C) and mental exertion (D) between tournament matches won and lost.

* Large effects for lower interaction effect than tournament matches won (d≥0.80)
§ Significantly lower interaction effect than tournament matches won (p<0.05)
Figure 5.3. Mean ± SD for training load (A), session duration (B), session RPE (C) and mental exertion (D) between tournament matches against seeded and non-seeded opponents.
External loads (i.e., stroke-rate and work/rest durations) and technical outcomes (winners, serves and errors) of drills, simulated match play and tournaments are presented in Table 5.1 (relative to session durations). Stroke-rates (str min\(^{-1}\)) in training were significantly lower than both simulated match play and tournaments (p<0.05; d=0.98 d=3.41 respectively). Tournament stroke-rates were also significantly greater than simulated match play (p<0.05; d=1.22). Within tournaments, stroke-rates were similar in both matches won (13±3.4 str min\(^{-1}\)) and matches lost (16±6.2 str min\(^{-1}\)) (p=0.98; d=0.63), as well as when playing a seeded opponent (17±8.2 str min\(^{-1}\)) compared to non-seeded opponents (13±4.2 str min\(^{-1}\)) (p=0.95; d=0.60). The work-rest durations of simulated match play demonstrated large effects for less work (i.e., time in play) compared to tournament matches (p=0.29; d=1.37), and significantly less rest (i.e., stoppages) in simulated match play than tournaments (p<0.05; d=3.00). Within tournament matches, work-rest durations of matches won (29.6 ± 10.6 mins work; 51.7±16.1 min rest) and lost (27.8±14.3 mins work; 50.2±17.3 mins rest) were similar (p>0.05; d<0.80). Furthermore, there was a large effect observed for greater rest durations during matches against seeded (25.0±11.1 mins work; 44.7±10.4 mins rest) than non-seeded opponents (31.7±14.6 mins work; 54.4±20.3 mins rest) (p>0.05; d=0.85).
### Table 5.1

Mean ± SD of relative external load measures for shot rate (sh/min), winners (w/min), serves (se/min), errors (er/min), work duration (mins), and rest duration (mins).

<table>
<thead>
<tr>
<th></th>
<th>Training</th>
<th>Simulated Match Play</th>
<th>Tournament</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot rate (sh/min)</td>
<td>7 ± 1.0</td>
<td>10 ± 5.1 *</td>
<td>14 ± 3.6 *#</td>
</tr>
<tr>
<td>Winners (w/min)</td>
<td></td>
<td>0.6 ± 0.2</td>
<td>0.5 ± 0.2 §</td>
</tr>
<tr>
<td>Serves (se/min)</td>
<td></td>
<td>2.6 ± 1.3</td>
<td>3.4 ± 0.8 §</td>
</tr>
<tr>
<td>Errors (er/min)</td>
<td>1.0 ± 0.2</td>
<td>1.1 ± 0.4</td>
<td>1.7 ± 0.5 *#^§</td>
</tr>
<tr>
<td>Work Duration (mins)</td>
<td>20 ± 7.0</td>
<td></td>
<td>29 ± 9.8 §</td>
</tr>
<tr>
<td>Rest Duration (mins)</td>
<td>30 ± 8.6</td>
<td></td>
<td>51 ± 11.1#§</td>
</tr>
<tr>
<td>Work : Rest</td>
<td>0.7 : 1</td>
<td></td>
<td>0.6 : 1</td>
</tr>
</tbody>
</table>

* Significantly greater than training external load (p<0.05)

# Significantly greater than simulated match play external load (p<0.05)

^ Large effects for greater external load than training (d≥0.8)

§ Large effects for greater external load than simulated match play (d≥0.8)
In a more detailed analysis of stroke characteristics, the absolute number of winners was similar between both simulated match play and tournament match play (p=0.92; d=0.41). However, relative for duration (Table 5.1), there was a large effect for more winners hit during simulated match play than tournaments (p>0.05; d=0.90). Similarly, there were no differences observed between winners hit during tournament matches won (11±4.9 total; 0.4±0.3 w·min\(^{-1}\)) or lost (13±6.9 total; 0.5±0.3 w·min\(^{-1}\)) (p>0.05; d<0.80). There was also no difference in absolute winners hit during matches played against seeded (12±6.8 total; 0.5±0.3 w·min\(^{-1}\)) and non-seeded opponents (12±5.0 total; 0.5±0.3 w·min\(^{-1}\)) (p>0.05; d<0.80). Absolute and relative serve counts (se·min\(^{-1}\)) of simulated match play (46±12.5 total; 2.6±1.3 se·min\(^{-1}\)) and tournament play (90±16.6 total; 3.4±0.8 se·min\(^{-1}\)) was increased during tournament matches compared to simulated match play (p<0.05, d=4.28; p=0.26, d=1.03 respectively). While, absolute serve volume was similar between matches won (88±15.8 total; 3.2±0.9 se·min\(^{-1}\)) and lost (93±27.4 total; 3.7±1.2 se·min\(^{-1}\)), as well as between seeded opponents (80±13.6 total; 3.6±1.3 se·min\(^{-1}\)) and non-seeded opponents (96±27.5 total; 3.4±1.0 se·min\(^{-1}\)) (p>0.05; d<0.80). Finally, error-rates (er·min\(^{-1}\)) were significantly lower in training drills and simulated match play than in tournament matches (p<0.05; d>1.00), whilst errors were similar between drill sessions and simulated match play (p>0.05; d<0.80). Within tournament matches, there were no significant differences in error-rates (p>0.05; d<0.80) between matches won (1.7±0.6 er·min\(^{-1}\)) and lost (1.8±0.7 er·min\(^{-1}\)), or against seeded (1.7±0.7 er·min\(^{-1}\)) and non-seeded opponents (1.7±0.5 er·min\(^{-1}\)).
DISCUSSION

An important component of the prescription of training loads is to ensure athletes are exposed to match-like demands within training. As with other sports, tennis uses on-court training drills and simulated match play for such preparation, generally alternating training at, or above match intensities. However, currently no literature has concurrently compared the demands of common training drills, simulated match play and tournaments within a homogenous group. Accordingly, the current findings indicate that both session duration and RPE during training tends to be lower than those typical of tournament play. Furthermore, training sessions elicited less mental exertion than both simulated match play and tournaments. From a technical standpoint, tournament stroke-rates exceeded those in training and in simulated match play, whilst greater (relative and absolute) serve loads were observed during tournaments than in simulated match play. A comparison of work–rest durations also revealed simulated match play to be less intensive (i.e., less work, less recovery). It should be noted that within the timeframe of the current data collection there were no injuries reported from the playing group. Consequently, it is clear that the physical and technical TLs of training drills and simulated match play warrant ongoing scrutiny to assist with the prevention of “over-training” or “under-training”, therein ensuring that the long-term consequences of poor training intensity are avoided.

As abovementioned, training drills were selected specifically due to the associated physical demands demonstrated in previous studies. As such, the authors are confident any bias towards technical foci during training was minimized. In any case, the present RPE responses in simulated match play (6±0.9 au) and in tournaments (6±0.8 au) were not dissimilar to previous discrete investigations.
Chapter 5: Comparison of Tennis Training, Match Play and Tournaments

However, simulated and tournament match play RPE exceeded training drill RPE’s (5±0.8 au). Previously, after examination of training sessions, we suggested RPE is greatest in those drills that most closely mimic match “worse case scenarios” or extreme time pressure situations (i.e., recovery/defensive drills; 6.5±1.8 au). To provide clearer context, we have also previously shown that closed technical drills are characterized by low RPE’s (4.6±1.9 au). Prior to these studies, Reid et al. describe discrete, work-rest ratio driven, “conditioning” drills (i.e., suicide, 7.6±1.1 au; and Big X, 7.6±1.0 au) of much greater RPE. As to be expected, it was also found that drill duration (i.e., 30s vs. 60s) was pivotal in the distinction of RPE for drills, a concept relevant to the interpretation of all training drill analyses. Thus, prescription of sessions to mimic tournament demands must not only take into consideration the RPE of drills, but also the duration of drills and work-rest ratios involved.

Notwithstanding the body of work that has reported internal load in competitive match play and invitational tournaments, few researchers have specifically explored the RPE’s of athletes following completion of tournament matches in which international junior or senior ranking points are in dispute. Indeed, the work of Coutts et al. represents a rare investigative foray in this regard, describing the RPE and session-TL of a top-level player from the 2008 Roland Garros. These researchers reported match RPE’s ranging from 5 - 7 (au), with a weekly competition-TL of 2908 (au), ~18% greater than during the final week of tournament preparation (2380 au). However, caution is required in comparing between different developmental stages of players, as many other factors might influence overall perception of effort during elite competition (i.e., prize money, media scrutiny, spectators), potentially increasing the RPE. Further it is unclear to what extent these influences may or may not affect the RPE’s reported in tournaments where rankings are in dispute as compared to other
competition/tournament formats. Nevertheless, in the current study, the RPE’s reported in a developmental training period could be interpreted to reflect a mismatch with tournament demands. As such, care should be taken to ensure that athletes are exposed to match-like physical intensities at some stage within preparatory training blocks.

Despite the abovementioned widespread use of perceptual load monitoring measures in tennis, mental exertion is an area that load monitoring literature has seldom investigated - particularly in tennis. Admittedly, this may be confounded by the validity of the construct, yet its simplicity is instructive within high-performance junior tennis environments. Indeed, within the current investigation it is evident that a discrepancy exists between the perceived mental demands of training, simulated and tournament match play. Both simulated and tournament matches’ required similar perceived mental intensity, which is considerably more than that of training. Previously, we have shown discrepancies between certain drill categories, with drills of greater focus (accuracy drills) and physical intensity (recovery/defensive drills) being characterized by significantly greater mental exertion than closed technical drills. Keeping in mind the current investigation has controlled for intensity of training drills, it can be interpreted that in order for mental exertion to approximate tournament match play, simulated competition or pressures (i.e., targets, time-pressure) must be incorporated in training.

Given that the selection of drills was chosen due to their prominent physical intensity rather than technical focus, the present findings identify a somewhat perplexing disparity between stroke-rates of training sessions (7±1.0 strokes min⁻¹), simulated match play (10±5.1 strokes min⁻¹) and tournament matches (14±3.6 strokes min⁻¹).
Despite similar durations observed between simulated and tournament matches, a reduced amount of work completed in simulated match play compared to tournament matches. This was despite greater rest periods during tournaments - further highlighting a disconnect in the intended training prescription from a physical perspective. The authors admit however, that such disparity may be due to the technical/tactical focus or development during simulated match play (i.e., tactical patterns, or stroke technique) within the corresponding training block. Alternatively, the observed increased winner rate during simulated match play sessions may indicate more aggressive mindsets during these sessions. This is according to the similar ratings of mental exertion perhaps corresponding to alternative pressures during tournament matches (i.e., match outcome/consequences). Nevertheless, with such disparity between simulated match play and tournaments, it is advisable that high-intensity drills be implemented within close proximity to simulated match play to compliment or elevate simulated match play demands. Previously reported tournament demands have been noted to reach 0.81±0.04 strokes/sec\(^{-1}\) for men and 0.76±0.03 strokes/sec\(^{-1}\) for women for matches during the Australian Open in 1997–1999.\(^\text{120}\) Such discrepancies highlight the difference in elite tournament match intensity and that of the current developing player cohort (0.23 strokes sec\(^{-1}\)).

In certain situations, increased error rates within matches may increase match durations, alter the work-rest ratio, and affect the mental state of players.\(^\text{101}\) As such, error rates become of interest to coaches when preparing players for competition demands. The present findings suggest that tournament matches result in greater error rates than both training and simulated match play. The authors postulate that such elevated error rates in simulated match play and tournaments may be due to increases in mental exertion compared to drills. Anxiety of players is perhaps increased in
simulated and competitive situations where opposition or situational pressure (i.e., increased strokes rates, physical demand, or importance of result) hinders an athlete’s ability to perform well. Earlier, descriptive analysis of training drills have identified that drills of technical focus and extreme physical (end range) requirements induced higher error rates. Furthermore, a recent tennis investigation has identified increased somatic and cognitive state anxiety, and lower self-confidence pre-competition on match-day compared to training-day. Moreover, following matches, somatic and cognitive anxiety (with associated with consequence of failure), were still elevated compared to training-days. Therefore, during simulated match and training sessions in which error-ameliorating practice is desired, the effect that both physical and mental exertion have on error rates should be acknowledged. Additionally, to effectively prepare athletes for the mental demands of competition, there appears limited alternative other than through tournament matches. Having acknowledged this however, a limitation of the current investigation is the lack of obtainable context under which matches were played i.e. environmental conditions, opposition, and ranking-points needed/on offer. Further, while it is likely that the currently investigated 10-week period is reflective of training and competition periods at any time throughout the year, the internal and external load responses may differ based upon the timing of these events within a periodised training plan (i.e., pre-season, in-season, taper). Accordingly, it should be acknowledged that other factors, including developmental or recovery focus, might also affect both physical effort and mental perception of the on-court demands, and whether a reduced training intensity is in fact a negative outcome.

Noteworthy is that the above findings are certainly subject to the constraints of individual matches and sessions. Accordingly, a secondary aim was to compare the
technical and perceptual loads of tournament matches won and lost, as well as against seeded and non-seeded opponents. The findings highlight that load of matches won are of greater RPE than matches lost, notwithstanding similar mental perception, and, match durations. Furthermore, similar stroke and work rates in matches lost were apparent. A recent tennis investigation observed greater post match salivary cortisol response and anxiety in losers than winners, while winners reported higher self-confidence. As such, the authors suggest that a final positive (or potentially positive) outcome may provide a buffering effect on the mental stress experienced by junior high-performance athletes. While no other literature has investigated the discrepancies in load between tennis matches won and lost, it is conceivable that developing high performance players are perhaps more “invested” physically for matches where a winning outcome is possible, or perceive matches won as more taxing as they produced a winning performance - despite no difference in external load. Internal load measures comparing seeded and non-seeded matches also found no key differences, however a moderate effect suggests potentially greater mental exertion was required during matches against seeded opponents. Furthermore, stroke-rate, winners and serves indicate limited differences between match types (despite a relatively low sample size). In summary, it appears that neither training drills nor simulated match play equals the duration, perceptual or technical load of tournament matches.
PRACTICAL APPLICATIONS

Current comparison of training drills, simulated and tournament matches reveals that the demands placed on tennis players in (developmental) training are not necessarily of sufficient physical requirement to prepare for tournament match play. Coaches should be aware of reduced internal (RPE) and technical (stroke-rate) demands in training to ensure appropriate stimuli, aiming for preparations to be as similar as possible to competition. Specifically, stroke-rates during tournaments exceeded those observed in training and simulated match play sessions. Additionally, coaches should be mindful that even the most physically demanding training sessions and simulated match play were of lower RPE than tournament matches. With mental exertion in training also lower than both simulated match play and tournaments, it appears that tournament match play is currently difficult to replicate during training. Given the disagreement of internal and external load between training drills, simulated and tournament match play, periodisation of training needs to be clearly driven towards the demands of competition at their stage of development.
CONCLUSIONS

Session durations and RPE during developmental training and simulated match play do not match that of tournament matches. Similarly, mental exertion in training was not comparable to simulated or tournament match play. From a technical standpoint, stroke-rates during tournament matches exceed those of both training and simulated match play, suggesting again that training and simulated match play intensity is mismatched. Furthermore, match specific measures of the serve (relative and absolute) demonstrate greater incidence during tournament matches than simulated match play. Likely due to the increased stroke volume, tournament error rates are also far greater than that of simulated match play, which is greater again than training sessions. Despite greater stroke counts during tournament play, comparison of work – rest durations reveal that simulated match play to be less intensive (i.e., less work, less recovery). Secondary analysis suggests loads of matches won are perceived as requiring greater physical exertion, notwithstanding similar mental perception. Of note, through an attempt to present an ecologically valid and concurrent comparison between training and competition, our analysis was limited to a small cohort of players and a host of uncontrolled external influences - the interaction of which might be more closely examined in future research. Nonetheless, it appears that both training drills and simulated match play do not match the perceptual or external TLs of tournament matches. Coaches should be aware of the disparity in load throughout developmental training blocks and aim to adequately prepare athletes for tournament requirements.
CHAPTER SIX

The relationship of training load to physical capacity changes during international tours in elite-oriented junior tennis players

As based on a publication:

Chapter 6: Fitness Changes After 4-Week Tennis Tours

ABSTRACT

Given the travel that punctuates junior tennis development, an understanding of the changes in fitness owing to touring and the association between load and fitness upon return, is vital. This study investigated physical capacity changes from pre to post tour, determining if those changes were related to the load of athletes on tour. Thirty junior athletes completed fitness testing prior to and following 4-week tours. Testing included; double-leg countermovement jump (CMJ-DL), dominant single-leg (CMJ-DOM) and non-dominant single-leg (CMJ-NON), speed (5-, 10-, 20-m), modified 5-0-5 agility (left and right), 10×20-m RSA, and multistage fitness tests. Repeated-measures ANOVA’s determined physical capacity change, with effect-size analysis establishing the magnitude of change. To avoid regression towards the mean, a 1/3 split technique was implemented for comparative analysis (high-low load). Moderate effects (d=0.50-0.70) for reductions of up to 3.6% in 5-, 10-, and 20-m speeds were observed. However, all remaining changes were only of trivial-small magnitude (d<0.40). Closer analysis of the interaction between load and physical capacities (1/3-split) observed that subjects who completed the greatest amount of total and tennis load returned with a greater decline in speed and aerobic capacities (d>0.80). Further, it was observed that match-load dictates on and off-court training load, with an increase in matches won understandably stunting exposure to off-court training load. Specific training should be prescribed on-tour to maintain speed characteristics over a 4-week international tour. On-tour training schedules should be carefully monitored to maximize specific training load exposure following losses on-tour.
Chapter 6: Fitness Changes After 4-Week Tennis Tours

INTRODUCTION

Elite tennis players travel extensively for tennis tournament play in order to gain/maintain ranking points.\textsuperscript{14,94} Owing to a lack of access to appropriate facilities, coaches and professional support associated with such travel, training exposure can become somewhat limited.\textsuperscript{190} Further, the loads acquired on-tour is highly variable as a result of the unpredictable nature of tournament scheduling, opposition draw and match results, possibly leading to physiological maladaptation.\textsuperscript{94} This potential deficit in load may in turn lead to post-tour reductions in physical capacities. Kovacs et al.\textsuperscript{190} have previously shown that an extended, unsupervised time away from coach and support facilities leads to declines in a range of physical capacities. Specifically, a 5-week period of unsupervised training among college players resulted in significant reductions in speed, power and aerobic capacity.\textsuperscript{190} Although training load was not reported, subjects completed significantly lower training volume than in-season (10 h tennis and 3.5 h gym per week).\textsuperscript{190} Therefore, suggesting that the training load whilst away from training bases for extended periods (i.e., on tour) may alter training stimuli, and suppress physical capacities.

The demands of tennis tournaments (i.e., volume and intensity of physical load) vary depending on the number of matches won and type of matches (i.e., qualifying, main-draw, doubles).\textsuperscript{314} Subsequently, load management is dependent on the number of days between matches or tournaments, associated travel to tournaments, and the recovery of the athlete (i.e., injury or soreness).\textsuperscript{94,106} Previously, it has been reported that as players compete in a large number of matches, they may accrue certain fitness benefit, or more likely limit physiological detraining.\textsuperscript{106} However on junior developmental tours, athletes generally travel in larger groups and therefore cannot
simply leave one tournament venue for the next tournament until the entire tour group can be accommodated. As such, coaches provide supplementary training for losing athletes to reduce the magnitude of physiological decrements when matches no longer provide a physical stimulus. Furthermore, individual athlete training dispositions will vary depending on tour success. Whilst care is taken to ensure athletes are in peak condition prior to tour departure, there is a lack of information available to coaches highlighting which physiological capacities are best maintained and how loads and post-tour fitness interact.

To understand post-tour fitness states, coaches use physical capacity testing batteries as quantifiable measures of changes in physical capacities over time. Kovacs et al. have identified key physiological variables for fitness testing of developing tennis players including speed, agility, strength, muscular endurance, anaerobic power, aerobic capacity and flexibility. Whilst tennis is not afforded the same luxury as other sports in terms of rigid seasonal competitive structures, numerous team and individual sports (i.e., hockey, volleyball, basketball and swimming) have investigated the seasonal changes to certain physical capacities. Endurance capacities such as maximal oxygen consumption (VO2MAX) appear to be easily maintained throughout competitive hockey, volleyball and swimming seasons, given the predominantly aerobic demands typical of competition. However, lower body power in elite volleyball and basketball athletes (i.e., leg extension, 30 s mean jump power, and vertical jump) is reported to reduce following completion of their respective seasons. Thus highlighting the potential regression of physical capacities during competitive seasons or tennis tour schedules. That said, it is recognized many of these physical capacity tests do not directly inform about tennis performance, rather the physical capacities that may be relevant to tennis.
To date, there is a lack of empirical evidence describing changes in athlete physical capacities following tennis tours or even a description of the type and role of load on those changes in physical capacities. As such, the present study aimed to investigate the change in physical capacity and the association with certain amounts and types of load of elite junior tennis athletes whilst on an international tour. Specifically, we aimed to describe changes from pre to post-tour and to determine if changes in physical capacities were related to load. Due to potential regression of fitness changes towards the mean, additional analysis implemented a 1/3 split technique to critique mean data of the most positive and negative changes for the respective physical capacity measures. We hypothesized that physical capacities would decline post-tour, with lower strength (resistance based exercise) and conditioning (energy system derived) (S&C) training load and higher match-load related to a reduction in physical capacities.

**METHODS**

**Subjects**
Thirty high-performance, junior tennis players (age: 17±1.3y, matches/year: 135±22, ITF junior ranking: 157±112, ATP ranking: 1309±370, WTA ranking: 792±41) representing Australia at junior ITF events were recruited. The cohort consisted of 20 males (mass: 66.9±8.6 kg, stature: 176.7±6.0 cm) and 10 females (mass: 60.5±5.5 kg, stature: 170.2±3.8 cm). Subjects within the current cohort routinely complete 2-3 training sessions per day. Specifically, training weeks often include 11 on-court sessions (~120 min), 3 strength sessions (~60 min), and 2 conditioning sessions (~45 min). On-court and off-court sessions are designed by coaches to address the specific priorities of each athlete. However, strength sessions will involve free weight exercises, while conditioning sessions typically will involve high-intensity interval
training (HIT). All subjects were given verbal and written description of all procedures and aims of the project. All subjects and parents provided written informed consent to the study and a University Human Ethics Review Committee approved the investigation.

**Research Design**
The current study examined the loads and physical capacity changes associated with 4-week international tours (junior ITF) on elite developing tennis players. Subjects were chosen after selection onto a Tennis Australia international tour across three different 28-day tours (13.0±4.5 matches across each tour). The current tour durations and match requirements represented typical tours for the study cohort, and were scheduled by the assigned coaches. Tour one involved travel to: New Zealand (~3.5 h travel), tour two: Thailand, Malaysia and Philippines (~10 h travel), tour three: Japan and Korea (~10.5 h travel) with each tournament played on hard (acrylic). Two days prior to and within two days following the tour (allowing sufficient recovery from match and travel accumulated fatigue), subjects completed physical capacity testing protocols. Testing protocols were designed by Tennis Australia and each athlete had prior familiarity with all procedures. Warm-up and testing procedures were standardized with the following order observed: double-leg (CMJ-DL), dominant single-leg (CMJ-DOM) and non-dominant single-leg (CMJ-NON) countermovement jump (CMJ), speed (5-, 10-, 20-m), 5-0-5 agility (left and right), 10x20-m RSA, and the multistage test (Tennis Australia Fitness Protocols). All physical activity, fluid, and food intake 24h prior to testing were standardized and replicated post-tour.
Measures
Counter movement jump- double, dominant, and non-dominant leg
A CMJ protocol was used to determine lower body power through peak height in
vertical displacement using a yard-stick (Vertec) jumping device with multiple vanes
distanced 1cm apart (Vertec, SWIFT Performance Equipment, Lismore, Australia). The test was carried out firstly with double-leg, then on both dominant and non-dominant single-leg. Subjects stood directly beneath the measuring vanes, prior to jumping subjects were also encouraged to execute a countermovement immediately before upward propulsion and were permitted to utilize upward arm swing. For each jump, athletes displace the vane at its maximum height (nearest 1cm). Subjects completed 3 trials with the best recorded for each protocol. The ICC of CMJ-DL, CMJ-DOM and CMJ-NON was 0.96. The technical error (TE) of CMJ-DL was 1.0cm, while the TE of both CMJ-DOM and CMJ-NON was 2.0cm.

Speed- 5, 10, 20m sprints
Dual-beam, electronic timing gates were used to concurrently measure near-maximal 5-m, 10-m and 20-m sprints over 20-m. Four gates were aligned and synchronised at 0-m (start), 5-m, 10-m and 20-m. The subjects started in their own time, sprinting with maximal effort without a racquet. Three trials were completed with the best time for each distance, detailed to the nearest 0.01 sec via telemetry to a computer (Speedlight, SWIFT Performance Equipment, Lismore, Australia). The ICC of the 5-, 10-, and 20-m sprints were 0.84, 0.87, and 0.96 respectively. The TE of each sprint distance (5-, 10-, and 20-m) was 0.06 s.
Agility- Modified 5-0-5 left and right
Agility was measured using a modified version (stationary start) of the 5-0-5 agility test.\textsuperscript{229,322,324} One set of dual-beam electronic timing gates were used to determine athlete’s ability to perform a single, rapid 180-degree change of direction over 5m. The subjects started in their own time, sprinting with maximal effort without a racquet. Three trials pivoting on both left and right foot were completed, with the respective best times recorded to the nearest 0.01 sec (Speedlight, SWIFT Performance Equipment, Lismore, Australia). The ICC and TE of both left and right 5-0-5 agility was 0.92 and 0.05 s respectively.

Multistage fitness test
The multistage test was used to determine aerobic power using previously cited protocols.\textsuperscript{322,325} Subjects performed continuous interval running over 20m indicated by a compact disc (Australian Sports Commission, Canberra, Australia) emitting a bleep to commence each shuttle, increasing speed by 0.5km h\textsuperscript{-1} every 2 min. Athletes were required to place one foot behind the 20-m marks at the sound of each bleep. Subjects failing to reach the distance were given a warning and eliminated from the test following subsequent failures. The level-shuttle immediately preceding the eliminating bleep was recorded and converted into a decimal number. The ICC was 0.90, while the TE (reported as a decimal) was 0.5.
Repeat sprint ability test
The 10×20-m RSA test protocol was used to evaluate the capacity to maintain maximum acceleration and speed across multiple efforts.\textsuperscript{214,322} Athletes sprinted the 20-m distance, with maximal effort, every 20 seconds for 10 consecutive times. Subjects started each subsequent 20-m repetition from where they finished the preceding repetition. All times were recorded to the nearest 0.01 sec via telemetry to a computer (Speedlight, SWIFT Performance Equipment, Lismore, Australia), summed for total time. The ICC was 0.86, while the TE of the RSA test total time was 0.61 s.

Load-monitoring
On tour subjects took part in training (outside of matches), as prescribed by tour coaches, meaning researchers did not alter, nor request coaches to alter training session in any way for the purpose of the investigation i.e., prescription was lead purely by coaches. The session-TL of all on and off-court sessions were recorded using methods described by Foster et al.,\textsuperscript{49} multiplying session RPE by duration. Session-TL’s (au) were calculated for total (all sessions), total on-court (i.e., all tennis related sessions, including matches), total off-court (i.e., all S&C training sessions), singles matches, doubles matches, tennis training, strength training and conditioning sessions. RPE was obtained 30 min after all sessions.\textsuperscript{308} Tournament outcome data (matches won/lost) was collated upon tour return.

Statistical analysis
Results are presented as means ± standard deviations (SD) unless otherwise stated. Comparisons between physical capacity test results were performed using repeat-measures ANOVA (measure × time). Significance was set at $p \leq 0.05$. Cohen’s $d$ effect size analysis established the magnitude of detraining effect pre to post-tour. Values $<0.20$, 0.20-0.40, 0.40-0.70, and $>0.80$ were considered trivial, small, moderate and
large effects respectively.\textsuperscript{326} Further, 90% CI and percentage change determined the magnitude of change.\textsuperscript{327} To avoid potential regression of physical capacity testing results towards the mean, a 1/3 split technique was implemented, whereby the cohort was divided into three groups based on load.\textsuperscript{328} The top and bottom-1/3 were then analysed using an ANOVA (group × load type) and effect size analysis to closer investigate the impact of load on post-tour fitness status. Pearson correlation coefficients determined the association between load and physical capacity, as well as match outcome and changes in physical capacity. ANOVA, and Pearson’s correlation were performed using SPSS (version 20, Chicago, USA).

RESULTS

Table 6.1 summarizes the mean (±SD) values of pre and post-tour testing, alongside the change in physical capacities (\%, ± 90% confidence limits) and magnitude of that change (effect size, \( d \)). Speed testing demonstrated non-significant, moderate effects for a decline in 5-m (3.6±0.6\%), 10-m (3.3±0.6\%) and 20-m (2.2±0.6\%) performance post-tour (\( d=0.70, 0.61, 0.51 \) respectively; \( p>0.05 \)). CMJ-DL (\( d=0.18; p>0.05 \)) and CMJ-NON (\( d=0.13; p>0.05 \)), and CMJ-DOM (\( d=0.21; p>0.05 \)) also demonstrated non-significant trivial-small changes in jump height pre to post-tour (CMJ-DL, -2.0±0.7\%; CMJ-NON, -1.8±0.5\%; and CMJ-DOM, -1.8±0.6\%; \( p>0.05 \)). Similarly, the magnitude of change in 5-0-5 agility post-tour was small and non-significant, with slower 505-Left (1.5±0.6\%) and 505-Right (0.9±0.7\%) test times (\( d=0.41 \) and 0.26 respectively; \( p>0.05 \)). Post-tour comparison of the multistage and RSA tests also observed non-significant detriments of small magnitude (\( d=0.23, -1.9±0.5\%; d=0.30, 1.4±0.6\% \) respectively; \( p>0.05 \)).
Table 6.1. Mean ± SD of pre and post tour results for physical capacity test measures of double leg countermovement (CMJ-DL), non-dominant (CMJ-NON) and dominant (CMJ-DOM), 5-, 10- and 20-m sprint, left and right 5-0-5 agility, 20-m multistage test, and 10 × 20m repeat sprint ability (RSA). Together with the change in testing results pre – post tour (%, ± 90% confidence limits) and the magnitude of that change (effect size).

<table>
<thead>
<tr>
<th>Measure</th>
<th>SWC (%)</th>
<th>Pre Tour</th>
<th>Post Tour</th>
<th>% Change</th>
<th>Effect Size</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ-DL (cm)</td>
<td>1.43</td>
<td>48.7 ± 8.5</td>
<td>47.7 ± 8.2</td>
<td>-2.0 ± 0.7</td>
<td>0.18</td>
<td>Trivial</td>
</tr>
<tr>
<td>CMJ-NON (cm)</td>
<td>1.18</td>
<td>36.6 ± 8.2</td>
<td>35.9 ± 8.1</td>
<td>-1.8 ± 0.5</td>
<td>0.13</td>
<td>Trivial</td>
</tr>
<tr>
<td>CMJ-DOM (cm)</td>
<td>1.21</td>
<td>36.7 ± 8.2</td>
<td>35.5 ± 8.7</td>
<td>-1.8 ± 0.6</td>
<td>0.21</td>
<td>Small</td>
</tr>
<tr>
<td>5-m Sprint (s)</td>
<td>0.01</td>
<td>1.13 ± 0.08</td>
<td>1.17 ± 0.08</td>
<td>3.6 ± 0.6</td>
<td>-0.70</td>
<td>Moderate</td>
</tr>
<tr>
<td>10-m Sprint (s)</td>
<td>0.02</td>
<td>1.92 ± 0.14</td>
<td>1.98 ± 0.13</td>
<td>3.3 ± 0.6</td>
<td>-0.61</td>
<td>Moderate</td>
</tr>
<tr>
<td>20-m Sprint (s)</td>
<td>0.04</td>
<td>3.30 ± 0.20</td>
<td>3.37 ± 0.20</td>
<td>2.2 ± 0.6</td>
<td>-0.51</td>
<td>Moderate</td>
</tr>
<tr>
<td>505 Left (s)</td>
<td>0.03</td>
<td>2.68 ± 0.13</td>
<td>2.72 ± 0.12</td>
<td>1.5 ± 0.6</td>
<td>-0.41</td>
<td>Small</td>
</tr>
<tr>
<td>505 Right (s)</td>
<td>0.04</td>
<td>2.68 ± 0.13</td>
<td>2.71 ± 0.13</td>
<td>0.9 ± 0.7</td>
<td>-0.26</td>
<td>Small</td>
</tr>
<tr>
<td>20-m Shuttle Test</td>
<td>0.24</td>
<td>12.8 ± 1.5</td>
<td>12.6 ± 1.5</td>
<td>-1.9 ± 0.5</td>
<td>0.23</td>
<td>Small</td>
</tr>
<tr>
<td>10 × 20m RSA (s)</td>
<td>0.37</td>
<td>34.66 ± 2.27</td>
<td>35.15 ± 2.42</td>
<td>1.4 ± 0.6</td>
<td>-0.30</td>
<td>Small</td>
</tr>
</tbody>
</table>

Note: Magnitudes of effect sizes are assessed using the following criteria: <0.2 = trivial, 0.2-0.49 = small, 0.5-0.79 = moderate, >0.8 = large. SWC = smallest worthwhile performance change (calculated as 0.2 × between-participant SD).
Highest and lowest tour loads (1/3 split; n=10 each) are compared in Table 6.2. Speed analysis determined that subjects in the top 1/3 for total load returned with significantly greater detriment, (d>0.80; p<0.05) in 10-m and 20-m times. Furthermore, non-significant, large effects (d>0.80; p>0.05) for reduced 10-m and 20-m speeds were also evident for those who completed greater tennis load. There were also non-significant, large effects observed (d>0.80; p>0.05) for detriments to multistage and RSA results when total and tennis load was in the highest 1/3, as well as for detriments in multistage and CMJ-NON in the highest 1/3 for match-load. Contrastingly, non-significant, large effects were evident for greater decline in CMJ-DL, CMJ-DOM, 5-0-5 agility (left and right) and RSA in those subjects completing the least on-court load (d>0.80; p>0.05). Finally, although non-significant, those completing greater S&C training load suffered greater detriment in 5-m sprint and RSA (d>0.80; p>0.05), whilst those who completed less S&C training load returned with poorer CMJ-DOM results (d>0.80; p>0.05).

Correlations comparing changes in physical capacity with load (Figure 6.1) identified moderate positive relationships between total tennis load completed on-tour and reduced 10-m and 20-m sprint performance (r=0.45 and 0.52 respectively). Further, a moderate negative relationship between total tennis load and the change in multistage test was observed (r=-0.44). Figure 6.2 reveals that the number of singles matches won was highly correlated with match-load (r=0.70), while slight negative associations were observed between the number of singles matches won and total off-court (r=-0.23), strength (r=-0.25), and doubles load (r=-0.25). Finally, slight positive relationships were present between the number of matches lost and total off-court (r=0.25) and conditioning training load (r=0.29), whilst there was a slight negative relationship between the number of matches lost and tennis load completed (r=-0.26).
### Table 6.2. Mean ± SD of % change physical capacities pre-post tour in double leg (CMJ-DL), non-dominant (CMJ-NON), and dominant countermovement jump (CMJ-DOM), 5-, 10- and 20-m sprint, left and right 5-0-5 agility, 20m multistage test, and 10 × 20-m repeat sprint ability (RSA) for top and bottom 1/3 athletes dependent on load.

Note, that a negative % change shows detriments to physical capacities for all measures.

<table>
<thead>
<tr>
<th>Total Load</th>
<th>Load (mean±SD)</th>
<th>CMJ-DL (%±SD)</th>
<th>CMJ-NON (%±SD)</th>
<th>CMJ-DOM (%±SD)</th>
<th>5-m (%±SD)</th>
<th>10-m (%±SD)</th>
<th>20-m (%±SD)</th>
<th>5-0-5 Left (%±SD)</th>
<th>5-0-5 Right (%±SD)</th>
<th>Multistage (%±SD)</th>
<th>RSA (%±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top 1/3</td>
<td>860 ± 50*#</td>
<td>-3 ± 5</td>
<td>-1 ± 6</td>
<td>-4 ± 6</td>
<td>-6.09 ± 3.41*</td>
<td>-7.69 ± 10.88*#</td>
<td>-4.44 ± 4.79*#</td>
<td>-1.88 ± 3.59</td>
<td>-0.38 ± 2.63</td>
<td>-3.46 ± 1.93*</td>
<td>-2.84 ± 2.82*</td>
</tr>
<tr>
<td>Bottom 1/3</td>
<td>544 ± 68</td>
<td>-3 ± 4</td>
<td>-2 ± 7</td>
<td>-4 ± 5</td>
<td>-2.48 ± 5.11</td>
<td>-0.48 ± 3.04</td>
<td>-0.18 ± 3.04</td>
<td>0.02 ± 3.61</td>
<td>0.80 ± 3.54</td>
<td>-0.84 ± 6.10</td>
<td>-0.82 ± 1.93</td>
</tr>
</tbody>
</table>

| Tennis Load (Match and on-court) | | | | | | | | | |
| Top 1/3    | 740 ± 30*#     | -2 ± 6         | -1 ± 6         | -4 ± 5         | -5.51 ± 3.79   | -7.14 ± 11.22* | -4.23 ± 4.89* | -2.56 ± 2.85 | -0.99 ± 1.53 | -3.39 ± 1.99* | -2.66 ± 3.04* |
| Bottom 1/3 | 461 ± 66       | -2 ± 4         | 2 ± 10         | -3 ± 5         | -3.36 ± 6.07   | -0.50 ± 2.48   | -0.43 ± 3.45 | -1.42 ± 5.73 | -1.18 ± 3.75 | -0.16 ± 6.06 | -1.16 ± 2.33 |

| Match-load | | | | | | | | | |
| Top 1/3    | 284 ± 38*#     | -2 ± 6         | -6 ± 8*        | -5 ± 10        | -2.59 ± 2.90   | -1.82 ± 2.23   | -2.59 ± 2.53 | -0.98 ± 2.32 | -0.57 ± 2.70 | -3.42 ± 2.11* | -1.26 ± 2.36 |
| Bottom 1/3 | 140 ± 22       | -2 ± 4         | 0 ± 6          | -1 ± 3         | -3.40 ± 6.00   | -4.22 ± 11.88  | -1.31 ± 5.65 | -1.91 ± 6.17 | 0.36 ± 4.03  | -0.18 ± 4.91 | -1.56 ± 3.11 |

| On Court Load (Exclusive of match-load) | | | | | | | | | |
| Top 1/3    | 302 ± 73*#     | 0 ± 6          | 0 ± 9          | -1 ± 4         | -4.25 ± 3.96   | -3.02 ± 1.67   | -2.93 ± 2.67 | -1.00 ± 2.64 | -0.30 ± 3.93 | -2.94 ± 4.28 | -0.61 ± 2.13 |
| Bottom 1/3 | 75 ± 18        | -3 ± 3*        | -1 ± 7         | -4 ± 5*        | -3.92 ± 2.27   | -3.34 ± 3.46   | -2.73 ± 2.01 | -2.95 ± 3.96* | -1.89 ± 1.28* | -2.21 ± 1.50 | -2.10 ± 2.19* |

| S&C Load   | | | | | | | | | |
| Top 1/3    | 151 ± 18*#     | -3 ± 4         | 2 ± 10         | -2 ± 4         | -6.38 ± 4.04*  | -3.40 ± 3.66   | -2.11 ± 2.23 | -1.49 ± 5.31 | -0.98 ± 2.78 | -1.86 ± 2.45 | -2.43 ± 2.06* |
| Bottom 1/3 | 54 ± 13        | -1 ± 6         | -4 ± 5*        | -2 ± 5         | -2.36 ± 5.66   | -4.27 ± 11.91  | -2.69 ± 6.03 | -1.53 ± 4.17 | 0.03 ± 3.23 | -1.21 ± 6.58 | -0.81 ± 2.91 |

* Large effect size for greater detriments post-tour in test measures between top and bottom 1/3 athletes (d>0.8)
# Significantly greater detriments post-tour in test measures between top and bottom 1/3 athletes (p<0.05)
Figure 6.1. Correlations between match, tennis, and off-court load whilst on tour and the change in physical capacity tests of double (CMJ-DL), non-dominant (CMJ-NON) and dominant (CMJ-DOM) countermovement jump; 5-, 10-, 20-m sprint; left and right 5-0-5 (5-0-5-L, 5-0-5-R); Multistage test; and 10 × 20-m repeat sprint ability (RSA).
Figure 6.2. Correlations of singles matches won and lost, with total load, total tennis load, total off-court load, match load, on-court load, doubles load, strength load, and conditioning load.
DISCUSSION

International tennis tours place athletes in unpredictable training and competition surrounds. Intensive travel, restricted access to facilities, and lack of professional support all result during overseas tennis tours, and can jeopardize training and match preparation, as part of long-term athlete development. Hence, the aim of this investigation was to determine whether physical capacities were affected following 4-week tours. A secondary aim was to determine whether changes in physical capacities were related to tour training and match-loads. Current findings highlight moderate effects for reductions of up to 3.6% in speed characteristics. However, all remaining changes in testing measures were of only trivial-small magnitudes. Moderate, positive correlations were evident between tennis load completed on-tour and deterioration in 10-m, 20-m and multistage test performance. The impact of on-tour load was further analysed using a 1/3 split technique, with subjects completing more total and tennis load returning poorer speed, aerobic and anaerobic test results. Finally, the number of matches won shared high, positive correlations with match-load, whilst the number of singles matches won slightly and negatively correlated with off-court training load. Unexpectedly, slight, positive relationships were present between matches lost and total off-court training load. Such findings highlight the unique effect tours can have on physical capacities and by virtue, the importance of appropriate physical training foci whilst on-tour.

Post-tour testing demonstrated increased (i.e., slower) 5-, 10-, and 20-m times. Subsequent analysis (1/3 split) demonstrated slower sprint results (10- and 20-m) among subjects whom completed greater total and tennis load; however, subjects completing greater S&C training load returned with poorer 5m results. Such
detriments to speed may be a consequence of a lack of specific training i.e., limited short-duration, maximal sprint-training, as well as the impact of concurrent strength training resulting in regression of acceleration characteristics. Previously, in an acute tennis study that investigated the effect of 3 consecutive days of competitive play on indoor hard court (Greenset comfort), there was no change in pre to post 5m-sprint time. As such, one tournament seems too short to elicit overt reduction in peak speed, with such acute tournament durations and loads being insufficient to elicit maladaptation. Conversely, Kovacs et al. demonstrated that following 5-weeks of unsupervised (yet prescribed training period) 5-, 10-, and 20-m times were all slower post-break. The discrepancy may describe a time effect, in that longer periods without sufficient training stimuli (i.e., high-speed running) can result in the detriments noted in the current study. Kovacs et al. suggest that because tennis points are generally 4-7 sec, detraining in speed qualities could be detrimental to match performance. However, given the fact that most tennis movements are within a 3constituents to 4m radius, there is rarely a chance for tennis players to reach maximum speed, and when extended movements (>4m) do occur, immediate deceleration follows. Furthermore, due to the court size, subjects who completed greater tennis load (therefore less S&C load) are seldom exposed such sprint distances (>10m). These results suggest continued match play may not provide enough training stimulus for extended sprint speeds, and when match play dominates over training for extended periods, speed capacities can suffer. Or rather, this may question the validity of 10-and 20-m sprint measures for tennis, as extended periods of competition load negatively affects these measures. Moreover, while 5m sprint times deteriorated greatest in those subjects completing greater total load, this decline may relate to increased S&C load, rather than tennis load; highlighting the likely correspondence
between on-court demands and shorter distance tests (5-m and 5-0-5 agility). Such limited exposure to peak velocity movements, and increased eccentric loading provide rationale for reduction in speed qualities (>10m), while agility and lower body power measures were maintained.

Despite the aforementioned reduction in linear speed, there were limited changes in 5-0-5 agility; although, 1/3-split analysis noted greater detriment in those completing the least on-court load. Kovacs et al.\textsuperscript{190} also failed to find any change in agility (spider-agility test) among players returning from an unsupervised college break. The spider-agility test differs in duration (16-18 s) to the 5-0-5 agility test (2-3 s) which closer resembles the duration and movement intensity of an acute end-range stroke and mid-court recovery (2-4 s).\textsuperscript{92} The lack of reduction in 5-0-5 agility noted here may be explained by the specificity of movement and energy system demands (i.e., movement patterns specific to baseline shuttles). For example, the similarity between the 5-0-5 movement pattern to typical movements in tennis training and match play may result in a sufficient training stimulus. As the current 1/3 split analysis further highlights, those completing less on-court load suffered greater decline in 5-0-5 agility, which can be interpreted to further reinforce the importance of load continuation following tournament exit, with on-court and eccentric loading demands crucial to agility maintenance.

There were no reductions in any lower body power tests following tours, suggesting power can be maintained throughout a 4-week tour. Subjects who completed the least on-court load suffered the greatest decline in CMJ-DL and CMJ-DOM. However, CMJ-NON was of greatest decrement for those subjects who completed greater match-load, whilst the same was observed with a reduction in S&C training load. The
interaction between lower-body power, match loads and total load may be due to incidental increases in muscular recruitment for the non-dominant leg given the repeated eccentric loading of the landing foot during the serve.\textsuperscript{330} Kovacs et al.\textsuperscript{190} investigated changes to lower-body power using standing long jump (SLJ). Although SLJ measures maximal power in a horizontal plane, no changes occurred following the 5-week unsupervised break.\textsuperscript{190} Previously, Ojala & Häkkinen\textsuperscript{94} found no changes to CMJ or 5-jump tests following 3 days of consecutive match play. The current investigation was sampled from a much greater duration than Ojala & Häkkinen\textsuperscript{94} (4-weeks), and as yet no literature currently reports post-tournament changes in tennis-related physical capacities. Presently, it seems that the loads associated with a 4-week international tennis tour are sufficient to maintain CMJ. Although, it is important that coaches ensure on exiting a tournament that players maintain on-court training loads to avoid declines in CMJ-DL and CMJ-DOM.

Post-tour comparison of aerobic and RSA capacities observed no changes following international tours. However, the split technique identified that those who completed the greatest total and tennis load had a larger reduction of both aerobic and RSA. Furthermore, greater aerobic fitness reductions occurred in those completing greater match-load. Kovacs et al.\textsuperscript{190} reported significant reductions to $\text{VO}_{2\text{MAX}}$ (11\%) and Wingate anaerobic fatigue index (7.15\%) following a 5-week break from supervised training. Such changes, for aerobic capacity in particular, have been previously reported in detraining literature, and have been attributed to reductions in blood volume.\textsuperscript{190,331} Furthermore, other reports describe that load reductions often result in a rapid decline in $\text{VO}_{2\text{MAX}}$ for highly trained athletes.\textsuperscript{190,332} Such findings may prove true for conventional detraining studies; however, in the present investigation, there was no cessation of load - instead loads were largely dependent on match outcome.
Chapter 6: Fitness Changes After 4-Week Tennis Tours

As such, the present data suggests that match-load’s are sufficient for sustaining endurance capacities. However, the negative relationship between total tennis load and aerobic test performance, suggest that an increase in match-load (i.e., resulting in increased total tennis load and decreased time available for conditioning training load) has the potential to interfere with the maintenance of aerobic capacities.

Clearly, the amount and type of load completed on tour during and between tournaments, contributes to the associated changes in physical capacity characteristics. Nevertheless, match loads (i.e., as dictated by the number of matches won and lost) affects the amount of match-load completed and subsequent weekly and total load. As expected, the present findings reveal a strong relationship between matches won and match-load. Correspondingly, there were trends for reduced off-court load completed as players won more matches. Such findings may be an artefact of player preparation, as coaching staff structure physical preparation toward a maintenance focus whilst athletes are winning matches (i.e., reduced volume). However, upon exit from a tournament, following appropriate recovery, off-court training becomes priority, as demonstrated by the positive relationship between matches lost and off-court training load. Alternatively, despite the mandatory 2 d recovery period following return from tour, it remains possible that any reduction in performance post-tour may be related to an accumulation of fatigue across the tour. Due to supervisory obligation, exited junior athletes must remain with the tour, and therefore strategies should be put in place to ensure maintenance of load, deterring physical capacity regression – particularly for speed characteristics as previously highlighted.
Chapter 6: Fitness Changes After 4-Week Tennis Tours

PRACTICAL APPLICATIONS

With extensive travel a necessity for professional tennis players, junior elite programs attempt to prepare promising athletes through international tours. An understanding of the loads associated with such tours and the impact tours have on physical capacity characteristics therefore becomes vital. Current findings reveal speed reductions, with no detrimental effect on agility, lower body power, or aerobic and anaerobic capacities. The present study further highlights the importance of speed-training exposures over a 4-week international tour, especially when match loads are high. Further, it was observed that match-load dictates on- and off-court training load, with an increase in matches won stunting exposure to off-court training load. Acknowledgement of reduced off-court training loads completed with greater match success will allow coaches to either alter training priorities on tour, or plan appropriate training sessions upon return, specifically targeting training to maintain speed characteristics. More research in this area is needed to describe typical loads completed pre-tour and investigate the appropriateness of tapers and evaluate stages of overreaching immediately prior to tour departure.
CONCLUSIONS

This investigation is the first to describe and compare the physical capacity changes, loads and performance outcomes associated with a 4-week international tennis tour. Results indicate reductions in 5, 10, and 20m sprints. Furthermore, observed relationships between tennis-load completed on-tour and 10m, 20m sprints and multistage test. Finally, correlations of load and match outcome also revealed match and off-court training load to be heavily dependent on matches won and lost. That said, some limitations of this study should be acknowledged. Training loads experienced on-tour were highly reliant on match outcome, each tour may represent a different training response. Tour length was also dictated by coaching staff, as such, it is possible that a longer tour length may produce different physiological changes than observed here. Moreover, owing to the consistent trade off between subject calibre and number - commonly leaving researchers of elite athletes to resort to case studies - analyses involved combined male and female data. Additionally, the authors also felt that due to the nature of the test-retest analysis of the exact same cohort, and within-individual delineation (i.e., 1/3 split), the analysis would provide practically relevant findings for the type of high-performance environments in which the subjects were recruited from (i.e., identical training programs across genders). Finally, the lack of flexibility in the testing protocols as prescribed by Tennis Australia means that there was some restriction from including strength testing protocols due to the high eccentric loads associated with the maximal testing protocols inherent of the national body. We would envisage strength testing in future research would provide a clearer picture of the musculoskeletal changes associated with tennis tours. Seemingly however, there is potential for speed and aerobic characteristics to decline throughout international tennis tours. As such, information on specific relationships between
match outcome and load is important to recognize trends of reduced load or decline in physical capacities, to employ a targeted training focus in subsequent periodisation. Such findings emphasize the effect tours can have on fitness characteristics, and in turn, long-term athlete development.
CHAPTER SEVEN

The effect of pre-departure training loads on post-tour physical capacities in high performance junior tennis players

As based on a publication:
Chapter 7: Impact of Tour Preparation on Physical Capacities

ABSTRACT

Difficulties in preserving physical capacities whilst on tennis tours necessitate targeted training prescription. This study analysed training and match loads performed prior to and on tour for their relationship with post-tour physical capacity changes. A secondary aim was to determine whether the presence of an S&C coach affected the type and volume of on-tour training load. The training and match loads of 30 high-performance junior tennis players were recorded over 8-weeks: 4-weeks prior and 4-weeks during an international tour. Fitness tests were conducted pre- and post-tour, including: double and single-leg counter-movement jump (CMJ-DL;DOM;NON), speed (5-, 10-, 20-m), modified 5-0-5 agility, 10×20-m RSA, and multistage fitness tests. Tour training and match loads were categorized according to whether S&C support was present of absent. Total and tennis training loads were significantly greater on-tour than pre-tour (p≤0.05; d>0.8). Increases in on-tour, on-court training loads were moderately correlated with decrements in speed and aerobic power (r=0.31–0.52). Finally, S&C presence on-tour significantly increased total, on-court and off-court training load completed (p≤0.05; d>0.8). While speed and aerobic capacities may regress with increased training on-tour, a practical observation was that on-tour S&C support resulted in increased S&C training load (around match loads), potentially countering the observed regression of physical capacities. Such a finding has the capacity to alter current physical preparation structures in high-performance tennis environments with finite resources.
INTRODUCTION

Due to the physicality of modern day tennis, technical and skill attributes alone are unlikely to compensate for poor physical preparation, therein reducing the likelihood of performance goals being achieved.\textsuperscript{2,106} For high-performance tennis players, the progressive improvement of physical capacities (i.e., strength, speed, agility and aerobic power) helps to ensure that players cope with the increased physical stress of matches as they transition from junior to senior competitions.\textsuperscript{21} It is therefore crucial that physical capacities are maintained throughout intensive touring schedules.

Previously, we have identified that speed capacities (5-, 10-, and 20-m sprints) are susceptible to decline over the duration of a 4-week high-performance junior international tour.\textsuperscript{333} Accordingly, specific training programs designed to counter physical capacity regression are imperative. However, whilst on tour, matches and on-court training take precedence and encompass the majority of training load.\textsuperscript{106,333} Prioritization of match and on-court preparation means off-court training time is often reduced, whether through necessity or circumstance. Notwithstanding the potential acute increase in fatigue throughout periods of a tour, it is also possible reductions in off-court training may result in the observed decrements in certain physical capacities whilst on prolonged tours.\textsuperscript{333} As off-court training is at the mercy of on-tour circumstances, it may be that pre-tour physical preparation (i.e., preparatory training load) is important to provide a prophylactic benefit against the regression of these physical capacities following prolonged tours. If so, pre-tour training loads may allow the favourable balance between maintenance of fitness within competition and tennis-specific training demands, potentially impacting subsequent performance outcomes.
Analysis of total load (a combination of training and match load) and physical capacity development (alongside match performance) ultimately describes the dose-response relationship of training within tennis sessions (i.e., fitness responses based on training and match loads). Training and match loads can be determined using the method described by Foster et al., multiplying the athlete’s RPE by their estimate of session duration, to calculate a session-RPE load value. Previous investigations have assessed the validity of session-RPE as a measure of internal load for tennis play by comparing it to Edwards’ HR zone method. Results yielded generally favourable/positive results, although it must be acknowledged that other training load monitoring techniques that utilize HR as an input (i.e., Banister’s TRIMP and Individualized TRIMP [iTRIMP]) may offer enhanced clarity when interpreting performance changes. Unfortunately however, HR monitors worn around the chest are generally viewed with suspicion by tennis coaches and athletes, owing to perceived restrictions on stroke play, particularly in the serve. Thus, in competitive situations where ranking points or remuneration are involved, current convention dictates that the use of such equipment is seldom embraced. International tennis tours and periods of unsupervised training can result in decrements in speed capacities; paradoxically, lower-body power, change-of-direction (COD), aerobic power, and anaerobic capacities are maintained. We have suggested that the preservation of these physical capacities may be explained by the associated match and on-court training loads. Correspondingly, maintenance of lower-body power may be achieved via eccentric loading. Specifically, it may be associated with serve repetitions and end of range COD, while maintenance of agility, aerobic power and anaerobic capacities logically stem from match and on-court locomotive demands. Kelly and Coutts highlighted the importance of providing an
appropriate training stimulus throughout competition periods in team sports, implementing plans to counteract associated physical regressions. However, tennis players and coaches cannot predict match loads (and subsequently training loads), and must react and adjust training loads around tournaments, particularly as most subsequent opponents are unlikely known until 24 h prior. Therefore, pre-tour preparation and on-tour maintenance of physical capacities become vital for ensuring athletes are prepared for any situation. Research into seasonal training plans for other sports (i.e., handball and volleyball) demonstrates that with the implementation of an appropriate in-season training program, speed and power qualities can be maintained and even improved.\textsuperscript{318,335,336} Specifically, Gorostiaga et al.\textsuperscript{335} reported that both speed and lower body power were successfully maintained in elite level handball with the completion of 5–6 S&C training sessions per week during the in-season phase. Häkkinen et al.,\textsuperscript{318} and later Marques et al.\textsuperscript{336} identified that lower body power in elite female volleyball athletes can be improved upon throughout a competitive period with an appropriately designed training program (i.e., including strength and plyometric exercises). Combined, these observations highlight a potentially critical balance between pre-tour fitness and physical regression across an international tour.\textsuperscript{121,337} In tennis, match loads, as well as on- and off-court training loads have been shown to poorly correlate with changes in physical capacities on-tour.\textsuperscript{333} However, whether classic (i.e., undulating or non-linear) periodisation models (pre- and on-tour) can be implemented effectively to reduce on- and post-tour physical regression remains unknown.

Another important issue for elite tennis environments is the struggle with access to on-tour S&C support due to financial constraints, inadequate facilities or facility access, and conflicting match scheduling (one S&C coach across multiple athletes
Chapter 7: Impact of Tour Preparation on Physical Capacities

playing different schedules). As a result, the most appropriate focus for S&C support – pre-tour preparation or on-tour support (that is, training vs. competing) – is debated. Clearly part of this debate is confounded by the abovementioned scheduling complexities, which challenge both load management as well as the use of the S&C coach on-tour. With a need to optimize the on-tour role of tennis S&C support, where tours are prolonged and continuous, previous research has identified the need for informed and precise training and match load monitoring (i.e., RPE, stroke count). However, the practical implementation of classic periodisation models is challenging in tennis, due to the reactive scheduling of training and the multitude of unknown variables (i.e., match duration). As such, presence of the S&C coach may prove critical for ensuring sufficient training occurs to prevent the regression of physical capacities, while also allowing for targeted monitoring of on-tour training and match loads, and precise prescription of the types and volumes of off-court training to be undertaken.

In summary, our current understanding of the interactions between physical capacity changes and associated training and match loads surrounding and throughout the competition blocks is lacking in tennis. Therefore, this study aimed to examine the difference between training and match loads completed prior to and on-tour, and their subsequent relationships with the changes in fitness characteristics across a 4-week tournament period. A secondary aim was to determine the effect of S&C coach presence on training loads whilst on-tour. We hypothesized that training loads completed prior to leaving for tour would be greater than on-tour, and that this greater pre-tour training load would share a stronger relationship with changes in physical capacity than on-tour training and match load. Finally, we also hypothesized that greater training load would be completed on-tour in the presence of S&C support.
METHODS

Subjects
Thirty high-performance junior tennis players (age: 17 ± 1.3 y, matches/year: 135 ± 22, International Tennis Federation junior ranking: 157 ± 112, Association of Tennis Professionals ranking: 1309 ± 370, Women’s Tennis Association ranking: 792 ± 41) representing Australia at junior international events were recruited. The cohort consisted of 20 males (age: 17.3 ± 1.4 y, mass: 66.9 ± 8.6 kg, stature: 176.7 ± 6.0 cm) and 10 females (age: 16.5 ± 0.9 y, mass: 60.5 ± 5.5 kg, stature: 170.2 ± 3.8 cm). All athletes were provided verbal and written description of all procedures and aims of the project. All athletes, and parents where appropriate, provided written informed consent to participate in the study and a university human ethics review committee approved the investigation.

Research Design
This study compared training and match loads performed in preparation for and during 3 different international tours throughout the Asia-Pacific region. Participants were approached after selection onto the Tennis Australia international tours. The tours involved travel to the following countries (approximate travel time in parenthesis): 1) New Zealand (3.5 h); 2) Thailand, Malaysia and Philippines (10 h); 3) Japan and Korea (10.5 h). To ensure minimal detrimental interference from travel (jet-lag), athletes completed fitness testing protocols two days prior to and two days following the tour. As outlined later, testing protocols were designed by Tennis Australia and each athlete had prior familiarity with all procedures. Previous literature using the current testing protocols have established the tests to be of relatively low typical error of measurement, with low variability and therefore are useful in tracking and analysing underpinning physical capacities of athletes. Warm-up and testing
was standardized from 09:00 each morning, and a standardized test order was maintained at all times. Specific testing protocols were performed in succession, approximately 15 min apart. An in-depth description of the protocols has been explained previously, along with respective technical error (TE; Table 1). All physical activity, fluid, and food intake in the preceding 24 h were standardized for testing, and normal fluid and food intake throughout tour preparation was maintained. Care was taken to guarantee that the same researcher carried out each testing battery, and environmental conditions (i.e., surface, temperature, clothing, shoes) were identical to optimize accuracy and reliability of test measures. The assigned coaches were responsible for planning tour preparations in the days immediately prior to departure; the authors are confident that research staff did not manipulate these plans or impede preparations in any way.

**Measures**

**Countermovement jump (CMJ)**
A CMJ protocol for double leg (CMJ-DL), dominant single leg (CMJ-DOM), and non-dominant single leg (CMJ-NON) was used to determine lower body power through peak height in vertical displacement using a yard-stick (Vertec, SWIFT Performance Equipment, Lismore, Australia) jumping device with multiple vanes distanced 1cm apart. The ICC of CMJ-DL, CMJ-DOM and CMJ-NON was 0.96. The technical error (TE) of CMJ-DL was 1.0cm, while the TE of both CMJ-DOM and CMJ-NON was 2.0cm.

**Speed: 5-, 10-, 20-m sprints**
Dual-beam, electronic timing gates (Speedlight, SWIFT Performance Equipment, Lismore, Australia) were used to measure maximal 5-, 10- and 20-m sprint, (as well as the modified 5-0-5 agility test, and the repeat sprint ability test times). Three trials
were completed over 20 m distance, with split times taken at 5- and 10-m, the best time was used for each distance. The ICC of the 5-, 10-, and 20-m sprints were 0.84, 0.87, and 0.96 respectively. The TE of each sprint distance was 0.06 s.

**Agility: Modified 5-0-5 left and right**
The athlete’s ability to perform a single, rapid 180° COD over 5 m was measured using a modified version (stationary start) of the 5-0-5 agility test. Three trials pivoting on both left and right foot were completed. For both left and right foot 5-0-5 agility, the ICC was 0.92 and the TE was 0.05 s.

**Multistage fitness test**
The multistage test was used to determine aerobic power using previously reported protocols. Athletes performed continuous interval running over 20 m indicated by a compact disc (Australian Sports Commission, Canberra, Australia). The ICC was 0.90, while the TE was 0.5 arbitrary units (au).

**Repeat sprint ability (RSA) test**
The 10 × 20-m RSA test protocol was used to evaluate the capacity to maintain maximum acceleration and speed across multiple efforts, each sprint summed for total time. The ICC was 0.86, while the TE of the RSA test total time was 0.61 s.

**Load monitoring**
Physical demands were calculated for total (all sessions), total on-court (all tennis related sessions, including matches), total off-court (all S&C training sessions), singles matches, doubles matches, tennis training, strength (resistance) training, and conditioning (metabolic conditioning) sessions (au). Daily training and match loads were collected and analysed to depict fluctuations and trends. RPE was obtained 30 min after all sessions. Pre-tour and on-tour, athletes’ schedules were established by the assigned coach. The S&C coach collected training loads in the 4-week
preparatory period as well as training and match loads throughout the on-tour period before leaving the touring group. Following the departure of the S&C coach from the tour group, a single tennis coach, who was familiar with data collection techniques, collected all training and match load data for the entire tour group. While bias caused by social desirability cannot be avoided within high-performance groups, standardization was provided by way of a single tennis coach who was deemed ‘neutral’ in that they were not the regular coach of any athlete (in their home environment). Accordingly, in this sense we attempted to minimize any coach-athlete reporting bias. For each of the 4-week international tours, the S&C coach was present for the initial 2 weeks of competition.

**Statistical analysis**

Results are presented as means ± standard deviations (SD). Repeated-measures ANOVA were performed to compare: 1) Training and match loads completed between pre and on-tour phases (Phase × Time, where Time is defined through weekly training and match load); 2) Different modes (i.e., match load, on- and off court training load) completed with and without S&C support (Mode × Support). The level of significance was set at $p \leq 0.05$, and normal distribution of data was confirmed through Shapiro-Wilk analysis. Effect sizes were also calculated to establish the magnitude of difference in loads completed pre- vs. on-tour, and with and without S&C support. Effect size results were interpreted as described by Christensen & Christensen with effect sizes of <0.2 classified as small, 0.4–0.6 as moderate, and >0.8 as large. Previous work has suggested that the smallest worthwhile change (SWC) represents the smallest change that is of benefit to athletic performance and can be calculated as $0.2 \times$ between-subject SD. As a result, variables in Table 1 were considered capable of detecting the SWC if the TE was ≤
Further, 90% CI were calculated to assess the uncertainty in the magnitude of differences observed. Pearson correlation coefficients were calculated to assess the association between pre- and on-tour training and match loads, and physical capacity test results. The following criteria were adopted to interpret the magnitude of the correlations: 0.10–0.30 small, 0.30–0.50 moderate, 0.50–0.70 large, 0.70–0.90 very large, and 0.90–0.99 nearly perfect. If the 90% CI overlapped positive and negative values, the magnitude was deemed unclear; all other effects were deemed to be clear. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) (version 20, SPSS Inc., Chicago, IL, USA).

RESULTS

Previously we have reported the absolute change in physical capacities following 4-week international tennis tours, and consequently Table 7.1 presents the results as percentage change. Accordingly, only trivial to small differences were evident for changes in most physical capacities from pre to post-tour tests \((d=0.13–0.41)\). However, a moderate effect was observed highlighting greatest susceptibility of decrement in 5-, 10- and 20-m speed \((d=0.70, 0.61, 0.51\) respectively).
Table 7.1. Mean ± SD of pre and post tour results for fitness test measures. Together with the technical error (TE), smallest worthwhile change (SWC), change in testing results pre – post tour (% ± 90% confidence limits) and the magnitude of that change (effect size).

<table>
<thead>
<tr>
<th>Measure</th>
<th>% Change</th>
<th>TE</th>
<th>SWC (%)</th>
<th>Effect Size</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ-DL (cm)</td>
<td>-2.0 ± 0.7</td>
<td>1.0 cm</td>
<td>1.43</td>
<td>0.18</td>
<td>Trivial</td>
</tr>
<tr>
<td>CMJ-NON (cm)</td>
<td>-1.8 ± 0.5</td>
<td>2.0 cm</td>
<td>1.18</td>
<td>0.13</td>
<td>Trivial</td>
</tr>
<tr>
<td>CMJ-DOM (cm)</td>
<td>-1.8 ± 0.6</td>
<td>2.0 cm</td>
<td>1.21</td>
<td>0.21</td>
<td>Small</td>
</tr>
<tr>
<td>5-m Sprint (s)</td>
<td>3.6 ± 0.6</td>
<td>0.06 s</td>
<td>0.01</td>
<td>-0.70</td>
<td>Moderate</td>
</tr>
<tr>
<td>10-m Sprint (s)</td>
<td>3.3 ± 0.6</td>
<td>0.06 s</td>
<td>0.02</td>
<td>-0.61</td>
<td>Moderate</td>
</tr>
<tr>
<td>20-m Sprint (s)</td>
<td>2.2 ± 0.6</td>
<td>0.06 s</td>
<td>0.04</td>
<td>-0.51</td>
<td>Moderate</td>
</tr>
<tr>
<td>5-0-5 Left (s)</td>
<td>1.5 ± 0.6</td>
<td>0.05 s</td>
<td>0.03</td>
<td>-0.41</td>
<td>Small</td>
</tr>
<tr>
<td>5-0-5 Right (s)</td>
<td>0.9 ± 0.7</td>
<td>0.05 s</td>
<td>0.04</td>
<td>-0.26</td>
<td>Small</td>
</tr>
<tr>
<td>20-m Shuttle Test (au)</td>
<td>-1.9 ± 0.5</td>
<td>0.5 au</td>
<td>0.24</td>
<td>0.23</td>
<td>Small</td>
</tr>
<tr>
<td>10 × 20-m RSA (s)</td>
<td>1.4 ± 0.6</td>
<td>0.61 s</td>
<td>0.37</td>
<td>-0.30</td>
<td>Small</td>
</tr>
</tbody>
</table>

Note: Standard deviation (SD); centimetre (cm); second (s); arbitrary units (au); percentage (%); countermovement jump (CMJ), double leg (DL), non-dominant single leg (NON), dominant single leg (DOM); repeat sprint ability (RSA).
Figure 7.1(A) highlights the mean daily total load, tennis (training and match load), S&C training loads in the 4 weeks prior to and whilst on-tour. Mean daily total load completed on-tour was larger than pre-tour (d=1.43). Such discrepancy in total load appears due to larger tennis load (training and match) (d=1.60), combined with match loads on-tour. However, there was only trivial difference between S&C training load pre-tour and on-tour (d=0.20). Figures 7.1(B) and 7.1(C) further compare training volume and RPE individually, to distinguish whether discrepancies in pre- and on-tour training and match loads are due to increased duration or intensity. A large increase was observed for the duration completed in tennis sessions and total training on-tour compared to pre-tour (d=0.80). However, only moderate differences in RPE were identified between sessions completed prior to and on-tour (d<0.60). Finally, to present typical training and match variations around tours, Figure 7.2 depicts the daily variation in all modes completed prior to and whilst on-tour. Training and match load data from only 25 days pre and on tour are reported in Figure 7.2, due to travel and transit days between Australia and the destination of the initial tournament.
Figure 7.1. Mean ± SD of the relative, daily; total load, tennis load, S&C training load and match load (A), volume (min) (B), and RPE (C) prior to and on-tour.

Note: Strength and conditioning (S&C); standard deviation (SD); arbitrary units (au); rate of perceived exertion (RPE); and minutes (min).

# Significantly greater load (p ≤ 0.05); * Large effect size (d > 0.80)
Figure 7.2. Daily variation of the mean total load, tennis load, S&C load, and match load completed prior to and on-tour.

Note: Strength and conditioning (S&C); arbitrary units (au)
Correlations were used to establish the strength of associations between training and match loads completed pre-tour and on-tour with changes in fitness post-tour (Table 7.2). There were moderate, positive correlations between on-tour total load/on-court training and match load and reductions in 5-m (r=0.31; 0.26), 10-m (r=0.38; 0.45), 20-m speed (r=0.44; 0.52) and multistage test (r=0.40; 0.48) performance. No other correlations between training and match load and physical capacity measures were significant.

Finally, Table 7.3 presents training and match load completed on-tour in the presence of S&C coach support. When an S&C coach accompanied players, a large increase in on-tour total load, on-court training and match load, and off-court training load was completed (d=2.39, 2.08, 2.86 respectively). It was apparent that this discrepancy manifested through a large increase in strength training load (d=3.25) and conditioning training load (d=1.90), rather than match load (d=0.30) or on-court training load (d=0.05), when S&C coaches were on-tour.
Table 7.2. Correlations of between pre- and on-tour training and match load compared to each fitness test.

<table>
<thead>
<tr>
<th></th>
<th>Total Load</th>
<th>On-Court Training and Match Load</th>
<th>S&amp;C Load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-tour</td>
<td>On-tour</td>
<td>Pre-tour</td>
</tr>
<tr>
<td>CMJ-DL (cm)</td>
<td>0.38*</td>
<td>-0.02</td>
<td>0.40*</td>
</tr>
<tr>
<td>CMJ-NON (cm)</td>
<td>0.07</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>CMJ-DOM (cm)</td>
<td>0.17</td>
<td>-0.09</td>
<td>0.16</td>
</tr>
<tr>
<td>5-m Sprint (s)</td>
<td>-0.10</td>
<td>0.31</td>
<td>-0.10</td>
</tr>
<tr>
<td>10-m Sprint (s)</td>
<td>-0.08</td>
<td>0.38*</td>
<td>-0.07</td>
</tr>
<tr>
<td>20-m Sprint (s)</td>
<td>-0.14</td>
<td>0.44*</td>
<td>-0.13</td>
</tr>
<tr>
<td>5-0-5 Left (s)</td>
<td>0.27</td>
<td>0.22</td>
<td>0.25</td>
</tr>
<tr>
<td>5-0-5 Right (s)</td>
<td>0.17</td>
<td>0.08</td>
<td>0.16</td>
</tr>
<tr>
<td>20-m Shuttle Test (au)</td>
<td>-0.18</td>
<td>-0.40*</td>
<td>-0.19</td>
</tr>
<tr>
<td>10 × 20-m RSA (s)</td>
<td>-0.36</td>
<td>0.36</td>
<td>-0.37*</td>
</tr>
</tbody>
</table>

Note: Strength and conditioning (S&C); centimetre (cm); second (s); arbitrary units (au); countermovement jump (CMJ), double leg (DL), non-dominant single leg (NON), dominant single leg (DOM); repeat sprint ability (RSA).

* Significant correlation p ≤ 0.05
Table 7.3. Comparison of training and match loads when S&C support was both present and absent on-tour.

<table>
<thead>
<tr>
<th></th>
<th>S&amp;C Support</th>
<th>No S&amp;C Support</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Load</strong></td>
<td>842 ± 332 *</td>
<td>492 ± 304</td>
</tr>
<tr>
<td><strong>Total Tennis Load</strong></td>
<td>688 ± 266 *</td>
<td>440 ± 293</td>
</tr>
<tr>
<td><strong>Total S&amp;C Training Load</strong></td>
<td>154 ± 88 *</td>
<td>52 ± 46</td>
</tr>
<tr>
<td><strong>Singles Match Load</strong></td>
<td>229 ± 127</td>
<td>203 ± 123</td>
</tr>
<tr>
<td><strong>On-Court Training Load</strong></td>
<td>155 ± 120</td>
<td>150 ± 133</td>
</tr>
<tr>
<td><strong>Doubles Match Load</strong></td>
<td>304 ± 200 *</td>
<td>87 ± 172</td>
</tr>
<tr>
<td><strong>Strength Training Load</strong></td>
<td>84 ± 43 *</td>
<td>29 ± 30</td>
</tr>
<tr>
<td><strong>Conditioning Training Load</strong></td>
<td>70 ± 51 *</td>
<td>24 ± 25</td>
</tr>
</tbody>
</table>

Note: Strength and conditioning (S&C).

* Significantly greater training or match loads with S&C support (p ≤ 0.05).
DISCUSSION

The current paper aimed to examine training and match loads performed prior to and on-tour, and further determine the effect of S&C coach presence on training loads whilst on-tour. Contrary to our hypotheses, our findings showed that on-tour total loads and tennis training loads were greater than training loads completed prior to tour departure. Furthermore, individual analysis of training and match load properties (volume and RPE) revealed that discrepancies in pre and on-tour load were due to greater on-tour tennis volume. On-tour training and match loads (total and on-court training) were positively correlated with increases in time for 5-, 10- and 20-m speed (i.e., greater decrements in aerobic power observed with increased on-tour training and match loads). Similarly, there were negative relationships between on-tour training and match loads (total and on-court) and multistage fitness test performance (i.e., greater decrement with increased on-tour training and match loads). Finally, analyses of on-tour training loads with and without S&C support revealed that greater strength training, and conditioning training loads were undertaken in the presence of S&C support, highlighting the important role of specialist S&C coaching staff in the management of on-tour training loads. Given such findings, the ensuing discussion explores the potential mismanagement of training load prescription during overseas tour, with specific consideration to declines in physical capacities whilst on tour.

Loads completed prior to and on-tour were analysed to investigate the relationships between training and match loads, and resultant post-tour changes in physical capacity. A negative association was observed between on-tour training and match loads and change in physical capacities; specifically, subjects who completed more on-tour, match and on-court training load suffered the greatest decrements to linear
speed capacities (5-, 10-, and 20-m sprints). There were similar negative associations in multistage test result. Such findings suggest that extended tournament play across a 4-week tour – during which match loads dominated – does not provide sufficient exposure to maximal-effort linear speed training. Similar to other applied high performance sport settings, there were only a relatively low number of elite level athletes available to participate in this research effort. As such, it should be acknowledged that the mixed gender approach - despite being highly reflective high performance environments - might be a methodological limitation. Furthermore, with the observed moderate relationships between speed decrement and on-tour total and tennis training and match load, further research is needed to determine whether linear speed is a valid and important physical capacity measure for tennis. If relevant, it is vital that near-maximal velocity is supplemented with appropriate conditioning training on-tour. If not, perhaps linear sprint tests of certain distances (i.e., 10- and 20-m) are not relevant performance indicators for tennis success. Accordingly, previous time-motion analysis has identified that players are required to cover ~3m per shot and 8–12 m (multilaterally) per point.2,19 Whilst speed intervals of 5-, 10-, and 20-m are common capacity measures of speed,229 Ferrauti et al.19 report that ~80% of all strokes played during tennis matches are within 2.5 m, with only 10% of strokes encountering 2.5–4.5m. Therefore, perhaps more relevant performance indicators for speed in tennis are 2.5 m (i.e., inner range), 5 m (i.e., extended range) and 7.5 m (i.e., end range).

Moreover, only small to moderate relationships were observed between training and match loads and all physical capacities assessed in this study. This may indicate some limitations in the sensitivity of the session RPE method for detecting dose-response relationships between training and match loads and changes in tennis-related physical
capacities. Despite criticism of the current measures of athletic capacity of tennis, there is still the possibility that the observed regressions were due to an accumulation of fatigue resulting in a post-tour overreaching state. Perceptual fatigue measures would have strengthened the current study to establish whether or not observed regression was in fact detraining. Despite a mandatory 2 d recovery period prior to post-tour testing, the possibility of athletes returning in an overreached state, thus explaining capacity regression, cannot be ruled out.

There were clear discrepancies between training loads completed in the weeks leading into the international tour and training and match loads completed on-tour (Figure 7.1). Specifically, total training and match loads (due to increased tennis volume) were greater on-tour. Figure 7.2 highlights that there were obvious weekly training segments characterized by heavily reduced training load (pre-tour) on weekends, as well as consistently higher tennis training load than S&C training load. Correspondingly, limited taper can be attributed to an inverse relationship between reduced tennis and increased S&C training loads rather than fundamentally stable training loads. Such observations align with greater tennis volume identified to take place on tour, without differences in intensity (RPE). We speculate that training loads in the lead up to tour departure may have been mismanaged or incongruent with the desired dose-response. Notably, despite a reduction in the prescription of training volume to compensate for the increase in high intensity training during the taper period, the volume reduction was not enough to decrease overall training load. Upon arrival at the tournament location, training loads are maintained, possibly owing to the importance placed on immediate practice at the tournament courts to adjust to the conditions.\textsuperscript{340} Ensuing total loads during the tour are seemingly a product of the increase in match load.
In Figure 7.1, tennis training and match loads are greater on-tour than pre-tour, principally owing to higher amounts of tennis training loads and match loads being completed on-tour. It is apparent that total loads are sustained on low match load days with increases in tennis training load (Figure 7.2). We also observed a marked increase in S&C training load coinciding with dramatic reductions in match load (following tournament losses). While the current data are the first to describe pre- and on-tour training and match loads for tennis, previous rugby league literature has identified fluctuations in physical capacities related to changes in training and match loads over a competitive season. In rugby league, players achieved improvements in aerobic and muscular power, reductions in skinfolds, and stable 10-, 20-, and 40-m speed during the initial weeks of competition, when training and competition loads were greatest. However, as the competitive season progressed, each aforementioned physical capacity regressed as preparatory training loads decreased, with match loads and injury rates at their highest. In tennis, Kovacs et al. reported negative changes to physical capacities over 5 weeks, although limited training and match load information was collected. Further, disparity to field-based sport loads may be explained by the nature of tennis training, whereby skills are practiced in a ballistic repetitive fashion (i.e., high intensity stroke-play and changes in direction), combined with the unpredictable duration of matches which makes it challenging to forecast match loads in advance.

Given the reduction in certain physical capacities on-tour and the understanding that S&C coach presence helps to maintain S&C training loads on-tour (a combination of all physical training modalities), it is conceivable that the importance of prescribing targeted S&C training modes on-tour (i.e., speed sessions) may outweigh the volume of S&C training completed on-tour. For instance, with increased match demands (i.e.,
winning more matches), training may be more appropriately focused on capacities not developed through on-court training/match loads (i.e., 5-m speed). Such responsiveness may reduce the likelihood of inappropriately high (i.e., non-functional overreaching or injury) or low (i.e., regression of physical capacities) training loads being prescribed. In turn, the capacity for athletes to complete sufficient doses of training to preserve on-tour physical performance, with presumed benefits for in-match performance, is clearly desirable and a function with which an on-tour S&C coach may assist. Noteworthy is also that the knowledge of S&C support staff, and close alignment with skills coaches, may also contribute toward athletes being able to complete more total training load (on- and off-court) on-tour.
PRACTICAL APPLICATIONS

Coaches should be aware that, if training loads completed prior to overseas tours are not sufficient, there is a possibility that meaningful declines in physical capacities during tours may occur (particularly speed and aerobic power). Specifically, we have identified that the disparities in training and match loads were due to reduced tennis volume pre-tour rather than intensity, with no difference in volume or intensity for S&C sessions. As such, S&C coaches may find greater value in the prescription of speed sessions over other physical training sessions (i.e., lower body power sessions). Further, in the presence of S&C coach support, strength training and conditioning training loads were maintained. Additionally, on-tour S&C support may assist tennis coaches in reactively manipulating training loads to target specific physical capacities based on the demands of match play. More research is needed to determine the validity of current physical testing protocols as performance measure for tennis. Specifically, further investigation is required to determine whether more tennis-specific measures may exhibit stronger dose-response relationships with training and match loads.
CONCLUSIONS

Pre-tour total loads and tennis training loads were lower than training loads completed while on-tour, due to lower training volume but not lower intensity. However, there was no difference between pre- and on-tour S&C training loads completed. While pre-tour training loads seemingly provide minimal maintenance effect on physical capacities, on-tour total and on-court training and match loads seem aligned with decrements to linear speed and aerobic test results (i.e., 5-, 10-, and 20-m speed, and multistage fitness test). With these potential repercussions of increased total load completed on-tour, it is apparent that the presence of S&C coach is vital for training load management, as well as the prescription of specific training modes when maximal physical capacities (in particular, linear speed and aerobic power) may not be maintained by tournament demands alone. Greater strength training and conditioning session loads were undertaken in the presence of an S&C coach. Thus, an S&C coach may provide valuable assistance to tennis coaches during tours by encouraging training load maintenance, which should, in turn, maintain physical capacities.
CHAPTER EIGHT

Discussion
Chapter 8: Thesis Discussion

8.1: OVERVIEW OF AIMS

The current thesis examined the use of training load monitoring in high-performance junior tennis players in Australia. An outline of the developed themes and foci of the thesis are presented in Figure 8.1. Specifically, this thesis investigated:

1) The agreement in perception of training load between high-performance junior tennis players and coaches.
2) The training loads of common drills typical within high-performance junior tennis environments.
3) The technical and perceptual demands of drill-based training sessions in comparison to training-based match play and tournament match play.
4) The change in physical capacity and its association with training and match loads of elite junior tennis athletes whilst on an international tour.
5) The difference between training loads performed prior to and on-tour, and their subsequent relationships with changes in physical capacities.

Whilst the current thesis specifically investigates the above areas, the following discussion will blend appropriate findings to address three key themes. That is, the discussion will present an understanding of: I) Common methods of training load monitoring in tennis; II) Training load monitoring during training and competition in tennis; and finally, III) Monitoring and manipulation of training load during international competition. Specifically,
Chapter 8: Thesis Discussion

- Theme I (Common methods of training load monitoring in tennis) will blend findings from Studies 1 and 2 (Chapters 3 & 4) discussing current misinterpretations of training loads within tennis environments and how the compilation of a tennis drill catalogue may influence training prescription.

- Theme II (Training load monitoring during training and competition in tennis) will then discuss findings from Studies 2 and 3 (Chapters 4 & 5) to identify, and elaborate upon similarities and differences between training and competition loads.

- Finally, Theme III (Monitoring and manipulation of training loads during international competition) will blend findings from Studies 4 and 5 (Chapters 6 & 7) in the context of current training load prescription in preparation for and whilst on-tour, and subsequently, the effect of differences in training loads on the maintenance of physical capacities.
Chapter 8: Thesis Discussion

8.2: Training Load Monitoring

8.2.1 Why measure training load?
- Purpose
- Current use in tennis

8.2.2 Do coaches and athletes understand training load?
- Coach vs. Athlete vs. actual
- Accumulating effect
- Explanation of variances

8.2.3 What do current tennis training loads look like?
- Drill types
- Internal, external

8.2.4 Summary of training load monitoring in tennis

8.3: Comparison of Training and Competition Loads

8.3.1 How does load monitoring differ for competition?
- External
- Internal

8.3.2 How does external and internal load differ between training and matches?
- Training data vs. match data
- Match data vs. match literature

8.3.3 Do simulated matches replicate tournament matches?
- External, internal
- Matches won vs. lost
- Seeded vs. non-seeded opponents

8.4 Monitoring and Manipulating Load During Competition

8.4.1 How does home and on-tour loads differ?
- Difficulties of training load prescription on-tour
- Types of training load

8.4.2 How do on-tour loads affect post-tour physical capacities?
Can pre-tour training loads maintain physical capacities throughout tours?

8.4.3 Does the presence of S&C coach on-tour affect on-tour training loads?
- Types of training loads
- Role of S&C coach

8.5 Load Monitoring Implementation Within High-Performance Tennis

Figure 8.1. A Schematic Representation of the Discussion Overview

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8.2 –TRAINING LOAD MONITORING

8.2.1 - Overview of Training Load Monitoring for Tennis

An abundance of literature supporting the efficacy of training load monitoring has been established over the past decade. The overarching logic for the implementation of load monitoring is to provide quantification of the relationship between a training stimulus and physical performance improvement. Despite continued debate as to the most appropriate measures, a growing body of research suggests that training load monitoring can successfully contribute to short and long-term athletic development.

Due to the complexity of tennis and taxing training/competition schedules, load monitoring may play a role in balancing physical stress on athletes to reduce the risk of injury, illness, and non-functional overreaching, while maximizing performance. However, given the lack of tennis-specific evidence in regards to the precise nature of the training dose-response relationships, background context to the current investigations is required.

Fundamentally, load monitoring strategies are best implemented within high-performance sporting environments where athlete and coach support is garnered on operational and practical merit. Whilst the current thesis does not specifically validate the use of load monitoring, the present discussion will critique current methods for load monitoring within tennis environments. Previously established load monitoring strategies involve long-term data analysis of pre- and in-season training programs and training logs, inclusive of both objective load measures (external load) and subjective perceptual measures (internal load). Session-RPE, session-TL, % maximum peak and mean HR, mental exertion and notational analyses (i.e., strokes and errors) are training load monitoring methods commonly used in tennis. From these data (particularly session-RPE and -TL), tennis practitioners are able to retrospectively examine load-performance relationships to inform
planning for training and tournaments.\textsuperscript{32} By default, RPE has been used as the criterion tool, owing to its logistical ease rather than substantive amounts of supporting evidence. However, as highlighted throughout Chapter 2 (review of the literature), and identified throughout studies 1 - 5 (Chapters 3 - 7), accurate and ultimately predictive load monitoring systems require both monitoring of the actual stimulus (external load) as well as the athlete response to that stimulus (internal load).\textsuperscript{22,67}

Essentially, the strength of training monitoring systems relies on coaches having a strong understanding of an athlete’s response to load, as well as an appreciation of the actual training loads being prescribed (i.e., number of efforts, distance covered).\textsuperscript{3,4,6,50} Alongside physical testing, external load measures can be used to assess training progress.\textsuperscript{26} Generally, coaches prescribe session content through external load (i.e., a distance to run or velocity to maintain).\textsuperscript{22} Accordingly, GPS, accelerometry and movement tracking systems are considered appropriate tools in the analysis and prescription of external load.\textsuperscript{22,83} AFL, hockey and soccer research suggests that the aforementioned motion-analysis systems offer valid and reliable measures of distance and velocity in both training and competition.\textsuperscript{52,53,294} However, whilst team sports have access to multiple appropriate external load measures (typically GPS), there is an absence of similar, suitable, practical or valid technology in tennis.\textsuperscript{50} Specifically, Duffield et al.\textsuperscript{50} reported that during an assortment of typical tennis movements, 1 and 5 Hz GPS devices underreport distance covered as well as mean and peak speed, by as much as 38\% when compared to a criterion VICON measure. Movement tracking software (Hawkeye) has also been studied in relation to tennis specific movement.\textsuperscript{2} Reid and Duffield\textsuperscript{2} present Hawkeye data collected during the 2012 Australian Open Men’s final, reporting external load measures of athlete movement, acceleration and speed, as well as stroke velocity and revolution analysis.\textsuperscript{2} However, while the data collected is of great benefit to determine external load, the system is only available to a select few players due to cost and practicality (i.e., Grand Slam, ATP, WTA
court only). Consequently, tennis currently relies on session count, duration, and simplistic stroke analysis (i.e., counts of stroke and error volume) to objectively quantify external load.\textsuperscript{46,149} With this in mind, Study 1 (Chapter 3) assessed coach understanding of session prescription through analysis of the level of agreement between objective measures of external load (i.e., stroke counts) and their own perceptions of external load. Coach perception was in good agreement with the stimulus being prescribed (number of strokes), and perhaps suggests a reduced need for more sophisticated measures of load. Whether coaches have similar insight in relation to understanding of internal responses to load (i.e., physiological responses and perception of intensity) is a separate question requiring attention.

Internal load monitoring tools, designed to describe responses to prescribed load, include measures such as HR, VO\textsubscript{2}, lactate, salivary and blood markers of stress, and RPE. However, the nature of tennis means that invasive measures of HR, VO\textsubscript{2} and lactate are often complicated by travel, portability, or reluctance from athletes.\textsuperscript{83,295} Accordingly, because ecologically valid load monitoring tools are important to high-performance sport, invasive load measures are currently utilized tentatively and minimally by tennis coaches and athletes.\textsuperscript{46,83,295} For example, physiological measures such as HR, which involve telemetric bands around the chest, are used cautiously owing to perceived restriction of stroke play, particularly the serve.\textsuperscript{46,308} Indeed, with ranking points or remuneration generally at stake, requests or recommendations to wear such equipment are usually denied. Thus, non-invasive questionnaires (i.e., session RPE, mental exertion) are likely the only practical measure of internal load in an ongoing sense for tennis; with RPE broadly acknowledged to be the most suitable and readily employed.\textsuperscript{22,98,295} Interestingly, to date no literature has validated the use of RPE within high-performance tennis environments. Multiple papers have nevertheless used it to provide descriptive analyses of training and competition; as well as to report standardized loads within acute intervention-based investigations.\textsuperscript{3,22,46,93,101}
Chapter 8: Thesis Discussion

It could be suggested that given RPE’s acceptance in a range of sports, the above findings advocate its translation (with other internal and external load measures) to tennis to understand the training demands of high-level competition.\(^3\,22,46,93,101\) Yet, where multiple investigations, including Study 1 (Chapter 3), advocate RPE as a valid, reliable and non-invasive measure of internal load for tennis,\(^8,22,99,313\) it is important to acknowledge that certain literature questions its efficacy in other dose-response relationships (i.e., marathon runners and later professional youth soccer players).\(^28,29\) In these contexts, other measures including iTRIMP were observed to better match blood lactate accumulation.\(^87,281\) Therefore, with such strong reliance upon perceptual load measures in tennis, the precision and understanding of any perceptual mismatches between coaches and athletes becomes vital for accurate periodisation.

8.2.2 - Coach and Athlete Understanding of Training Loads

Effective manipulation of training load requires coaches to have an accurate understanding of their athletes’ response to the imposed load to appreciate the expected recovery and/or subsequent adaptation.\(^26,83\) The abovementioned ‘theoretical’ use of load monitoring strategies emphasizes the fact that tennis load measures are typically adopted from other sports. The research literature conditionally supports the use of RPE as a descriptor of athlete training load response; however, due to the individualised nature of RPE, there is always risk of misinterpretation associated with relying solely on perceptual responses.\(^49,297\) The results from Study 1 (Chapter 3) lend support for the parameters of training load monitoring used here, particularly notational analysis, drill-RPE, HR, and mental exertion for tennis. Interestingly though, it is evident that coaches significantly underestimate athlete RPE for overall training sessions (Study 1 [Chapter 3]). Seemingly, current coach interpretation of load resides in the macro-prescription of session design (i.e., interpreting session load based on the actual drills),
with no regard for the accumulation of subsequent drill load, and the intricacies associated with
the collection or accumulation of certain drill types. These findings are consistent with previous
similar accounts in other sports.48,297

While there may be disparity between the internal perceptions of effort of athletes by coaches
during training, Study 1 (Chapter 3) revealed that coach/athlete stroke counts were comparable.
Athlete counts were substantially correlated with coach count and also objective notational
analysis. In contrast, coach perceived stroke counts presented only moderate correlation with
notational analysis. Given the absence of similar literature on tennis, comparative examples
need to be sourced from other sports. Previous swimming data report that athletes are able to
comply with coach prescribed swim distances, suggesting that no additional monitoring of
external load in training is warranted.303 Similarly, the high-level of awareness of external load
(i.e., stroke count) from tennis athletes in this study suggests that prescription of external load
in un-supervised practice may be appropriate, so long as athletes are well educated on the
required volume. Meanwhile, Study 1 (Chapter 3) also demonstrates that coaches overestimate
error count within training settings. Interestingly, athletes show no difference in the estimation
of errors compared to a notated count. At present, no research has compared estimations of
error count between coach, athlete and post-session notation for any sport, limiting any
subsequent direct comparison of results. Worth noting however, is that coaches progress or
regress drills depending on errors made and the ability of an athlete to handle a task.304 In terms
of overall session intensity, previous literature reports identified differences between planned
and actual session loads by coaches and athletes, plus warn of potential maladaptation if coach
education is not invested in.48,297 In a similar vein, the currently reported ‘mismatches’ in
planned and perceived training intensity (via RPE) insinuates some misunderstanding of
training variables, further highlighting the importance of coach education of athlete responses
to training load in tennis environments.
While coaches need to be aware of deviations between their perception of intensity and those of their players, the internal and external load variables that actually explain such variance are equally important (i.e., what load variables should coaches be most attentive to). Regression analysis revealed that 54.5% of variance in coach (post) session-RPE could be explained by individual drill-RPE combined with the rating of intended session exertion (pre-session RPE). Meanwhile, 45.3% of variance in athlete (post) session-RPE could be explained through individual drill-RPE and HR$_{peak}$. Seemingly, internal load markers of athletes explain more of the variance in athlete session-RPE than external load measures, though it is accepted the extent of external markers utilised was small. With respect to athlete RPE, similar results have been observed in rugby league, with Lovell et al.$^{40}$ reporting that a combination of load and intensity measures explained 62.4% of the variance in session-RPE. Understanding and regulation of session-RPE is therefore contingent upon coaches garnering an improved appreciation of the varying subtleties of individual athletes when designing and prescribing training sessions.

As Study 1 (Chapter 3) observed incongruity between coach and athlete actual (i.e., external stimuli) and perceived intensity (i.e., internal response), it is logical to suggest a need to continue quantification of typical training loads in tennis, so as to provide evidence in which coach education can draw from. Study 2 (Chapter 4) assists in this prescription of training load by providing descriptions of differing categories of tennis drills from which practitioners can prescribe sessions. Such application of load monitoring within high-performance tennis environments can be successfully utilized provided coaches are aware of the tendencies within sessions to underestimate the intensity of the entire session.
8.2.3 - Current Training Loads of High-Performance Junior Tennis

Ultimately, heightened understanding of the dose/stimuli presented to players at training may enhance prospective or subsequent training design. In Study 2 (Chapter 4), training drills \( (n = 285) \) were distinguished by intensity, technical focus, or tactical outcome resulting in the formation of 8 categories: 1) Recovery/Defensive, 2) Open-Pattern, 3) Accuracy, 4) 2-on-1 Open, 5) 2-on-1 Net Play, 6) Closed Technical, 7) Point Play, and 8) Match Play. While this study was the first to group common training drills into categories, previous studies have described the internal and external loads of discrete drills; observing notable relationships between increased internal load, speed of movement, and the duration of each drill effort.\(^3\) As such, findings within Study 2 (Chapter 4) describe training loads in relative terms to account for distance, speed and duration of each drill. These findings (Study 2 [Chapter 4]) also provide insight into the differences between certain session types or drills and tournament match play demands (Study 3 [Chapter 5]). In turn, such findings (Study 2, Chapter 4) provide practitioners with evidence-based knowledge that may be used to shape training programs.

**External Load**

Discounting the contemporary use of Hawkeye, measures of external load in tennis are generally limited to duration, and stroke count/rate. Accordingly, analysis in Study 2 (Chapter 4) established that Open-Pattern and Recovery/Defensive drills were characterized by the highest stroke rates. Specifically, Open-Pattern drill stroke rates were greater than Closed-Technical drills, Point-Play, and Match Play, while Recovery/Defensive, 2-on-1 Open, and Accuracy drills exceeded Match Play stroke rates. Previously, Reid et al.\(^3\) described the stroke count of 4 hand-fed drills over 30 and 60 s. After adjusting the 60 s stroke counts for comparison with our data (i.e., normalized to 6 s periods as per mean point duration in matches), two of the drills (Star and Box) presented stroke rates well above any drill categories in this study. However, the Suicide \((0.7\text{strokes/6sec}^{-1})\) and the Big X \((0.8\text{strokes/6sec}^{-1})\) drills
were comparable to 2-on-1 Open, Closed-Technical drills and Point-Play. The discrete, hand-fed, nature of these drills (1 set/6 repetitions) combined with high metabolic demand, infer that none of these drills may be sustainable if comprising the bulk of a 90-120 min session.\textsuperscript{3} However, tennis athletes often complete an array of training drill types and session designs with the goal of tournament preparation as compared to simply relying on discrete drills.\textsuperscript{3,21}

Moreover, it appears that stroke-rates during Point-Play and Match Play in practice are generally below those that characterize tournament play. Previous tournament stroke-rates have been reported as 2.7 (7.5 sec)\textsuperscript{7} to 4.7 strokes/rally (6.7 sec).\textsuperscript{95} The Open-Pattern drills most closely approximated “match-like” stroke frequencies, but all drill categories failed to simulate tournament stroke rates. It should be noted that Study 3 (Chapter 5) specifically excluded drills of a technical nature, including only more dynamic, open drills. In saying this, whether stroke rate is interpreted as a proxy for shot quality, competitiveness or intensity is currently unknown.

Given the discrepancies between stroke-rates in training and match play, error rates (a proxy external load measure) provide additional context into how athletes are coping with drill intensity or technical demand. The data in Study 2 (Chapter 4) suggest that Closed-Technical drills produced the greatest error-rates, despite being the least physically demanding (low stroke-rates). This is likely due to the technical focus and likely adjustments in stroke mechanics that occur during these drills, whereby errors are tolerated, even expected, in the pursuit of technical outcomes. Recovery/Defensive drills (highest external and internal intensity) also comprised of high error-rates, likely owing to the comparatively heightened physical demands. Coaches should take caution in prescribing drills of increased physical intensity when the session focus is to alter stroke mechanics or specific movement patterns, as excessive acute physical fatigue may affect stroke performance. Further, during rally-based
drills, where the intensity is high, increased error-rates may interrupt drills of continued nature, resulting in reductions to the physical demands within sessions. There is a scarcity of literature reporting the error-rates associated with tennis tournaments and training, limiting direct comparison of this study’s error rates. Nevertheless, they compare favourably to the data of Pieper et al.\textsuperscript{305} who analysed seven hard-court men’s singles matches of ATP players ranked 1-63, establishing low, medium and high time pressure error percentages of 13.7, 21.0 and 26.4% on the forehand and 13.5, 16.8 and 25.6% on the backhand.\textsuperscript{305} Reid et al.\textsuperscript{46} reported similar error-rates of four 2-on-1 tennis drills on both hard and clay-courts. The error-rates reportedly increased through drill difficulty and movement intensity, from 10.6 ± 6.1% (hard-court) for 2-on-1 alternating forehand and backhand rally patterns on 3 min rotations; to 23.9±11.8% (hard court) for open, 2-on-1 point play alternating after each unforced error on 5 min rotations.\textsuperscript{46} Owing to such a decrease in accuracy, aligning to increased drill intensity, it is likely technical ramifications and changes to precision relate to increases in the internal load demand.

**Internal Load**

Despite the well established\textsuperscript{22,23,26,32} value of external load prescription in the context of an athletes’ internal response; in tennis, the current understanding of such relationships are limited. In essence, there is no long-term analysis of the interactions between training load and performance in tennis, mainly owing to the difficulty associated with quantifying internal load during certain movements (i.e., perceived restrictiveness of HR bands during serve). Consequently, tennis practitioners generally rely on perceptual measures of internal load.

Accordingly, Study 2 (Chapter 4) reveals internal load measures determined from drill-RPE were highest for *Recovery/Defensive* drills, followed by *Open-Pattern* drills and *Point-Play*. *Closed Technical* drills were of lower perceived intensity than *Recovery/Defensive* drills, *Open-Pattern* drills and *Point-Play*, logically owing to their abovementioned technical aims. Comparison of these drill-RPE’s to those reported to characterize the discrete drills reported in
Reid et al.\textsuperscript{3}, highlight that the post-drill RPE of the Star drill was of similar intensity to Accuracy, 2-on-1 Net Play drills, Point-Play, and Match Play throughout Studies 2 and 3 (Chapters 4 and 5). Suicide and Big X drills however, were of intensities higher than any of the currently reported drill categories (including Match Play). The Box drill, which was characterized by the lowest intensity in Reid et al.\textsuperscript{3}, resembled Closed Technical drills. Given the limited relevant literature to which directly compare in tennis, use of other sporting examples is warranted. For example, RPE values within rugby league distinguished between the different training components of training sessions.\textsuperscript{40} That is, the more physically engaging components of training were perceived hardest (i.e., conditioning and wrestling, over-speed training and skill development).\textsuperscript{40} Interestingly, this rugby league example (also reported in water polo\textsuperscript{44} and taekwondo\textsuperscript{38}) identifies that the internal load of certain training types, such as high intensity – limited motion activities (i.e., wrestling) might not be accurately depicted by measures such as HR and GPS.\textsuperscript{40} While this could be argued to apply to the current descriptive analysis of tennis drills, it is equally plausible that the specific mechanical and movement loads (i.e., small accelerated displacements) typical of tennis are different to high-intensity, limited motion activities.\textsuperscript{28,29} Nevertheless, there remains a need to constantly monitor, and catalogue internal load demands (similar to Study 2 [Chapter 4]).

While RPE has been utilized frequently within the tennis literature for the description of load, the mental exertion of tennis athletes during matches and training (i.e., concentration, anxiety and arousal management) warrants specific measurement. The current data observed Accuracy drills to be of greatest perceived mental exertion, followed by other high-pressure drills (i.e., Recovery/Defensive drills) and open, match-like situations (i.e., Match Play, Open-Pattern drills, and Point-Play). The mental exertion of these drills was perceived to be greater than Closed Technical drills, which is surprising due to the presumably high mental demands of technical alterations. Recovery/Defensive drills most closely reproduced the physical and
mental intensities typical of tournaments, while Open-Pattern drills induced substantial physical and mental exertion and Accuracy drills may have the potential to, directly or indirectly, foster psychological skill development (i.e., focus and concentration). This study’s novel use of this measure holds promise for future research in tennis, owing to the emergence of research in laboratory settings, highlighting impairment of endurance performance with increased mental exertion.

Contrary to the significant perceptual differences between drill categories, there were no significant differences in HR measures (%HR$_{\text{max}}$, peak or mean HR). Categories inducing the greatest absolute peak-HR and relative (%HR$_{\text{max}}$) were Point-Play, Recovery/Defensive, and Open-Pattern drills, while Closed-Technical drills featured the lowest peak-HR, which is consistent with the trends observed for RPE and mental-exertion. Mean-HR was greatest in 2-on-1 Open and Recovery/Defensive drills, and lowest across the duration of Match Play. Previous studies to describe the physiological characteristics of training have noted comparable mean and peak HR’s, while tournament data are in similar agreement - albeit the current HR measures reside nearer the lower end of the tournament ranges. Point-Play, 2-on-1 Open and Recovery/Defensive drills elicited the greatest absolute peak and mean-HR values. This is most likely due to the increased intensity and pressure associated with the open-play nature of these drills. Conversely, drills that could be prescribed for reduced physiological load tended to be closed, technical and target-hitting drills. Prescription of these drills could be used during de-loading cycles, tapers, or within sessions designed to reduce cardiovascular strain.
8.2.4 - Summary of Training Load Monitoring in Tennis

Although tennis training is commonly designed with long-term athlete development in mind, ultimately training sessions should approximate the demands of competition. Armed with the information from these studies, we now better appreciate that *Open-Pattern* drills are characterized by the greatest stroke rates of any drill type, likely beneficial for high-repetition practice. *Recovery/Defensive* drills are punctuated by compromised training quality, eliciting high error rates; while, *2-on-1 Net-Play* drills experience the lowest error rates, making these drills appropriate for error-ameliorative practice. Furthermore, *Recovery/Defensive* drills place the highest physiological stress on players, and along with *Accuracy* drills are characterized by high mental stress, making these drill types ideal for challenging the physical and mental status of players. Despite this insight into the demands of junior high-performance tennis environments, there remains a dearth of insight into the typical correspondence between training load and the load of competition - thus providing rationale for Study 3 (Chapter 5).
8.3: COMPARISON OF TRAINING AND COMPETITION LOADS

8.3.1 - Load Monitoring for Competition

Having focused on monitoring load in a training context, the following discussion now compares training loads to competition. One commonly reported limiting factor of tennis periodisation is access to training time. This relates to the demanding international competition schedules at a high-performance level.\textsuperscript{21,106} Effective performances in tennis are therefore suggested to be the product of the successful prescription of on and off court training, while navigating the constraints of travel, injury, and logistics.\textsuperscript{21,108} Thus, an obvious benefit of load monitoring is the ability to prescribe quantified loads in response to the actual competition demands. In reality, as discussed below, there are several limitations in the collection of load data during competition.

External load currently relies on notational analysis of stroke count and rates. An exception to this are the Grand Slam events, where Hawkeye computer vision techniques and motion tracking software can provide accurate positional and stroke data.\textsuperscript{2} Of further interest, in-racket technology from racquet manufacturer Babolat (Babolat Play) recently announced the release of a “smart” tennis racquet, capable of analysing ball speed, spin, and impact location.\textsuperscript{344,345} However, to date, this technology has yet to be proven accurate within scientific literature, and combined with a lack of availability across all racquet types, leaves these advances in the hands of future training load research. Therefore, for the most part, simple digital cameras mounted on court fences provide the most feasible and widely used means of quantifying external load (via the laborious notation of stroke rates). Unfortunately though, in many cases, due to the financial and personnel restraints, matches are often not recorded, resulting in no external load data being collected. Thus, throughout competition phases away from home environments, methods to capture internal load become vital. Internal
load monitoring during competition is nevertheless not without its own limitations. Even more so than during training sessions, athletes and coaches are less accepting of wearing HR monitor bands around the chest in competition, owing to perceived restriction during serve and groundstrokes.\textsuperscript{3,46} Through a process of elimination, this leaves perceptual measures (i.e., RPE and mental exertion) as the markers of (internal or external) load, which can be collected for all matches (home or overseas). The following section will compare published external and internal load demands of competition with training.

8.3.2 - Training vs. Match Demands

External Load

\textit{Current Training data vs. training literature}

Given the context that measurement of the tennis physical demands are limited by the lack of reliable positioning and tracking equipment,\textsuperscript{50} stroke count and rate presents the most readily available indicator of external load during tennis matches. Indeed, it has been reported that an increased stroke rate is generally indicative of greater intensity.\textsuperscript{2,3} Reid et al.,\textsuperscript{3} quantified training drill stroke data, describing the stroke count of 4 discrete hand-fed drills over 30 and 60 seconds. Of these, Star and Box drills presented much higher stroke rates than any of the current drill categories in Study 2 and 3 (Chapters 4 and 5). As reported previously, Study 2 (Chapter 4) highlighted that stroke rate was greatest within \textit{Open- Pattern} drills ($1.2 \pm 0.8$ strokes per 6s), making these drills ideal for imparting intensive stroke accumulation. The other quantifiable proxy measure of external load is error rate. Study 3 (Chapter 5) reported error rates to be highest in \textit{Recovery/Defensive} ($17.3\% \pm 6.5\%$) drills. Thus, when attempting to identify drills of physical demands similar to competitive matches (i.e., Study 3, Chapter 5), the link between external load and error rates should be considered. Importantly, the major strength and novelty of the within-cohort design of Study 3 (Chapter 5) was the comparison of prescribed training loads with what was typical for tournament play for that same cohort.
Training data vs. match data
As noted earlier, the design of Study 3 (Chapter 5) compared only the most physically demanding training categories. Already, Study 2 (Chapter 4) has identified that the stroke rates of the Recovery/Defensive drills, Point-Play and Open Pattern drills were below those reported to characterize tournament play.\textsuperscript{23,42,43} Study 3 (Chapter 5) subsequently aimed to investigate training drills within the same cohort for (domestic) tournament matches. Accordingly, training session stroke rates ($7 \pm 1.0$ strokes min$^{-1}$) were lower than those of matches ($14 \pm 3.6$ strokes min$^{-1}$). Perhaps, the differences observed between stroke frequency relate to the amount of coaching cues given (i.e., inadmissible during competition matches). However, as training sessions intend to prepare athletes for tournament demands, coaches should be mindful of this discrepancy. Error rates on the other hand, were greatest during (domestic) match play. As such, this appears to align to the view that the greater the physicality of sessions (be it training or competition), the greater the error rate.\textsuperscript{121}

Match data vs. match literature
While external loads from both Study 2 and 3 (Chapter 4 and 5) contrast greatly with previously reported tournament demands, the current domestic match loads of Study 3 (Chapter 5) need to be understood in the context of previously reported match literature. When converted to align with O’Donoghue & Ingram\textsuperscript{120} (i.e., strokes played per second of rally time), stroke rates were observed to be $0.23 \pm 0.06$ strokes sec$^{-1}$. Comparatively, the stroke rates of professional tennis players competing in the Australian Open between 1997-99 reportedly reached $0.81 \pm 0.04$ strokes sec$^{-1}$ for men and $0.76 \pm 0.03$ strokes sec$^{-1}$ for women.\textsuperscript{120} In terms of error rates, indications are that they i) rise under increased acute fatigue, and ii) reduce in more advanced players.\textsuperscript{2,120,121,139} Conceivably, with increased tolerance to high levels of stroke frequency, athletes can expect reductions in error rates, which ultimately may contribute to greater performance outcomes.
Chapter 8: Thesis Discussion

Such discrepancies highlight the difference in match intensity and loads between professional tournaments and developing player environments. With such disparity between training and tournament match loads, as well as between junior and elite match loads, it is advisable that high-intensity drills are considered to compliment or elevate match practice demands. With the limitations faced by practitioners to accurately and consistently monitor external loads, care must be taken to ensure training prescription is established from an informed view of tournament demands (i.e., through notational analysis). Therefore, assisting in the bid to effectively manipulate training sessions and gauge match intensity, a further understanding of the internal load responses typical of training and match play is critical.

**Internal Load**

*Training data vs. training literature*

As outlined previously, invasive and restrictive measures of internal load (i.e., HR and blood analysis) are used cautiously in tennis, which limits markers of load to perceptual questionnaires (i.e., RPE and mental exertion). Currently, Reid et al. appear to be the sole investigations to have quantified the loads that characterize discrete training drills. Despite our best intentions to specifically select only drills of high physical load, drills reported in Reid et al. still far exceed the RPE’s of the current data. As alluded to earlier, no previous training literature has examined the mental exertion of training drills. Therefore, limited comparison to literature is available; however, the within cohort comparison between training and competition (to be discussed) forewarns of the importance of monitoring the mental exertion of training in combination with physical exertion.

Previously (Study 2, Chapter 4), discrepancies between certain drill categories have been highlighted, with drills of greater focus (accuracy drills) and physical intensity (recovery/defensive drills) being characterised by significantly greater mental exertion than
closed technical drills.\textsuperscript{309} Bearing in mind that Study 3 (Chapter 5) controlled for intensity of training drills, it would seem intuitive that in order for mental exertion to be appropriately prescribed, simulated competition or pressures (i.e., targets, time-pressure) must be incorporated into training. Moreover, due to the highly individual perception of load, the current within-cohort comparison between training and domestic matches is important, although it is acknowledged that this effectively represents a “case study” of one tennis population.

**Current training data vs. match data**
Similar to external load, comparison between the internal load data from Study 2 (Chapter 4) and the competition literature suggests that the intensity of the present training categories do not effectively prepare athletes for the intensity of competitive matches.\textsuperscript{3,14,22,150,308,309,313} It was evident that RPE is greatest in those drills that most closely mimic match “worse case scenarios” or extreme time pressure situations (i.e., recovery/defensive drills) (Study 2, Chapter 4). However, in Study 3 (Chapter 5), the comparison between training drills and matches revealed that the RPE of matches exceeded that of training. Similarly, Studies 2 and 3 (Chapters 4 and 5) both observed discrepancies between the mental requirements for training and both simulated and domestic tournament match play. Despite the increasing use of monitoring of perceived physical effort in tennis (i.e., RPE),\textsuperscript{3,22,46} the same cannot be said of perceived mental exertion (particularly within competition). Recently, Rozland et al.\textsuperscript{343} investigated the laboratory-based effects of mental exertion on neuromuscular function in intermittent maximal voluntary contractions of the knee extensors, suggesting that mental exertion had no effect on the neuromuscular function. However, the non-fatiguing Stroop task, combined with the isolated closed-skill performance measure (i.e., intermittent knee extension) used, likely relate poorly to the movement demands of tennis (i.e., maximal force production, rapid change of direction, and frequent decision-making). Thus, prescription of
sessions to mimic tournament demands should consider RPE and mental exertion, alongside an understanding of how they are affected by stroke demand, drill duration, and work-rest ratios.

**Match data vs. match literature**
To provide a greater level of context surrounding the apparent disconnect between the internal training loads and domestic tournament loads (within the same junior cohort), the reader should be provided with a comparison of the internal loads of the current match data to the previously reported match literature. Unfortunately however, there is a scarcity of research that has investigated the RPE’s of athletes following completion of “live” tournament matches (i.e., ranking points on offer). Moreover, as outlined in the previous section, the evidence base pertaining to the mental demands of tennis players during tournament matches is also lacking. The case study of Coutts et al.\(^\text{22}\) is one of the limited investigations to have described the RPE and session-TL of a top-level player from a tournament event (2008 Roland Garros). They reported match RPE’s ranging from 5 - 7 (au), with a weekly competition-TL of 2908 (au), ~18% greater than during the final week of tournament preparation (2380 au).\(^\text{22}\) While the external loads of junior high-performance tennis appear lower than the professional level, caution is advised when comparing internal load (responses to external stimuli) between different developmental stages of players, as a myriad of other factors likely influence overall perception of effort during competition (i.e., prize money, media scrutiny, spectators). Still, in the current study, the RPE’s reported in training reflect a lower level preparation in training for related tournament demands (Study 3, Chapter 5). Thus, where specific (physical) preparation for tournament match play RPE is intended, care should be taken to ensure drills reflect this.
While these data suggest that the intensity of training sessions may not compare favourably to the intensity of tough matches (despite obvious age and expertise differences), one important component of tennis match preparation is simulated (or practice) match play. Study 3 (Chapter 5) hence sought to compare (within a concurrent cohort) this type of training with ‘live’ match play to assess its efficacy for readying players for tournament play.

**8.3.3 - Efficacy of Simulated Match Play for Competition Preparation**

*External Load*

Study 3 (Chapter 5) identified that stroke-rates of simulated match play (10±5.1 strokes min⁻¹) were below that of domestic tournament matches (14±3.6 strokes min⁻¹). Despite similar match durations and shorter rest times, simulated match play featured significantly reduced work time as compared to domestic tournament matches. This highlights the contrast in the external load in both modes of practice/play, which may relate to the legacy of coaching cues during training blocks, where technical/tactical objectives may still be in focus during simulated match play (i.e., tactical patterns, or stroke technique).

Domestic matches also resulted in higher error rates than simulated match play, likely owing to their more elevated levels of mental exertion and perceived importance. The descriptive analysis of training drills that featured in Study 2 (Chapter 4) identified that drills with a technical focus and extreme physical (end range) requirements induced higher error rates. This also seems to fit with the elevated somatic and cognitive anxiety (with associated with consequence of failure) that has been reported during days of tennis competition as compared to training days.⁹ Interestingly, the higher winner rates during simulated match play sessions may be indicative of more aggressive mindsets during these sessions (Study 3, Chapter 5). Given these differences, it would seem problematic for coaches and players to prepare athletes for the perceptual demands of competition (i.e., RPE and mental exertion) through the type of simulated match play examined in this thesis.
**Internal Load**

Study 3 (Chapter 5) observed RPE during simulated match play to be lower than domestic tournament matches. However, as outlined earlier, the present RPE responses in simulated match play and domestic matches are not dissimilar to previous simulated match investigations.\(^3,14,22,150,308,309,313\) Similar to Fernandez-Fernandez et al.\(^9\), it appears that the cognitive demand on players during training sessions, where opposition or situational pressure is increased (i.e., increased strokes rates, physical demand, or importance of result), hinders an athlete’s ability to execute drill outcomes (i.e., target accuracy) (Study 2, Chapter 4). While there may be limited differences in mental exertion between simulated and tournament matches, several other load markers appear greater during tournament matches. As such, this prompted an investigation of whether other variables (i.e., winning vs. losing, and seeded vs. non-seeded opponents) within domestic matches affected match load.

**Match Variables Affecting Load**

To this point, we have discussed the differences in external and internal load markers of training, simulated matches and domestic matches. However, variables such as match outcome and the standard of the opponent may affect these comparisons, especially among young tennis athletes. Accordingly, subsequent analysis of external load markers that accounted for these interactions, observed that similar stroke rates and work-rest ratios were evidenced between domestic matches won and lost. Similarly, a comparable number of winners, count of serves and number of errors were made during domestic matches won or lost (Study 3, Chapter 5). Thus, it is conceivable that the variance of external load between matches does not rely on the outcome of the match, or that other variables impact their analysis (i.e., offensive vs. defensive players). Conversely, the internal loads of domestic matches won elicit greater RPE’s than matches lost, despite similar perceptions of mental exertion (Study 3, Chapter 5). Whilst unanticipated, a recent tennis investigation observed greater post-match salivary
cortisol response and anxiety in losers than winners, while winners reported higher self-confidence, suggesting that a final positive (or potentially positive) outcome might provide a buffering effect on mental stress.

The stroke-rates, number of winners, serve count, and number of errors also appeared to manifest independent of whether domestic matches were played against seeded or non-seeded opponents (Study 3, Chapter 5). Furthermore, seeded and non-seeded matches were comparable for session-TL, RPE and mental exertion (Study 3, Chapter 5). Despite, limited perceptual (internal load) differences observed in matches against seeded and non-seeded opposition, it is remains conceivable that high-performance junior athletes are perhaps more “invested” in certain situations - despite no difference in external load.

Summary
The discussion thus far has highlighted a mismatch between training drills, simulated match play and domestic matches for the external and internal loads among high-performance junior tennis players. Coaches should be aware of the discrepancies in session intensity and aim to adequately prepare athletes for tournament requirements through evidence-based practices. Through quantifying tennis loads during training and tournaments, tennis stroke volume and intensity can be appropriately maintained in training. This is particularly the case given the first section of the discussion chapter highlighted discrepancies in the perception of load between players and coaches. However, the most appropriate dosage of both tennis and physical loads required to successfully maintain physical capacities is unknown. Thus, investigation into the effect that training and competition can have on athlete physical capacity upon return from competition periods is required. Accordingly, while the previous section discusses the demands of domestic tennis competition, the loads associated with tournaments removed from such high-performance environments (i.e. during international tours) will be discussed below.
8.4: MONITORING AND MANIPULATING LOAD DURING COMPETITION

High-performance tennis necessitates year round travel as part of the competitive demands, and as a result the training environment is constantly changing. The impact of these changes on physical performance measures has not previously been investigated. Specifically, the impact that overseas tournaments have on training and match load, and the ability of players to maintain certain fitness capacities over the period of those tours is unknown. Studies 4 and 5 (Chapters 6 and 7) provide evidence of the post-tour change in fitness capacities, alongside descriptive analyses of training loads prior to and during international tours. Acknowledging the extent of tennis coaches understanding of training load monitoring and prescription, the role of specialist S&C coaching staff in the management of on-tour load would seem to provide essential support in this area. Study 5 (Chapter 7) hence assesses changes in training loads completed in absence and presence of an S&C coach on-tour.

8.4.1 - Limitations of Load Monitoring on International Tours

Given the travel demands of the sport, load monitoring systems must extend to training and competition settings that occur away from the home environment. Indeed, considering the accumulation of time on-tour faced by developing tennis players, there is a surprising absence in literature that has explored this issue. While the limitations of load monitoring measures for domestic environments have been made clear, these are further exacerbated in an international context. Specifically, while the reader has been made aware of the limited availability of valid measures for domestic competition (i.e., GPS) resulting in a reliance on notational analysis, such analysis during international competition becomes even less realistic without accompanying specialists. Yet as with many other studies, outside of the data collected for the purpose of this thesis, tennis coaches will rarely travel with a camera for notational analysis.
purposes. This is likely owing to several concerns from an organisational and personnel perspective, including; cost of travelling support staff, transport of recording devices, skill-sets of travelling coaches, and logistical constraints (i.e., court dimensions and design limiting prospect of video capture). Accordingly as with domestic events, perceptual measures of internal load (i.e., RPE) likely serve as suitable measures during international travel.

With load monitoring during international tours limited to RPE and session-TL units (derivative of RPE and session duration)\(^49\), it is assistive to differentiate the quantification these measures into specific training or competitive modes. For example, Studies 4 and 5 (Chapters 6 and 7) categorize load types as follows: total (all sessions), total on-court (all tennis related sessions, including matches), total off-court (all S&C sessions), singles matches, doubles matches, tennis training sessions, strength training sessions, and conditioning sessions. The following sections will discuss these training modes, providing firstly context of differences between on-tour loads and training loads performed in home environments and then relationships to changes in physical capacities upon return.

### 8.4.2 - Preparatory and On-tour Load Demands

Comparison of training loads in a home environment and those on-tour, highlighted greater on-tour loads due to increased tennis (on-court) volume. Further, match loads experienced during international matches were greater than simulated matches in preparation to those specific tours (Study 5 [Chapter 7]). Given Study 3 (Chapter 5) also reported greater loads during domestic matches than simulated match play, a comparison of loads across data sets was pursued. It was observed that the highest loads typified international match play (690 ± 250.21 au; Study 5 [Chapter 7]), followed by simulated match play completed on international tours (584 ± 63.62 au; Study 5 [Chapter 7]), domestic matches (489 ± 106.42 au; Study 3 [Chapter 5]), and finally simulated match play in a home environment (284 ± 90.05 au; Study
3 [Chapter 5]). While there is a dearth of research analysing on-tour tennis loads, it is suspected that the difference in competition load results from the external stress of tennis competition itself. To expand further, the precise motor-patterns and temporospatial demands of tennis, the unpredictable match durations and stressors (match significance, opponent etc.) are likely to explain the different perception of load. Again, this idea resonates with salivary stress marker (cortisol) and psychological stress (CSAI-2R assesment) observations described in the recent paper from Fernandez Fernandez et al. It was suggested that junior high-performance tennis players, experience an increase in stress responses on match days when compared to training days, and for losing players (potentially more cognitively unstable), compared to winners. Understandably, with the external stressors typical of international competition, tours ultimately prove problematic for coaching staff attempting to forecast match loads in advance and accommodate these into training planning.

*Effect of On-tour Load on Physical Capacities*

To the knowledge of the author, research into the effects of on-tour load on changes in physical capacities is non-existent. The closest related tennis investigation explored absolute changes in fitness prior to and following a 5-week unsupervised period during the U.S. college tennis season (‘Spring Break’). Kovacs et al. reported that a 5-week interruption of normal training, though not on-tour, resulted in reductions to speed, power and aerobic capacities, suggesting it was likely owing to poor compliance with prescribed training regimen. The authors proposed that coaches and trainers might benefit from the enforcement of pre- and post-testing, therefore increasing athletes’ accountability for unsupervised workouts. However, while increasing accountability of the athletes is perhaps one solution, targeted training prescription when on-tour or unsupervised (based on knowledge of fitness capacities most likely to regress) may further assist in the mitigation of fitness decline.
A novel component of the current thesis is the comprehensive recording of loads completed throughout each 4-week international tour, alongside physical testing pre- and post-tour (Studies 4 and 5, Chapters 6 & 7). Accordingly, Study 4 (Chapter 6) highlights the post-tour detriments of up to 3.6% for speed capacities (i.e., 5-, 10-, and 20-m sprints). In addition, increased tennis loads prescribed on tour were associated with a decline in 10- and 20-m sprints, likely owing to the limited exposure to such specific distances. Previously, an acute tennis study observed no detrimental effect in 5-m sprint time following 3 consecutive days of competitive play on indoor hard court (Greenset court). Therefore, one tournament seems too short to elicit overt reduction in 5-m speed from a fatigue perspective, let alone detraining. However, this is not to say that fatigue will accumulate throughout a tour period across multiple weeks. With the current decline in physical capacities observed over a 4-week period in Study 4 (Chapter 6), it is plausible that such regression in fitness may be due to athletes experiencing a state of overreaching (functional or non-functional), similar to previous research of endurance-trained athletes. Alternatively, such discrepancy may reveal a time effect, in that longer periods without sufficient training stimuli (i.e., high-speed running) can result in physical decline in that capacity (Study 4, Chapter 6). Kovacs et al. suggested that because tennis points are generally 4-7 sec, detraining in speed qualities could be detrimental to match performance. However, given the fact that most tennis movements are within a 3-4m radius, there is rarely a chance for tennis players to reach maximum speed, and when extended movements (>4m) do occur, immediate deceleration follows. With the well-documented premium placed upon training time, particularly during tournaments, the current data infers that targeted training load prescription may help to alleviate specific fitness declines during heavy and extended tournament blocks.

Study 4 (Chapter 6) hence sought to investigate the training loads prescribed in the immediate preparation to tour departure, in an attempt to find appropriate pre-tour training loads that may
alleviate physical regression during 4-5 week tours. It is worth noting however, the challenges associated with high-performance tennis environments on-tour. Firstly, only upon exit from a tournament, following appropriate recovery, off-court training may or may not become a priority.\textsuperscript{13,21} This is highlighted in Study 4 (Chapter 6), which demonstrated strong inverse correlations between matches outcome and off-court training load.\textsuperscript{22,106} As suggested by Reid et al.,\textsuperscript{106} following the completion of an extended match (i.e., \sim 4 h), an additional S&C training session, in most cases, would not be appropriate. Secondly, owing to duty of care obligations, exiting junior athletes must remain with the tour but not always have regular access to facilities or coaching personnel. Physical training can thus become opportunistic. As a result, if physical capacities can be sufficiently advanced prior to tour departure, this may minimize the extent of physical regression on-tour.

\textit{Effect of Pre-tour Load on Physical Capacities}

Study 5 (Chapter 7) investigated the impact of the training loads prescribed in the 4-weeks immediately prior to tour departure on post-tour fitness capacity changes. Surprisingly, pre-tour training loads revealed minimal effects on post-tour physical capacities. To provide greater context, comparison of training loads completed pre-tour and on-tour highlighted that total load and tennis loads were greater on-tour, while S&C training loads were similar. A search of previous detraining literature identifies that even a 70-80\% reduction in training volume can be sufficient to maintain maximal capacity measures (i.e., VO\textsubscript{2max}, and speed).\textsuperscript{346-348} Seemingly, while training loads may not always be ideal on-tour, targeted prescription of training modalities, may allow even the most sensitive physical capacities (i.e., speed training), to be maintained across international tour periods.\textsuperscript{348} While Kovacs et al.,\textsuperscript{190} did not report on the typical training loads of their cohort, nor compare between training prior to the unsupervised break and those self-reported by each athlete during the break, it could be speculated that pre-break training loads (i.e., typical training weeks) were substantially
greater. In any case, the fact that the current study’s tour loads were not reduced (they were higher), may explain the observed limited reductions in the players’ physical capacities.

Both Studies 4 and 5 (Chapters 6 & 7) noted that increases in on-court training load, whilst on-tour, were related to a decline in speed and aerobic capacity upon return. Given the lack of other relevant tennis literature, comparison must be drawn from related research in other sports (i.e., rugby league). For example, the physical capacities of rugby league players have fluctuated with changes in loads throughout a competitive season.\(^{341}\) That is, increases in aerobic capacity and muscular power, reductions in skinfolds, and stable 10-, 20-, and 40-m speed were noted during the initial weeks of competition, when training loads were greatest.\(^{341}\) As the competitive season progresses however, each aforementioned physical capacity regressed in line with reductions in training load.\(^{341}\) Importantly, such reductions in load not only corresponded with regression in physical capacities, but also an increase in injury rates.\(^{341}\) While such breadth of analysis was not possible within the current studies, these observations forewarn tennis practitioners of the potential implications in tennis athletes given similar susceptibility as a result of reductions in training loads. Hence, on-tour, where ad hoc prescription of training loads are at their highest, professional opinion (i.e., S&C staff) will likely assist the tennis coach. Accordingly, the thesis will now explore the efficacy of S&C staff support during tournament periods, in the context of the external loads performed on-tour – with and without an S&C coach.
8.4.3 - Efficacy of an S&C Coach on Tour

Despite the unavoidable limitations of current training monitoring systems for tennis (i.e., poor reliability of external load monitoring tools, and heavy travel commitments), one key variable that can avoid mismanagement of athlete training loads is coach education. The current data highlight that there is an apparent: i) underestimation of training session RPE between coach and athlete; ii) under-prescription of intensity during training and simulated match play sufficient to replicate domestic matches; and iii) lack of specifically targeted S&C sessions prescribed on-tour, resulting in a decline of linear sprint and aerobic capacities. These key findings raise a strong argument for greater scrutiny being applied to the management of training and match loads on-tour.

An obvious key stakeholder whom is most skilled in this area is the physical preparation coach or S&C coach, though it still remains unknown if S&C coaches actually have more refined perception of athlete loads. Regardless, Study 5 (Chapter 7) observed an increase in training loads completed on-tour in the presence of S&C support. In light of this discrepancy in training load in the presence or absence of support on-tour, it appears that athletes (and coaches) may realise tangible benefit from this support. Yet, there are often various constraints that can affect the availability of S&C support on-tour, including budgetary, personnel and logistical constraints. Thus, with these constraints in mind, where S&C support is not available, solutions may involve an emphasis on the compliance of daily load recording, and frequent correspondence with S&C staff via telecommunication.
8.5: LOAD MONITORING FOR HIGH-PERFORMANCE TENNIS

In summary, on-going coach and athlete education in training monitoring systems seems vital to maximise acute and long-term training benefits. Comparisons within athlete-coach dyad and mode of play (training, simulated and competitive match play) identified misinterpretations of training loads, as well as discrepancies between training and competition loads. The differences in coach perceptions of training load appear to relate to miscalculations of a load accumulation effect across entire training sessions. When comparing training loads with that of competition, the current data indicates a common theme of under-preparation across most external and internal load measures. Education for coaches may come in the form of continuous re-alignment of intensity perceptions within day-to-day training sessions, as well as the introduction of drill databases, assisting in the quantification of training, to ultimately drive evidence-based decision making and the anticipation of session response.

Comparison of pre- and on-tour training and match loads revealed greater overall load completed on-tour, owing to greater on-tour tennis volume rather than discrepancies in intensity. Fitness testing either side of the international tour identified detrimental effects to speed qualities (5-, 10-, and 20-m sprints), and to a lesser extent, aerobic capacity. Pre- and on-tour training loads targeted to address these modalities specifically present a solution in the assistance of these physical capacities. The presence of S&C support on-tour was shown to relate to the completion of greater training loads, also presenting a possible resolution in the mitigation of physical capacities deterioration. In sum, this body of work illustrates that training load monitoring strategies - particularly perceptual questionnaires (i.e. RPE) - can be successfully tailored to high-performance tennis structures. The use of which ensure that training loads throughout sessions and training cycles are recorded, allowing evidence-based prescription of the most appropriate training loads (rather than coach intuition) to ultimately ensure optimal tennis development, performance improvement, while reducing the risk of injury and/or OTS.
CHAPTER NINE

Summary and Conclusions,
Practical Applications,
Future Research
9.1: SUMMARY AND CONCLUSIONS

The aim of the current thesis was to examine training load monitoring within high-performance tennis environments in the preparation of domestic and international tournaments. Conclusions from the current thesis include:

- While coach perception of individual drill-RPE did not differ from athletes (within the same session), coaches seem to misinterpret accumulated training load accumulation from a sequence of prescribed drills within a session. These results indicate some misunderstanding of session design and prescription, or misperception of athlete response to on-court training (Study 1, Chapter 3).

- Coaches demonstrated greater perception of drill mental intensity than RPE. With regard to quantifying external training load, there was an inclination to over-estimate stroke volume, particularly for coaches. As such, coaches may be prone to relying on intuition too heavily to guide on-court training load, rather than objective measurement (Study 1, Chapter 3).

- Regression analysis of load markers used to explain variance of coach and athlete RPE indicate that coaches rely on pre-planned session RPE’s and perceived drill-RPE to inform perceived session-RPE. Conversely, athletes’ variance in session-RPE is explained by internal markers of drill-RPE and peak HR. Accordingly, it would seem that internal markers of training load are well suited to session-RPE prediction (Study 1, Chapter 3).
Chapter 9: Summary and Conclusions

- Compared to the previously reported external load demands of tournament play, all current drill categories were characterized by lower comparative external loads. Within Study 2 (Chapter 4), Open-Pattern and Recovery/Defensive drills featured the most intense stroke demands, while Point-Play and Match Play were lowest. Technical performance (error-rate) was poorest during Closed-Technical and Recovery/Defensive drills, yet best during 2-on-1 Net-Play and Match Play. These data provide specific external load evidence to appropriately prescribe training with stroke demand and expected error rates in mind (Study 2, Chapter 4).

- Recovery/Defensive drills, and then Open-Pattern drills, were characterized by high internal psycho-physiological loads (i.e., RPE, mental-exertion, and HR). Mental-exertion was greatest during Accuracy drills, while 2-on-1 Open and Closed-Technical drills were lowest for both RPE and mental-exertion. Point-Play and 2-on-1 Open drills were of highest HR response along with Recovery/Defensive drills. Closed-Technical and Match Play were of lowest physiological demand (i.e., mean and peak HR). These data provide coaches with greater understanding of the demands of typical tennis drills, logically leading to more informed future session planning and recovery needs (Study 2, Chapter 4).

- When compared within the same group of adolescent players, session durations, session RPE, ground strokes and serve count/rate of training and simulated match play were lower than those that characterize actual competition. Further, mental exertion during training was inferior to both simulated and tournament match
play. Thus, within high-performance tennis settings, when a stimulus is matched for duration, training appears of inadequate intensity compared to tournament match play (Study 3, Chapter 5).

- More forensic examination of tournament matches reveals internal loads of matches won to be of greater RPE despite similar mental-exertion to matches lost. External load measures such as stroke-rates, error-rates, work-rest durations, winners, and serve volume were all comparable across matches won and lost. As such, it appears that there is a perceptual and/or psychological (internal) shift for greater physical effort during matches that are won (Study 3, Chapter 5).

- Irrespective of match result, matches against seeded and non-seeded opponents featured similar RPE and external load. However, it seems that the seeding of an opponent does increase players’ perceived mental requirements during tournament matches, requiring greater match focus (Study 3, Chapter 5).

- Reductions of up to 3.6% were observed in 5-, 10-, 20-m sprint performance following a four-week international tour, despite all other physical capacities being preserved. As such, it seems that, during extended overseas tours, athletes are not exposed to sufficient linear speed stimuli (within training or matches) to maintain the state of this capacity (Study 4, Chapter 6).
Chapter 9: Summary and Conclusions

- Detrimental changes were observed for athletes completing greatest amounts of tennis load on tour, with those in the top 1/3 for tennis load (i.e., highest TL) producing the poorest 10- and 20-m sprint times and aerobic capacity upon return. Accordingly, it appears that not only the amount of load completed on tour affects post-tour fitness, but also when tennis and match load is high physical capacities will suffer greatest (Study 4, Chapter 6).

- Strong relationships exist between the amount of completed match and off-court load and the number of matches won. Further, an increase in match load appears to blunt the amount of S&C training load completed, inferring S&C training occurs once an athlete exits from a tournament. Hence, tennis and S&C coaches should ensure subsequent training schedules include sufficient S&C training load post-tournament (Study 4, Chapter 6).

- Negligible changes were observed in match or on-court training on-tour when an S&C coach was present. However, there were reported increases in total and S&C training load completed. As such, S&C coach presence on-tour appears valuable in maintaining the S&C training load prescription of athletes, logically stemming in mitigating any risk of physical capacity regression. Additional benefits would appear to include a reduction in the likelihood of inappropriately high (i.e., non-functional overreaching or injury) or low (i.e., regression of physical capacities) training loads being prescribed (Study 5, Chapter 7).
9.2: PRACTICAL APPLICATIONS

Some practical applications to be derived from this thesis include:

- Coaches need improved awareness of the individualised accumulating effect of drill loads across entire training sessions.
- Stakeholders involved in player development should catalogue the internal and external training loads of the drills implemented within their environment to ensure the loads they envisage align with their intended developmental objectives.
- Training sessions (including both drills and simulated matches) need to be carefully planned and scrutinized to ensure that both internal and external training loads align to those that can be expected of tournament matches.
- As linear speed (5-, 10-, and 20-m sprints) is most vulnerable to detraining whilst on-tour, S&C training load should consider targeting maximal-effort linear sprints to maintain this capacity throughout tournament weeks.
- Given that greater load is completed on-tour than pre-tour, the presence of S&C coach support should be utilized to ensure specific S&C training loads are completed to maintain pre-tour training gains.
9.3: FUTURE RESEARCH

Recommendations for future research, related to or motivated by the findings of this thesis, include:

- The development of other reliable, valid and practical external load markers for tennis is key. As identified throughout each study - outside of Grand Slam, ATP and WTA tour events where Hawkeye multi-camera systems can be utilized - typically, external load for tennis is limited to notational analysis and duration of sessions. External load measures will increase the systematic understanding of the physical demands of training and matches to further refine the specificity of training loads and training session prescription for players.

- Longitudinal investigation of the interaction between training load, and injury, and performance awaits future researchers. Such information may also assist in the validation of current load monitoring practices.

- While acute court surface comparisons have been undertaken, the actual effect of acute, but more so, chronic exposure to different surfaces on tennis performance, development of physical capacities, and occurrence of injury is still relatively unknown.

- As Study 4 and 5 involved the analysis of changes in fitness capacities across an international tour period, future work should critique the effect of competition blocks on muscular strength capacities (not investigated in the current study).

- It is pertinent to also extend the current studies to investigate the influence of specific match and training loads (both volume and intensity) within different genders and age/development groups. Specific analyses may also help determine if the annual tournament schedule consists of appropriate training and tournament types, tournament concentration, and access for each gender and across developmental stages.
CHAPTER TEN

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Appendices

Ethics Information
MONITORING OF TRAINING LOAD IN AN ELITE JUNIOR TENNIS ENVIRONMENT

INFORMATION ABOUT THE RESEARCH

- The aim of this project is to investigate the methods to monitor training loads of junior, high performance tennis players.
- Recently there has been a growth of training monitoring strategies in elite tennis, with tennis environments eager to understand appropriate training loads of their athletes.
- Matches involve periods of short, explosive, bursts of energy at maximal or near maximal efforts, as well as moderate exertion and complete rest. Unlike other sports there is an increased element of unpredictability with matches ranging in length from less than an hour to over 5 hours involving different match demands (best of three or five sets), style of play (offensive v defensive), opponent skill, and weather.
- With coaches continuously manipulating athlete training plans due to the complicated schedules of year round tournaments and travel, it becomes important to gain reliable knowledge as to what training dose is being prescribed during training.
- This study will be completed as part of usual training schedules under the supervision and agreement of assigned coaches.

WHAT YOU WILL BE ASKED TO DO

- Following familiarisation with all experimental measures and procedures (heart rate monitors and perceived exertion scales) you will continue scheduled training with minimal impact.
- Participants should be aware that each session will be video recorded and coded exclusively by the chief investigator.
- Data collection will occur during normal training sessions on two days of each week for each player. Each session will begin with pre-training measures of athletes rating their perceived muscle soreness, and coaches will be asked to predict the perceived exertion (RPE) of the pending session.
- Following the usual warm up conducted by assigned tennis coaches, heart rate monitors will be fitted to each participant involved in the session.
- The session will be run by the assigned tennis coaches as usual. While seated away from the main session, investigators will time code and record which drills are used in what order for recording purposes and ease in interpreting heart rate data at a later stage.
- Following the completion of the entire training session, heart rate monitors will be removed. Participants will then be asked individually, away from coaches, as to their perceptual ratings of each drill and the entire session. These measures include sessional rate of perceived exertion (RPE), muscle soreness, drill specific physical RPE, drill specific mental RPE, an estimation of shots hit during each drill, and finally, an estimation of unforced error made during each drill.
- Following the individual questioning of each participant involved in the session, coaches will be asked the same questions. The coaches will be asked individually, away from other coaches and participants, so as no indication as to the responses given by the participants are provided.

OTHER INFORMATION

RISKS AND DISCOMFORTS

- Heart rate monitors are likely to be uncomfortable to train with initially, however the monitors used are the same as those used by coaches when required for session purposes.
- The issue of gaining consent from both the underage participants and the parents/guardians and coaches are major considerations involved in this investigation. Further, due to the involvement of all parties in gaining consent it is important to establish true consent outside of any element of force, fraud, deceit, duress, coercion, or undue influence on their decision.
- All measures and procedures are part of a normal training routine for these high-performance junior players.

The risks of complications related to any testing protocol are always present, however with correct instruction and supervision all dangers will be kept to a minimum.

BENEFITS

- Experience of being involved in an applied sport science research project through Tennis Australia.
- Being involved in an applied sport science research project, where the results could benefit Australian tennis athletes in their preparation for future tournament preparation.
- Information can be utilised by coaches providing greater understanding of drill and session workload outcomes to appropriately plan training programs.
- The information will also be used to compare training workloads to match workloads to ensure that athletes are better prepared for the physical and mental extremes of a competitive match.
WHAT WILL BE DONE WITH MY RESULTS?

- Your privacy will be guaranteed and all data acquired will be kept strictly confidential.
- Only the Chief Investigator will have access to your identity and the only other people to have access to the raw data will be the members of the research team for this project.
- All raw data will be held in a password protected, secure location with access restricted to members of the research team.
- Reports, oral presentations and any published data resulting from this project will exclude the names of participants in order to protect your identity.
- It is expected that the data gained from this investigation will be included in a scholarly research article published in an esteemed international sports science journal.
- Furthermore, as this study is being conducted as part of a collaborative research partnership with the Tennis Australia, the results of the study will be shared with coaches and scientists at Tennis Australia. However, no individual names or individual data will be revealed.

COERCION AND WITHDRAWAL

You have the right to participate in this investigation without the intervention of any element of force, fraud, deceit, duress, coercion, or undue influence on your decision. In the event that you agree to participate you have the right to withdraw your consent and cease involvement in the investigation at any time.

INSTITUTIONAL REVIEW BOARD

Charles Sturt University’s Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:

Executive Officer
Human Research Ethics Committee
Office of Academic Governance
Charles Sturt University
Panorama Avenue
Bathurst NSW 2795
Tel: (02) 6338 4628
Fax: (02) 6338 4194

Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.
If you are interested in participating or have any questions regarding this study please do not hesitate to contact:

**Alistair Murphy** (Principal investigator)
PhD Student
School of Human Movement Studies
Charles Sturt University
Panorama Ave
Bathurst, NSW
2795
Tel: +61 409 848 381
Email: amurphy@csu.edu.au

**Dr Rob Duffield** (Supervisor)
School of Human Movement Studies
Allen House, N1
Charles Sturt University
Panorama Ave
Bathurst
NSW, 2795
Tel. 0438 897 349
Fax. 02 6338 4065
Email: rduffield@csu.edu.au
Monitoring of Training Load in an elite junior tennis environment

INFORMED CONSENT

Thank you for expressing interest in this research. Please read and retain the attached information sheet. Should you have any questions regarding this study do not hesitate to contact:

Alistair Murphy (Principal investigator)
PhD Student
School of Human Movement Studies
Charles Sturt University
Panorama Ave
Bathurst, NSW
2795
Tel: +61 409 848 381
Email: amurphy@csu.edu.au

Dr Rob Duffield (Supervisor)
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Allen House, N1
Charles Sturt University
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Bathurst
NSW, 2795
Tel. 0438 897 349
Fax. 02 6338 4065
Email. rduffield@csu.edu.au

I, ____________________________ (print name) consent to participating in the research project titled Monitoring of Training Load in an Elite Junior Tennis Environment.

My consent to participate in this research is based on the following terms;

The purpose of the research has been explained to me, including the potential risks and discomforts involved.

I confirm that I am capable of completing the physical requirements of this research.
I have read and understood the information sheet provided to me, and have retained a copy of the information sheet provided to me.

I have been given the opportunity to ask questions about the research and received satisfactory responses to all questions I have asked.

I am content that I understand what I will be required to do as research participant.

I understand that any information or personal details gathered in the course of this research about me are confidential and that neither my name nor any other identifying information will be used or published without my written permission.

I understand that I can withdraw my consent at any time before, during, or after testing, without any penalty.

I nominate the person below as someone that can be contacted on my behalf in the unlikely event of an emergency:

Name: __________________________________________

Address: __________________________________________

Phone: __________________________________________

I am aware Charles Sturt University’s Human Research Ethics Committee has approved this project. I understand that if I have any complaints or concerns about this research I can contact:

Executive Officer
Human Research Ethics Committee
Office of Academic Governance
Charles Sturt University
Panorama Avenue
Bathurst NSW 2795
Tel: (02) 6338 4628
Fax: (02) 6338 4194

Participant signature: __________________________________________

Date: __________________________________________
6 October 2011

Mr Alistair Murphy  
N1, Allen House  
School of Human Movement Studies  
BATHURST CAMPUS

Dear Mr Murphy,

Thank you for the additional information forwarded in response to a request from the Human Research Ethics Committee (HREC).

The CSU HREC reviews projects in accordance with the National Health and Medical Research Council’s National Statement on Ethical Conduct in Research Involving Humans.

I am pleased to advise that your project entitled “Monitoring Of Training Load In An Elite Junior Tennis Environment” meets the requirements of the National Statement; and ethical approval for this research is granted for a twelve month period from 6/10/2011.

The protocol number issued with respect to this project is 2011/120. Please be sure to quote this number when responding to any request made by the Committee. Please note the following conditions of approval:

· all Consent Forms and Information Sheets are to be printed on Charles Sturt University letterhead. Students should liaise with their Supervisor to arrange to have these documents printed;
· you must notify the Committee immediately if any serious and or unexpected adverse events or outcomes occur associated with your research, that might affect the participants and therefore ethical acceptability of the project. An Adverse Incident form is available from the website; as above;
· amendments to the research design must be reviewed and approved by the Human Research Ethics Committee before commencement. Forms are available at the website above;
· if an extension of the approval period is required, a request must be submitted to the Human Research Ethics Committee. Forms are available at the website above;
· you are required to complete a Progress Report form, which can be downloaded as above, by 6/10/2012 if your research has not been completed by that date;
· you are required to submit a final report, the form is available from the website above.

You are reminded that an approval letter from the CSU HREC constitutes ethical approval only.

If your research involves the use of radiation, biological materials, chemicals or animals a separate approval is required from the appropriate University Committee.

The Committee wishes you well in your research and please do not hesitate to contact the Executive Officer on telephone (02) 6338 4628 or email ethics@csu.edu.au if you have any enquiries.

Yours sincerely

Julie Hicks  
Executive Officer  
Human Research Ethics Committee  
Direct Telephone: (02) 6338 4628  
Email: ethics@csu.edu.au

www.csu.edu.au

The Commonwealth Register of Institutions and Courses for Overseas Students (CRICOS) Provider Number is 00005F for Charles Sturt University and the Charles Sturt University Language Centre
5/8/11

To: Alistair Murphy

Re: Tennis Australia Workload Research Study

Dear Alistair Murphy,

This letter serves as an in principle agreement to provide access to the National Academy (Melbourne based) Tennis Australia squad for a research project investigating training load regarding physiological and perceptual responses to on-court training. Further, it is acknowledged that access will be granted to previously collected tournament data for data analysis. It is expected that the research will be conducted during a period over September 2011- March 2012, with a summary report containing the final results to be sent before March 2011.

Regards,

[Signature]

Dr Machar Reid
Sport Science and Medicine Manager
Tennis Australia